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Conservation Agriculture: Building entrepreneurship and resilient farming systems

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Of the

First Africa Congress on Conservation Agriculture

18-21st March, 2014, Lusaka Zambia

"*Putting farmers at the centre of agricultural innovation and development is considered one of the effective ways towards sustainable production intensification. To support the farmer-centred CA adoption,* ***the First Africa Congress for Conservation Agriculture (IACCA)*** *intends to bring together key CA stakeholders, including farmers and their organisations, from the continent to interact and co-own a permanent CA knowledge and information sharing platform that takes into account the needs of farmers, increased networking, partnerships and information sharing on CA.***"**

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1st Africa Congress on Conservation Agriculture

"Share and Expose experiences and lessons and facilitate alliances to unblock hindrances to expanded and scaled-up adoption of conservation agriculture especially among the smallholder farming systems and related industry in Africa"

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Introduction

First Africa Congress on Conservation Agriculture

Intercontinental Hotel. Lusaka Zambia. 18-21 March 2014

Conservation Agriculture: Building entrepreneurship and resilient farming systems

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The International Steering Committee of the First Africa Congress on Conservation Agriculture (IACCA) and the Zambia host welcomes farmers, policy makers, development partners and practitioners to Lusaka to discuss current and future developments of sustainable agriculture in Africa in March 2014.

The choice of Zambia, the country with the highest population of smallholder farmers practicing CA in Africa, and the "real Africa, provides provides a great opportunity to explore the application of CA practices and principles for both food security and supporting a growth agenda. The common objective is to Share and Expose experiences and lessons and facilitate alliances to unblock hindrances to expanded and scaled-up adoption of conservation agriculture especially among the smallholder farming systems and related industry in Africa.

Putting "**farmers first**" and **at the centre** of all congress discussions, they farmers will be given the initial opportunity to share their CA **experiences**; articulate their **visions** and where they desire to reach using CA; and voice the hold-up/**challenges** to attainment of their ambitions.

All other participants – being service providers in their various disciplines and stakes – need to identify a niche value adding service to assist farmers to adapt and adopt profitable CA in the millions. Key demanded services are under the seven sub-themes of the congress as follows:

1. Growing more with less
2. Weather proofing agriculture
3. CA for sustained wealth creation
4. Food sovereignty
5. Effective research and targeting strategies for enhanced CA adoption
6. Harnessing the power of collaboration
7. Increasing CA adoption

Congress program options and tours will cater for different interest groups, and take advantage of Lusaka's proximity to smallholder CA subsistence; medium and large scale commercial farming. Other options include world leading research on CA and unique organic farmers. Do not forget to enjoy views of the Victoria Falls - the Zambian heritage of World Fame.

We look forward to meeting you in Lusaka

Congress Sub-Theme Keynote papers

Conservation Agriculture: Growing more with less – the future of sustainable intensification

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Sustainability:

Satisfy human food, feed and fibre needs (and contribute to biofuel needs)
Enhance environmental quality and the resource base
Sustain the economic viability of agriculture
Enhance the quality of life for farmers, farm workers, and society as a whole (NRC, 2010)

Sustainable intensification: sustainable increase in production per unit of land.

Sustainability and Efficiency

There are biophysical, economic, social and political aspects to sustainability and a set of agricultural practices alone cannot provide sustainability – rather the technology needs to be embedded in a comprehensive set of actions that lead to sustainable agriculture. Conservation agriculture (CA) itself without markets, input supply, knowledge development and sharing, stable and non-prejudicial policies etc. will not lead to sustainable intensification. There have been a number of publications in recent years arguing that CA is only applicable to relatively small groups of farmers (e.g. Giller et al., 2009) or exploring for which farmers CA may be applicable (e.g. Corbeels et al., 2013). Undoubtedly there are many impediments to adoption of CA, but today most accept that, biophysically, CA is functional under most conditions in Africa, and more sustainable than current tilled systems. However, institutional and market factors limit adoption in many instances (Ndah et al., 2013). I believe that this is indicative that far more attention should now be paid to overcoming these institutional bottlenecks - rather than identifying which farmers can benefit from CA, we should be identifying and investing in changing those factors that limit adoption. The Green Revolution in South Asia was based on technology (high-yielding dwarf varieties of rice and wheat, fertilizers, irrigation and pest control) – but the Green Revolution took place because there was decided political will and the institutional aspects necessary for widespread technology adoption (input and output markets, credit, subsidies where deemed necessary, seed production/importation, etc.) were put in place.

Growing more for less implies increased efficiency in agricultural systems. It is pertinent to ask here of what the farmer is going to grow (produce) more, and of which resource he/she is going to use less. For sustainable intensification, agriculture needs to produce more (food, feed, fibre, fuel) per unit of land area, but often, especially among smallholder famers, this is not the primary objective. The farmer's priority is normally to produce more income per hectare, but it could also be to produce more income per day worked (Ekboir et al., 2001), per dollar (or Kwacha) invested, or even per bag of seed. This shows the disparity between different views and aspects of sustainability, depending on who is defining the objectives.

What measure of efficiency should we use? If we are comparing two agricultural systems, then comparing efficiencies would appear to be relatively simple: define the most limiting factor and whichever system gives the most production (of a defined output) for each unit of the most limiting factor is therefore the most efficient. However, comparing efficiencies with respect to yield per hectare, the most common measure used by agronomists, between a conventionally tilled system and a conservation agriculture system - two complex, multi-component, systems that often require different equipment and weed control methods, land preparation activities, may have different planting dates and may need modifications in nutrient use and other factors - may in fact give erroneous results as to which is the “best” or most efficient system. An economic analysis is better able to integrate the different effects and factors than an analysis of yield *per se* and is therefore arguably far more meaningful for comparing different systems than physical yield - unfortunately economic analyses are seldom reported in the literature. I should stress that of course for this analysis to be meaningful, we should be comparing two locally adapted systems – too often an untried and unadapted CA system imported from another environment has been compared in research trials with a traditional system that has been adapted, practiced and fine-tuned by farmers over decades. That CA has performed as well as or better than conventional practices in most of the published results from sub-Saharan Africa, especially eastern and southern Africa (Wall et al., 2013), is testimony to the resilience and potential of the system.

While research comparisons between systems are academically interesting, far more meaningful is the question “how efficient is the CA system?” What is the gap between actual yield and potential yield? Fischer et al. (2009) differentiate between farmer yield, economically attainable yield and potential yield (set by the environment – temperature, radiation and available water). Interestingly attainable yield under present market conditions may be very different from attainable yield under efficient market conditions. They differentiate between non-water-limited potential yield, and the water-limited potential yield of French and Schultz (1984). The demonstration of the water-limited wheat yield potential by French and Shultz was not only a very meaningful measure for South Australian farmers, still used today. French and Schultz also demonstrated that in many cases published research yield results showing (significant) treatment effects, were well below the water-limited potential yield, suggesting that there were other factors limiting yield and not solely the research treatments or the environment. The utility of the French-Schultz relationship for South Australia stresses the need for a realistic measure of yield potential in any environment so that farmers, and researchers, can measure their crop yields against what they should have been able to achieve.

Numerous studies have shown that CA is not a low-input system (e.g. Thierfelder and Wall, 2012; Thierfelder et al., 2013) – system functionality relies on relatively high productivity, not only to produce sufficient crop residues, but presumably also to produce sufficient root mass. Therefore where farmers currently use extremely low-input production strategies, such as in many areas of sub-Saharan Africa, it is doubtful that CA can in fact “produce more for less”. At the same time these current practices are not sustainable, and moving towards more sustainable systems will involve more inputs, whether from renewable, on-farm resources, or from off-farm “imported”, non-renewable inputs. However, where the majority of farmers use extractive, low-input management practices it implies that the attainable yield under current market conditions is very low, and that efforts to improve markets and institutions will have a greater effect on productivity and technology choice than will technology *per se*.

Achieving potential yield (or water-limited potential yield) requires optimal levels of nutrients, efficient management to optimize both the aerial and edaphic environments, and limit the effects of other organisms (pests, diseases and weeds) on system productivity. Achieving efficient production systems may often require more inputs than smallholder farmers’ use today, but the key is to use these inputs efficiently – grow more with less wastage – as inefficiency and wastage lead to reduced and/or uneconomic benefits.

Efficiency is best measured in terms of the most limiting factor(s) – water, nutrients, labour, land, capital investment etc. If other factors restrict system productivity, efficiency will be reduced. So what are the most common principal limiting factors in African agriculture, and can CA increase the efficiency of their use?

CA and sustainable intensification.

Nutrients water and risk. Excessive nutrient mining over most of Africa (Stoorvogel *et al*., 1993) is acute, and adequate plant nutrition is often cited as the most limiting factor to crop production in sub-Saharan Africa, while at the same time fertilizer use is very low (less than 10 kg ha^{-1} in sub-Saharan Africa [NRC, 2010] and about 20 kg ha^{-1} of nutrients in eastern and southern Africa in 2009/10 calculated from FAO's FAOSTAT database [Wall et al., 2013]). Even lower levels of fertilizer are applied to staple crops – considerably more is applied to cash crops (Groot, 2009). Therefore the problem is not that farmers do not understand the benefits of fertilizer but rather that they make a conscious decision not to apply fertilizer, or to apply very little, to their staple crops. Fertilizer use by smallholders is not just a function of availability and affordability, but also of both production and market risk (Morris *et al*., 2007). Smallholder farmers, in particular, are averse to risk given their precarious financial situation and their poor access to credit – if fertilizer application to a crop is perceived as too risky, it will not be applied (Rockström *et al*., 2002). One of the major causes of risk in much of Africa is the risk of moisture stress, which is often more a function of inefficient use of rainfall than of insufficient or poorly distributed rainfall *per se*. Between 70 and 85% of rainfall is lost to surface runoff, deep drainage and evaporation rather than being used by crops for productive transpiration in the semi-arid tropics of Africa (Rockström *et al*., 2002) while in Zimbabwe 30% of rainfall may be lost to runoff alone (Elwell and Stocking, 1988). Even though total rainfall may be sufficient for optimal crop growth, available water may be considerably lower and limit crop productivity.

As a result of climate change, increased variability of seasonal distribution of rainfall is expected throughout most of Africa coupled with a reduction in rainfall in much of the continent (Lobell *et al*., 2008) - factors that will aggravate the inefficiencies in rainfall use noted above. CA can reduce the risk of moisture stress by increasing water infiltration and storage (summarized in Wall et al., 2013), reducing compaction impediments to root growth and reducing evaporation (Mrabet, 2008), and therefore remove some of the barriers to smallholder fertilizer use. By improving the crop water balance, CA reduced risk at eight of nine sites in Malawi – yield in the worst seasons was significantly higher under CA than it was under the normal farmer ridged and cultivated practice (Wall et al., 2010, Ngwira et al., 2013). We hypothesize that reduced risk will increase the feasibility of farmers using higher levels of fertilizer – once they are convinced of the risk reduction.

CA also markedly reduces soil erosion (generally by over 90%) avoiding nutrient losses by erosion - annual farm losses of soil organic matter through erosion in Zimbabwe were over 850 kg ha^{-1} together with approximately 50 kg ha^{-1} nitrogen and 8 kg ha^{-1} phosphorus (Elwell and Stocking, 1988) – i.e. in reducing erosion CA reduces nutrient wastage, and more will be produced for every kilo of fertilizer applied – because it stays where it is applied and the crop has moisture to be able to use it.

ICRISAT and CIMMYT have recommended the use of very low levels of nitrogen fertilizer (micro-dosing) for maize production in the semi-arid areas of Zimbabwe, as has ICRISAT in parts of West Africa (Twomlow et al., 2011). Micro-dosing is based on the normal response curve to applied fertilizer and takes advantage of the initial steep slope of fertilizer response. However, I believe that micro-dosing is not a feasible technology for CA situations, especially as it is promoted largely for semi-arid situations. In conventional agriculture, nitrogen fertilization focuses on the present season and has little effect on subsequent seasons, whereas under CA N fertilization, because of the effect on residue amounts (especially important in semi-arid situations), has a large effect on crop performance not only in the present season but also in subsequent seasons. Of course this is only true if farmers do manage to keep some of the residues on the soil surface.

CA, labour and fuel use. Labour is frequently the most limiting resource for smallholder farmers, and labour savings have been cited in numerous surveys as the principal reason for adoption of CA by smallholders. However, labour savings depend to a large degree on weed management and the type of CA practiced. If herbicides are used, then labour savings from both the lack of tillage and the weed control are large (e.g. in Ghana – Ekboir et al., 2001), whereas if manual weeding is practiced, there may be a higher labour requirement in CA than in conventionally tilled fields (Rockström et al., 2001; Djamen et al., 2013). In Malawi, labour costs were lower in CA systems with chemical weed control than with conventional tillage by between 28% (Ngwira et al., 2012) and 63% (Ito et al., 2007). Costs of production were higher with CA because of the cost of the herbicides, but yields were higher with CA: net returns were increased by US$130–370ha^{-1}, net benefits by 69% and returns to labour 92-100%. Weeds may also be controlled by green manure cover crops (GMCC). The work of Mariki (2004) in northern Tanzania showed that initially more labour (11%) was used with CA because of the greater weed populations, but after four years with a maize-GMCC system (Mucuna or Lablab) labour use was 45% lower in the CA system than in the conventional system.

The basin system of CA, called Conservation Farming in Zambia and Zimbabwe, also requires more labour than conventional tillage (34 versus 13 person days ha^{-1} [Umar et al., 2012]). However the labour requirement for digging basins is in the winter when competing labour requirements are low, and because of the increased maize yield the returns to labour ($ day^{-1} worked) in Zambia were five times higher in the basin system than with conventional tillage (Umar *et al*., 2012). More production for more work – but more production for each day worked.

More efficient machinery use has been one of the drivers of CA adoption on mechanized farms in the Americas (e.g. Wall, 2002-80% reduction in fuel use with CA in the lowlands of Bolivia). There are few data on machinery use in CA in sub-Saharan Africa, but on the ART farm near Harare, machinery costs for CA were reduced by 66% compared to conventional tillage (MacRobert *et al*., 1995). Considerably more production per liter of fuel used.

Capital. Not only are the returns to investment generally higher under CA than under conventionally tilled fields (Wall et al., 2013), but the risks of losses are lower (losses are less frequent) under CA (Wall et al. 2010). Cost savings, as noted above, depend to a large degree on the type of CA conducted and weed management methods. Some of the benefits of CA only accrue over time, but to be acceptable to smallholders the CA system must give economic benefits immediately. Because of the effects of CA in moisture saving, these short-term benefits are more likely in drier and unirrigated environments than they are in wetter or irrigated environments.

Knowledge. One area where growing “more with less” does not apply is knowledge. CA is more knowledge-intensive than traditional low input systems, partly because it is new, but also because of the need for the farmer to understand the basis of the system and so be able to mould it to his or her particular conditions, the need in most instances for chemical weed control, and the need for good farm and crop management. Smallholder farmers are often poorly linked to knowledge systems external to the community (Wall, 2007). Overcoming this barrier and increasing the knowledge base of the smallholder farmers of Africa is probably the biggest hurdle to be overcome in achieving widespread adoption of CA in the continent. Success will not only depend on enhancing the knowledge of CA and CA systems among researchers, extension (change) agents and policy makers, and the facilitation of farmer-to-farmer knowledge flow, but the development of local innovation systems incorporating agents representing as many as possible of the principal components of the local agricultural value chains, using their own comparative advantages and information networks to remove bottlenecks to farm productivity.

Conclusions.

Conservation agriculture is not a low input system, and therefore "growing more for less" is unlikely, especially in situations, such as smallholder farming situations in much of sub-Saharan Africa, where farmers currently apply very low levels of inputs. The benefits of CA lie rather in using applied inputs (fertilizer, water, labour, fuel) more efficiently than conventionally tilled systems. In the short term, CA generally gives crop yields equal to or greater than yields under conventionally tilled situations – with higher yields more common in situations where moisture stress limits yield in tilled systems. However, economics and labour savings depend, to a large degree, on weed management strategies – if herbicides are used labour use and production costs are markedly reduced in CA, but if weeds are controlled manually labour requirements for weeding may offset all of the benefits of reduced tillage. CA, because of the increase in available water, does however permit the intensification of cropping systems. Sustainable intensification of agriculture in Africa will require more than technology alone, and institutional change and adequate markets may be just as, or more, important than technology in increasing farmers' economically attainable yields and achieving sustainable intensification.

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Growing more with less – the future of sustainable intensification

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Introduction

Most of the agricultural land in the world is currently producing below its capacity. Yield gaps, defined as the difference between potential and current yield levels, are wide for most major crops on a global scale. Their magnitude and their determinants vary from crop to crop, from region to region, and from farm to farm (e.g., van Ittersum et al., 2013). At global scale, however, the average yield of most major crops has increased steadily over the last 50 years (FAO, 2012). Yet, growth in both production and productivity has been unequal across the world and today's yield gaps tend to be the widest in the poorer regions of the world, and even wider for the less resource endowed farmers at any given location (Tittonell and Giller, 2013). In the least favoured regions of the world, food production per capita remains at the same level as in the 1960s. Such is the case in much of sub-Saharan Africa unfortunately (WFP, 2012). There are three major reasons, in my view, for such disparities:

1. Inadequate models of agricultural development coupled with increasing (settled) population densities in rural areas led to severe degradation of the natural resource base;
2. Poor farmers in the poorer regions of the world do not have access, cannot afford or are unwilling to adopt 'modern' agricultural technologies;
3. Such technologies were not developed to fit the reality of smallholder systems (in the tropics) and hence they are ineffective at increasing crop and livestock productivity;

In the most affluent regions of the world, by contrast, agricultural intensification through the use of inputs in excess of what their factor elasticity would dictate led to environmental pollution with often noxious consequences for human health and high costs for society as a whole (costs that are never internalised in the price paid for the agricultural produce). The two most emblematic regions of the world to showcase the success of the so-called green revolution, the Punjab in India and the Yaqui valley in Mexico, are also the most conspicuous examples of environmental degradation associated with agricultural intensification (e.g., Maredia and Pingalli, 2001). We do not want to take that road again. A decade ago, Tillman et al. (2002) already warned us on the fact that the doubling of yields experienced over the last 50 years was paralleled by an increase in nitrogen fertiliser use by a factor seven, in phosphorus use by three, and in irrigation water by two. If we need to increase food production by an extra 70% over the next 40 years, as the most pessimistic scenarios seem to suggest, then such an increase cannot be fuelled by further inputs of N, P and water – at least not at the same rate as experienced over the last 50 years. We need new forms of agricultural intensification in order to produce more but differently, to produce more food where food is urgently needed, and to make use of the natural functionalities that ecosystems offer in order to reduce the need for and increase the efficiency of external inputs. This paper explores some promising avenues in this regard based on recent experiences in sub-Saharan Africa in which agroecological principles are put at the service of designing restorative and resource use efficient agriculture.[1]

A need for systems re-design

"*Design is the first signal of human intention*". This sentence was coined by William Macdonough, one of the proponents of the 'Cradle to cradle' approach to industrial design and architecture. The approach relies on three major principles that are also largely applicable in the field of agriculture: (i) waste is food, (ii) use current solar income, (iii) celebrate diversity. The first principle refers to recycling and reusing materials (nutrients, carbon, water) in different production processes, the second one points to a maximisation of capture and utilisation efficiencies of solar radiation, and the third one refers to diversity in different ways, which in the particular case of agriculture can be assimilated directly to the idea of (agro-)biodiversity in space and time or to the concept of combining diverse knowledge systems (e.g., scientific and lay knowledge). Many of the sustainable agricultural production technologies and practices, such as those used in agroecology or in conservation agriculture, were originally built on these principles, namely on recycling, efficiency and diversity, which are the principles behind ecological intensification (Tittonell, 2014). A strong implication of these principles is the need for a gradual decoupling of agriculture from the petrochemical industry and/or from any other form of exploitation of non-renewable resources.

Is it possible to imagine a future for smallholder agriculture in which the natural functionalities of the agroecosystem are used in a smart and intensive way, reducing its dependence on fossil fuels and its impacts on the environment, while ensuring sufficient and stable food production in the face of global environmental and demographic change? This is undoubtedly a challenging question, but there are promising avenues to be explored. One of them is the insufficiently tapped potential of biological nitrogen fixation. Figure 1A shows recent evidence from a multi-year no-tillage experiment in central Mozambique in which the response to N and P fertiliser by maize is compared across cropping systems consisting of continuous maize monoculture, maize and pigeon pea (*Cajanus cajan*) intercrops and maize in rotation with pigeon pea (Ruzinamhodzi et al., 2012). Responses to chemical fertilisers, as well as yields without fertilisers, were very poor in maize monoculture. The amount of crop residue biomass was consequently low in these treatments and thus insufficient to provide enough soil cover through mulching, impacting negatively on soil thermal and hydrological regimes. In the maize-pigeon pea intercrop and rotation, maize responded to 20 kg ha-1 P and only in the rotation to 30 kg ha-1 N. Maize yields without fertiliser in intercrop or in rotation with pigeon pea were five times greater than the average maize yields of sub-Saharan Africa.

A major problem that faces global agricultural production nowadays is the degradation of formerly productive – although often fragile – soils. The FAO estimates that about 25% of the agricultural soils worldwide are in a state of severe degradation. Restoring productivity of these soils will not only contribute to food security (specially because such soils are mostly

[1] Most of the experiences and data that will be presented during the conference are drawn from the on-going EU-funded projects ABACO (Agroecology-based aggradation-conservation agriculture), CA2Africa and WASSA. Here, I just introduce two illustrative examples from the literature.

located in resource-poor environments) but also represent a large sink for atmospheric CO_2, therefore contributing to climate change mitigation. The hypothesis often put forward during the first decade of this century that chemical fertiliser use can boost productivity and therefore restore organic matter in degraded soils has not yet been demonstrated. Figure 1B shows evidence from a degraded sandy soil in Zimbabwe (an 'outfield') published by Zingore et al. (2007). In such situations, absolute control yields (i.e., no fertiliser or manure inputs) are impractical, as the soils are too depleted in nutrients to produce a yield without inputs. That is why the control treatment in Fig. 1B received 100 kg ha-1 N. The applications of 30 kg ha-1 P were done as simple super phosphate or as the equivalent amount contained in cattle manure (for which 15 t ha^{-1} had to be applied). The results indicate that productivity is hard to restore in these soils under conventional tillage, even with relatively large amounts of fertilisers. Application of 100 kg ha-1 for three consecutive years did not allow to reaching more than half a tonne of maize yield. Adding phosphorus lead to more than doubling yields, but yet productivity remained around 1 t ha-1, and was low during the third year due to poor rainfall. Adding manure had a build-up effect on crop yields that was not cumbered by the lower rainfall received in the third year. Yet, to be able to collect 15 t of manure for application in one hectare of land means that a farmer needs to own the equivalent to 10-15 cattle heads, which is most often not the case. Thus the amounts of both fertilisers and manure in this experiment are hardly or not affordable to most smallholders in resource-constrained regions.

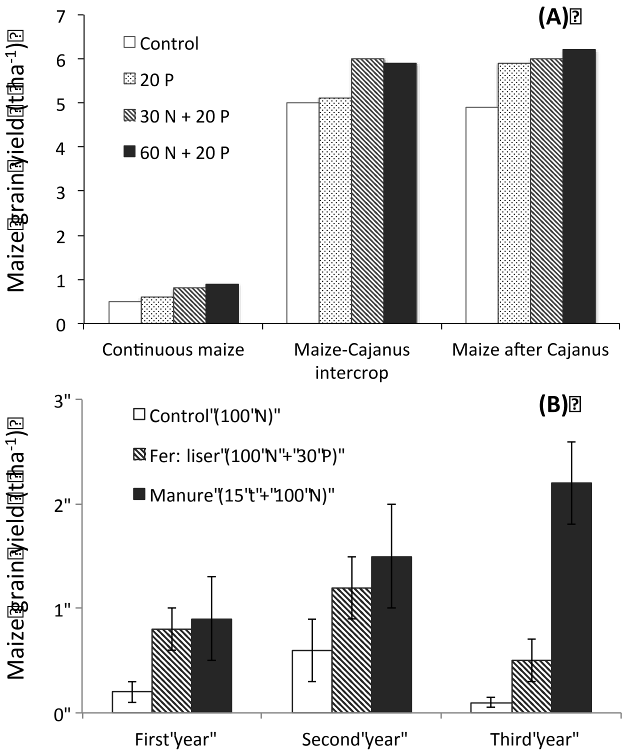

Figure 1: **(A)** Yields of sole maize and maize intercropped or in rotation with pigeon pea (Cajanus cajan) with different rate of N and P fertiliser application per ha under no-tillage in central Mozambique (Ruzinamhodzi et

al., 2012). **(B)** Yields of maize on a degraded sandy soil in Zimbabwe during three consecutive years with application of fertiliser and manure (Zingore et al., 2007).

Scientific evidence is mounting on the integration of agriculture with elements of the natural vegetation in savannah agroecosystems. The case of cereals growing under Fahiderbia albida trees is well known and documented (e.g., Garity et al., 2010). In a different tropical context, Sà et al. (2011) showed that the maximum soil temperatures that can be measured with or without soil cover can differ in 30 °C, with enormous consequences for water storage and organic matter dynamics. A yet less explored example of integration of agriculture and natural vegetation is the combination of crops and native shrubs in Sahelian agriculture. This practice was developed by smallholder farmers and is now being optimised through scientific research, and has been documented by Lahmar et al. (2012) (Figure 2). Deep-rooting shrub species that grow on residual water during the dry season are a source of biomass for soil amendment (mulching). Due to the accumulation of organic matter and biological activity (e.g. association with mycorrhyza) under the shrub canopy, soil physical quality (water infiltration and storage) and nutrient availability tend to increase creating 'islands of fertility'. Farmers recognise this effect and traditionally prune the shoots of these shrubs at the onset of the rainy season to grow crops in and around these islands. Alternatively, when shrubs are not naturally occurring due to soil degradation, the collection of shrub biomass and its application to crops can increase productivity and also boost the response of crops to fertiliser inputs. In the example from Burkina Faso (Barthélémy et al., 2014) presented in Figure 3 sorghum yields did not differ significantly from the unfertilised control when they received either chemical fertilisers (100 kg ha^{-1} of NPK plus 50 kg ha^{-1} of Urea) or 2.5 t ha^{-1} of leaf biomass of *Piliostigma reticulatum* – a native shrub to this region. Sorghum responded significantly to such relatively large amounts of fertilisers when they were applied together with shrub biomass.

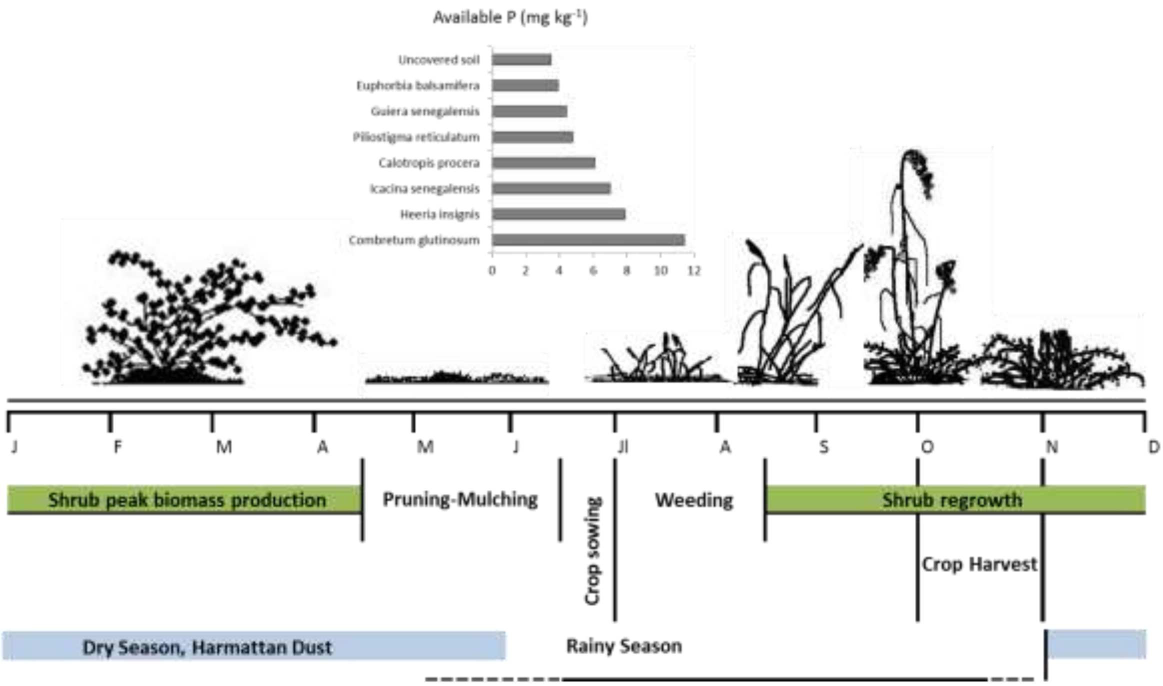

Figure 2: An illustration of a crop-native shrub sequence as practised by smallholder farmers in the Sahel (adapted from Lahmar et al., 2012). The inset shows phosphorus availability in the topsoil under different shrub

species (From Duponnois, 2011) as compared to uncovered soil. Farmers make use of such islands of fertility to grow crops on degraded soils.

Crop-livestock integration is crucial in low input farming systems. Livestock mediate nutrient flows to and within the farming system, they provide manure and draught power for crop production, allow capitalisation and diversification of the farm system, and create opportunities to establish crop-grassland rotations or to grow N-fixing legume cover crops with the dual purpose of improving soil fertility and feeding livestock. But crop-livestock integration can lead to farm-scale nutrient inefficiencies when either the system is not well designed or its management or infrastructure are not the appropriate ones. In other words, increasing the diversity of systems components and the complexity of their interrelations can only lead to more favourable system regimes when such diversity and complexity are organised in a particular way. Such organisation can be studied by conceptualising the system as a network, in which the nodes of the network represent the various components within the system, and the connections between nodes represent the flows of energy, matter or information between system components. Table 1 presents a number of indicators of N network size, diversity and organisation corresponding to case study farms of higher or lower resource endowment from highland cereal-cattle agroecosystems in Ethiopia, Kenya, Zimbabwe and Madagascar (Rufino et al., 2009; Alvarez et al., 2013).

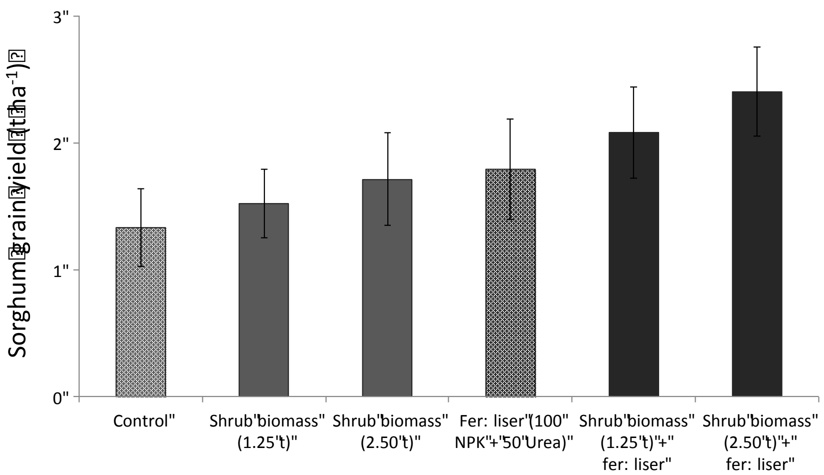

Figure 3: Sorghum yield Sahelian Burkina Faso with application leaf biomass of *Piliostigma reticulatum* at rates of 1.25 and 2.5 t ha-1, without or with application of 100 kg ha-1 NPK fertiliser and 50 kg ha-1 urea for topdressing (from Barthélémy et al., 2014).

Across sites, the presence of livestock or their increasing number was associated with greater system N throughput, and in some cases with less dependence on N imports and a greater proportion of N recycled on-farm. System N throughputs were larger in Ethiopia, where cattle ‘import’ N through grazing on communal land. Madagascar systems were the least dependent on external N due to the presence of grasslands or fodder produced on-farm and substantially greater stocks of N in their soils. In all cases the proportion of N recycled was below 10% of all N flowing through the farm system, and only the wealthier farms owing livestock in Kenya and Zimbabwe were able to recycle more than 5%. The relatively low values of AMI (average mutual information) calculated across sites and farm types indicate that system components are connected and that N flows through most of them. There is room for improvement. The presence of livestock and their number increase the organisation of N flows within the system, notably in the case of Kenya and Zimbabwe. This contributes to explaining the differences in N recycling, in whole-farm N use efficiency and ultimately in food self-sufficiency between poorer and wealthier households. Within each site, the size of the total N flow within the farm is associated with food self-sufficiency, but not when comparisons are made between sites. While open grazing systems like the one in Ethiopia are often less efficient in using N imports, the higher efficiency of N use by Kenya and Madagascar farms may be in part only apparent, simply associated with greater stocks of N in the soil or with more conducive environments for agricultural and animal production (ample rainfall and deeper, more fertile soils).

Table 1: Indicators of resource endowment, and of the size and organisation of the network of nitrogen flows within eight case study smallholder farms (from: Rufino et al., 2009; Alvarez et al., 2012)

Location/ Farm type	Cropped land (ha)	Livestock owned (TLU)	Farm N network size			Farm N network organisation		Farm N use efficiency (kg kg N^{-1})	Food self sufficiency ratio
			Total system throughput	Dependency on imports (%)	Finn's cycling index (%)	Average mutual information	Diversity of flows		
Ethiopia									
Poorer	0.3	1.2	230	72	2.9	1.1	2.2	23	0.4
Wealthier	2.4	10.0	1340	66	2.6	1.3	2.4	18	1.7
Kenya									
Poorer	1.0	0	45	45	2.2	1.1	2.5	74	0.3
Wealthier	2.9	3.5	190	34	11.0	1.7	3.3	216	1.2
Zimbabwe									
Poorer	0.9	0.3	40	65	0.9	1.0	2.2	44	0.5
Wealthier	2.5	5.4	480	45	5.5	1.5	2.9	86	3.4
Madagascar									
Poorer	2.7	3	110	33	3.5	1.2	2.6	122	1.9
Wealthier	6.9	12	400	31	2.5	1.4	3.4	198	4.7

Total system throughput is the sum of all N flows between all components (activities) of the farming system, expressed here in kg N per family member to allow for comparisons across farms of different size; Dependency on imports is the ratio between N flows into the farm system and total system throughput; Finn's cycling index is calculated as the ratio of the sum of all internal flows to total system throughput; Average mutual information (AMI) is the average number of connexions of each system component and the diversity of flows (HR) or statistical uncertainty is the maximum number of possible connexions between components, or the upper limit to AMI; both AMI and HR are measured in bits (binary decisions); if all the components of a system are connected and the total flow is equally distributed among all components, AMI will approach zero; typical values of AMI in natural ecosystems range between 0 and 6; Farm N use efficiency is the ratio of total biomass productivity to total N flowing into the system; Food self-sufficiency ratio is the ratio of edible calories produced on farm to caloric household needs.

Towards an ecological intensification of smallholder agriculture

Increasing agricultural productivity is one of the necessary stepping-stones to achieve current and future food security at global scale. Yet, further increasing yields in already highly productive environments will entail enormous energy costs and environmental risks, and rather than alleviating poverty this will contribute to further deepening the North-South divide. Increasing yields in the poorest regions of the world is more cost effective, requires less energy inputs, and can more efficiently contribute to global food security and poverty alleviation. Most agricultural systems developed since the so-called green revolution, during the second half of the 20th century, were designed by ignoring the structure of the original ecosystem to which they were introduced and/or the lay knowledge of people managing those landscapes. Often the design responded to a need for simplification of structures and diversity in space and time, leading to uniform and mono-specific crop and livestock systems. This facilitated practices, mechanisation and sanitary control. The simplification of the ecological structure of the agro-ecosystem led to a loss of functionalities, notably of the ecosystem regulation functions provided by biodiversity (Bianchi et al., 2013). Oligo-specific agroecosystems as those that predominate in the world nowadays are not only vulnerable to pest and disease outbreaks but also less efficient in making use of natural resources such as light, water and nutrients. Due to such inefficiencies, some of these resources have to be often brought from outside the system in the form of energy, nutrient or financial subsidies.

The examples presented here show that there is potential for synergistic effects between agriculture and nature through crop diversification, crop-livestock integration and use of locally available resources and knowledge. The case studies from Table 1 in particular indicate that the total nutrient flow through a farming system is only partly associated with food production or self-sufficiency. They indicate that more can be done with less. Even when fertiliser inputs are affordable by farmers, their use efficiency can be much improved through crop diversification (cf. Figure 1), especially on degraded soils in which crop responses tend to be poor (cf. Figure 2, 3). Yet closing yield gaps in smallholder tropical agriculture, which are in the order of 80% for many cops in several regions (Tittonell and Giller, 2013), requires a paradigm shift in the way we think agricultural technologies and intensification. We need to be aware that:

a. Making agricultural inputs more accessible to smallholders may be a necessary – in some cases – but not sufficient condition to close yield gaps;
b. Agricultural inputs do not work on degraded soils; soil rehabilitation is a prerequisite for any form of agricultural intensification;
c. Replacing the natural vegetation of tropical landscapes with annual crops and frequent tillage disrupts their basic ecological infrastructure and leads to degradation and/or inefficient capture and use of energy, water and nutrients;
d. Smallholder farmers do not reason in terms of crops or cropping systems, they make decisions that concern their whole livelihood system;
e. Regulatory ecological services that can contribute to pest and disease management do not operate at the scale of a single field, they operate across and are influenced by the wider agricultural landscape;

Closing yield gaps in smallholder agriculture requires research that contributes to a thorough re-design of agroecosystems, drawing inspiration from the structure and functioning of the natural ecosystems that evolved in each region, taking stock of the wealth of local agricultural knowledge and institutions governing natural resource management, and reasoning at scales broader than the agricultural field plot. We need to move away from the idea of crop yield gaps and embrace the concept of whole-farm productivity gaps (Cortez Arriola et al., 2013). But none of this would be effective without paying due attention to the geographical and socio-political contexts in which smallholders operate. In other words, closing yield gaps in smallholder farming systems implies closing socio-economic gaps, technology gaps, and institutional gaps. The challenge is complex and requires multi-disciplinary action. But through focusing our effort to help find solutions to smallholders we will be targeting 500 million farms, which produce about half of all the food that the world eats in only 20% of the agricultural land. Targeting smallholder farms means working for 97% of all the farms in the world (FAOSTAT, 2012).

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Making Conservation Agriculture EverGreen: It's Climate Smart and Key to the Success of CA in the Tropics

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After decades of research, and the sustained efforts of pioneering farmers, the practice of conservation agriculture (CA) has been steadily expanding globally. Currently, about 120 million hectares of land are now managed under minimum or zero-tillage conservation farming practices. Meanwhile, worldwide concerns about the potentially devastating effects of climate change on food production continue to accelerate. CA has been highlighted as an important component of a climate-smart agriculture.

Investments in CA in the developing world are increasing. However, the uptake of CA in Africa, and in the rainfed upland areas of Asia, has been quite modest so far. Evidence from research, and from widespread indigenous practice, indicates that successful CA systems for tropical smallholders benefit substantially from the integration of trees into these systems. Such an EverGreen Conservation Agriculture (ECA) addresses a number of the critical constraints to sustained smallholder CA uptake, to increasing and sustaining productivity in these systems, and to buffering them in the face of climate change. We are now beginning to observe the success of ECA at scale in several countries in Africa.

There are three long-established principles in conservation agriculture: Minimum soil disturbance, crop residue retention, and crop rotation. The short-term advantages observed where CA is currently practiced are earlier planting that enables better use of seasonal rainfall, and increased rainwater conservation in the soil to better tide crops over during drought periods (Rockstrom et al 2009). But there are a number of unique constraints to smallholder adoption of CA that are retarding its more rapid uptake. Most important among these are: Competing uses for crop residues where livestock production is common, inadequate biomass accumulation of cover crops in the off-season, increased labor demands for weeding when herbicides are not used, variable yield results across soil types, and the need for greater application of organic and inorganic nutrients.

EverGreen Conservation Agriculture Systems in Africa

Most African smallholders are engaged in both crop and livestock production. But their available fodder resources are usually very inadequate, particularly in the late dry season. Thus, farmers typically use all of their available crop residues for animal fodder or fuel, and cannot afford to retain them as a soil cover. There must be other ways to increase plant biomass in their farming system. In addition, more than 3 out of 4 African smallholders are not applying any inorganic fertilizers, often because of cash constraints and high climatic risk. Low yields and declining soil fertility are inevitable in this situation if greater use of biological nitrogen fixation and more efficient nutrient cycling are not practiced.

How can biomass production be increased to enhance surface cover and to generate more organic nutrients to complement whatever amounts of inorganic fertilizers a smallholder farmer can afford to apply?

The CA and agroforestry research and development communities have now recognized the value of integrating fertilizer trees and shrubs into CA systems to dramatically enhance both fodder production and soil fertility (e.g. FAO 2010; FAO 2011). Practical systems for intercropping fertilizer trees in maize farming have been developed and are being extended to hundreds of thousands of farmers in Malawi and Zambia (Garrity et al 2010). The portfolio of options includes intercropping maize with fast-growing N-fixing trees, including *Gliricidia sepium*, *Tephrosia candida* or pigeon peas, using trees such as *Sesbania sesban* as an improved fallow, or integrating full-canopy fertilizer trees such as *Faidherbia albida* into the CA system (Akinnifesi et al 2010).

The integration of the *Faidherbia albida* into CA systems has proven to be a particularly effective practice (conservationagriculture.org). *Faidherbia* is an indigenous African acacia that is widespread on millions of farmer's fields throughout the eastern, western, and southern regions of the continent. It is highly compatible with food crops because it is physiologically dormant during the rainy season. It sheds its nitrogen-rich foliage at the beginning of the wet season, and re-foliates at the beginning of the dry season. Thus, it exhibits minimal competition with food crops grown in association with it, while enhancing yields and soil health (Barnes and Fagg 2003; Garrity et al 2010). Several tons of additional biomass can be generated annually per hectare to accelerate soil fertility replenishment, and/or provide additional high protein fodder livestock. Numerous publications have recorded increases in maize grain yield when it grown in association with *Faidherbia,* ranging from 6% to more than 200% (Barnes and Fagg 2003), depending on the age and density of trees, agronomic practices used, and the weather conditions.

Faidherbia's effects tend to be most remarkable on soils of low inherent fertility. In semi-arid cropping systems based on millet and sorghum, double-story production systems with medium-to-high densities of fertilizer trees are now observed across more than five million of hectares in the Sahelian countries (Garrity et al 2010). Depending upon which woody species are used, and how they are managed, their incorporation into CA helps to maintain vegetative soil cover, increase nutrient supply through nitrogen fixation and nutrient cycling, suppress insect pests and weeds, enhance soil structure and water infiltration, increase carbon storage and soil organic matter, and conserve above- and below-ground biodiversity.

ECA systems expand on the principle of residue retention to include the integration of trees and shrubs throughout the crop fields to supply increased high-quality residues from tree biomass and other organic sources of nutrients. This broadens the concept of crop rotations to incorporate the role of fertilizer/fodder trees to more effectively enhance soil fertility and to provide needed biological and income diversity in the system.

Conservation Farming in Zambia Champions Faidherbia

In Zambia, maize production is the foundation of agriculture and the basis for the country's food supply. However, the average maize yield is only 1.1t/ha. Nearly seven out of every 10 Zambian smallholders farm without use of mineral fertilizers. Since 1996, a coalition of stakeholders from the private sector, government and donor communities has promoted a package of agronomic practices based on the principles of conservation farming (Haggblade and Tembo, 2003). The effort is spearheaded by the Zambian Conservation Farming Unit (CFU), and during the past decade conservation agriculture has been introduced over large areas of the country.

As the Zambian CFU worked to make conservation farming feasible, they encountered a problem that defied conventional solutions: More than two-thirds of the country's smallholder farmers were unable to afford inorganic fertilizers, and had little or no access to livestock manure or other nutrient sources. This fundamentally limited smallholder maize yields and further depleted their soil fertility each year. To address the problem, the Zambian CFU investigated the incorporation of *Faidherbia albida* trees into maize-production systems. They found that maize yields were dramatically increased when the crop was associated with these trees.

The Zambian CFU incorporated *Faidherbia* into its CA extension program, recommending that *Faidherbia* seedlings be planted in a grid pattern at a density of 100 trees per ha. Fields with *Faidherbia*-maize systems managed with such a planting pattern (10m x 10m) can accommodate full mechanization. The result is a maize-farming system under an agroforest of *Faidherbia* trees. The trees may live for 70 to 100 years, providing inter-generational benefits for a farm family, with a very modest initial investment. As the trees mature and develop a spreading canopy, they are gradually thinned down to about 25 to 30 trees per hectare. Currently, 68,000 farmers are estimated to have *Faidherbia* trees on their farms (Nkatiko, 2013). The technology is also widely recommended in Malawi. There is increasing recognition of *Faidherbia's* potential in many other parts of Africa, including the launch of a National Faidherbia Program in Ethiopia.

In Niger, millet production in combination with *Faidherbia* is accompanied by non-inversion tillage methods. The majority of Nigerian farmers do not use a plow or the hoe for land preparation on their typically sandy soils. Rather, they use a hand-drawn form of shallow-sweeping implement that is passed just underneath the soil surface, loosening the soil and undercutting the weeds. Thus, agriculture in Niger is now essentially an ECA system (Garrity et al 2010). Fuel wood availability has now become a critical constraint in many farming systems. ECA farms, however, have a ready supply of fuel wood for household use with a surplus for sale. The creation of medium-to-high density agroforests on the farmlands of Niger has stimulated the widespread development of wood markets where excess wood is being marketed by farmers as an additional source of cash income. Some of this wood is now being exported to Nigeria.

In Burkina Faso, *zai* cultivation in planting pits is a variation of ECA. Its practice has been steadily expanding for decades. The pits intensify cereal and tree production in combination. Biomass production in these systems is dramatically increased, for both soil amelioration as well as livestock fodder (Reij et al 2009). The experiences of Zambia, Malawi, Niger, and Burkina Faso indicate that the principles of ECA are applicable to a broad range of food crop systems in Africa, if accompanied by adequate testing and farmer engagement.

Climate-Smart EverGreen CA

Incorporating trees into crop farming may confer sustainability benefits through ecological intensification. And they may increase the resilience of the farm enterprise to climate change through greater resilience to drought at the crop level and at the household level.

At the crop level there are two key processes in play for drought resilience. First, the presence of the trees increases rainwater capture and storage. This improved rainfall infiltration and soil moisture storage are particularly valuable on farmlands where rainfall runoff is a problem. According to farmers in Niger the presence of the trees not only provides more soil moisture to their sorghum and millet crops, but also elevates the entire village water table levels.

Tree cover on crop fields also reduces wind speeds at the canopy level, providing a windbreak effect that reduces the deleterious effects of desiccating winds. In the Sahel, for example, farmers report that high winds and sand-blasting often destroy crop seedlings as they emerge, necessitating repeated planting of the crop to achieve a successful establishment. But with a moderate density of fertilizer trees they no longer have to plant more than once a season.

Daytime and night temperatures are increasing as a result of climate change. Higher temperatures increase crop heat stress, particularly at mid-day, and they are a particularly devastating prospect during the crop flowering stage. Higher temperatures also reduce the length of the grain-filling period, which is now being observed to directly lower crop yield potential in Europe as well as Africa. The dispersed light shade provided by the trees in an ECA system reduces crop canopy temperatures significantly during the mid-day period, thus providing a helpful canopy-temperature buffering effect (CIMMYT, personal communication, 2013). Global temperatures will continue to rise rapidly, as predicted by the global climate models, intensifying the utility of this microclimate buffering effect. Thus, the value of tree-based CA systems is expected to become increasingly important in the future.

ECA systems also increase drought resilience at the household level. Trees on croplands serve as an additional household asset that can be harvested for cash during periods when severe drought or other emergencies are experienced. This was observed to be an important means by which families coped with household food deficits during the 2009-10 drought in the Sahel.

The climate change mitigation potential of ECA is also significant. They accumulate much more carbon than is possible with CA alone. Conventional CA systems tend to sequester a maximum of 0.2–0.4 t C $ha^{-1}yr^{-1}$. ECA systems accumulate carbon both above and below-ground in the range of 2–4 t C $ha^{-1}yr^{-1}$, roughly an order of magnitude higher than with CA alone. This is particularly true for systems incorporating fertilizer trees such as *Faidherbia* or *Gliricidia* (Makumba et al. 2007).

Consequently, there is considerable interest in the development of reward systems to channel carbon offset payments from developed countries to stimulate more carbon sequestration in African food crop systems, while simultaneously enhancing the livelihoods of smallholders and the environment. These investments will encourage development pathways resulting in higher carbon stocks at a whole landscape scale.

Making conservation agriculture evergreen could therefore be one of the most significant ways to help climate proof agriculture in the future while also helping agriculture to reduce the level of its CO_2 emissions, and thus become part of the solution to climate change.

From Fertilizer Subsidies to Sustainability

The incorporation of fertilizer trees into CA systems offers a major opportunity for countries to increase food production by enhancing the biological fixation of nitrogen in farmers' fields. This in-field fertilizer production can help to reduce the costs of fertilizer purchases at the farm level, and help offset fertilizer importation and subsidies at the national level. For example, the Government of Malawi launched an input-subsidy programme in 2004 that generated large maize surpluses and helped improved rural welfare. This success caused a surge of interest among African governments in deploying fertilizer subsidies as a means of enhancing food security. However, in Malawi itself, the recurrent costs of the programme later contributed to the country's recent near-bankruptcy, which has brought on massive economic difficulties. The fertilizer-subsidy programme is now being gradually scaled back, while an alternative strategy for the long term is taking root.

The Malawi Agroforestry Food Security Programme has been assisting farmers to deploy biofertiliser trees on about 200,000 farms across the country. These practices have doubled farm yields without inorganic fertilizer inputs, although modest additional fertilizer applications may further increase yields. A pilot programme is currently being implemented to link the fertilizer subsidies with these evergreen agriculture investments to provide long-term sustainability in nutrient supply and to build up soil health. This 'subsidy to sustainability' pathway for integrated soil-fertility management has provided a medium-term solution to the fertilizer-subsidy conundrum (Garrity et al, 2010).

A recent evaluation of the performance of fertilizer subsidies among the 12 countries that are currently implementing them has emphasized the their generally poor return on investment, and the major burdens that they place on incurring national trade deficits and budget deficits (IFPRI 2013). By shifting attention to upscaling fertilizer tree technologies, governments can reap substantial benefits and create a sustainable crop nutrient supply situation.

Looking forward

ECA systems should attract much more research and extension attention than has been the case so far. Their success will depend on more knowledge and practical solutions in a number of areas, including: the identification of a wider range of tree species for varied agroecologies, higher quality tree germplasm, better tree seed dissemination systems, and further improvements in tree propagation and establishment methods. The optimum tree densities for different ECA systems have yet to be fully understood, and the best practices in exploiting the soil fertility synergies between organic and inorganic nutrient sources also need to be elucidated.

CIMMYT and ICRAF are now actively collaborating in a number of projects to document the effects of trees incorporated into maize and wheat cropping systems, and to determine the best management practices for a range of cereal-based farming systems in eastern and southern Africa. Pioneer Hi-Bred Seeds Corporation has recognized the future importance of ECA systems and has been evaluating their maize hybrids under ECA systems in order to recommend the best varieties for these management systems. The company has entered into a collaboration with ICRAF to promote evergreen agriculture as a key direction in creating a more sustainable and climate-smart agriculture.

Targeting and scaling-up methodologies for ECA deserve particular attention. These need to be supported by work to reverse the policy frameworks in some countries that currently discourage farmers from cultivating trees. Farmer organizations have always been instrumental in the development and spread of CA. They will play an increasingly important role in expanding the practice of ECA. There is, for instance, a growing interest in Landcare for community-based grassroots mobilization in Africa and Asia (landcareinternational.net). Landcare can provide a particularly suitable approach for the engagement of farming communities in the refinement and spread of ECA.

The EverGreen Agriculture Partnership

Currently, there are efforts under way to upscale evergreen agriculture including ECA in 17 countries in Africa and several countries in Asia. But an accelerated effort is needed to expand the reach of these systems to transform the farms of tens of millions of the poorest small-scale farmers. Therefore, a global partnership has been launched to support governments, farmers' organizations, the NGO community and civil society to achieve a massive scaling-up movement, known as The Partnership to Create an EverGreen Agriculture (ICRAF 2012; evergreenagriculture.net). The Partnership is supporting the information needs, capacity building, and knowledge generation required to assist in this effort. The major international and regional organizations have endorsed this work and are they supporting it. Many NGOs are now engaged in implementing this work on the ground. Thus, the momentum that has been generated is encouraging. We are beginning to glimpse a future of more environmentally sound and productive farming where much of our annual food crop production occurs in conservation agriculture incorporating trees.

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EverGreen Conservation Agriculture with *Faidherbia albida* trees is now practiced by tens of thousands of farmers of farmers in southern Africa.

Food security: integrating conservation agriculture into smallholder and family farms in Africa.

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Increasing the productivity of smallholder agricultural and family farms is key to achieving sustainable agriculture that includes the practice of Conservation Agriculture (CA). This requires improving access to production inputs especially improved seeds and fertilizers, extension and advisory and remunerative markets. There is ample evidence from various pilot projects that these interventions can achieve remarkable results within a 2-3 year period, especially if access to financing to procure inputs and farmer organizations are also improved. These are core interventions that AGRA is now supporting in 16 countries in sub-Saharan towards catalyzing a uniquely African Green Revolution, one that not only increases smallholder agricultural productivity but also conserves the environment.

AGRA is on course and well advanced into its target of reaching 20 million smallholder farmers by 2020. Key achievements so far include:

a) Over 80 local seed companies strengthened to enhance access to improved seeds that are bred locally by National Agricultural Research programs with the participation of farmers; together, they are now providing over 80,000 metric tons of seed annually to farmers;

b) Over 23,000 agro-dealers trained and supported to stock production inputs; they have helped reduce the distance farmers have to travel to access farm inputs, to under 2 km, in some regions;

c) About 1.0 m hectare within 1.5 m smallholders land brought under sound soil fertility management practices. This includes the integration of organic and inorganic fertilizers, as well as increased area under grain legumes that if well managed, can improve soil fertility naturally. The yield of staple food crops (e.g., maize) on many farms has increased by 2-3 folds over the typical low yields of 1.0 t/ha under smallholder production;

d) Over 360 on-farm storage facilities established/refurbished in many countries with about 730,000 farmers trained on post-harvest handling, quality management and market linkages;

e) About 20,000 famer organizations strengthened; and

f) Financing mechanisms established with banks in nearly all the AGRA-focal countries.

Additionally, universities and training institutions in many countries have been strengthened to train the next generation of breeders, soil scientists, agribusiness experts, and agricultural economists and policy experts. On the policy front, the establishment of local policy hubs and nodes are providing opportunities for "home grown" evidence- based policies.

These achievements provide unique opportunities for docking on initiatives to scale up Conservation and Climate-Smart Agriculture in Africa. This is, indeed, the roadmap that AGRA is taking. In this regard, several projects on CA are currently supported by AGRA in Kenya, Malawi, Mozambique, Zambia, Tanzania, and Ghana. An additional one is currently under development for Tanzania. In some cases, the interventions promoted include agroforestry technologies.

The lessons emerging from these projects and others would allow us to guide the promotion of CA practices that are productive and sustainable (enhance the use of yield-enhancing technologies especially fertilizers and improved seeds as well as good agronomic practices), promote minimum tillage and soil cover. This, however, has to take into consideration the biophysical and socio-economic constraints of farmers and improve their access to markets and affordable sources of credit. This will require forging strong public-private sector partnerships. We are well poised to do that given the tremendous potential and promise of CA towards enhancing the productivity and resilience of smallholder agriculture in Africa.

Sub-Theme 1: Growing more with less – the future of sustainable intensification

Let's dream big! How can we cover millions of hectares with Conservation Agriculture?

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Introduction

Allow me to be quite frank for a moment. I am tired of hearing people say that conservation agriculture (CA) isn't spreading as fast as it should. I am tired of reading that smallholder farmers in Africa rarely dedicate more than half a hectare to CA. I like it even less when I am told that CA is just a temporary fad, or when people insinuate that CA will eventually die a sad and lonely death.

I am not saying that all of these statements are false. I agree that CA is not spreading as fast as it should. And I am disturbed by how often even the earliest adopters are still using CA on less than 0.5 ha. But I do not think CA is going to die away. In fact, I believe that if we do things right, it could become, over time, the dominant way of producing food in sub-Saharan Africa.

To achieve such a goal, we need to look at CA with a cold eye to its faults as presently practiced, and then find practical solutions that will a) significantly increase basic grain productivity, b) require less labor than do other farming systems, c) use only local resources that are plentiful, and d) increase net benefits for the farm family.

A surprising number of these changes can be achieved with the incorporation of green manure/cover crops (gm/cc) into the CA system. In southern Brazil, gm/ccs were a part of CA right from the start in the 1980s, and over two million farmers are now using CA in Brazil.

Gm/ccs are defined as "any species of plant, usually leguminous, whether it is a tree, a bush, a climbing vine, a crawler or a water-borne plant, that farmers grow to maintain or improve their soil fertility or control weeds, even when they have many other reasons for growing these plants."

Material and Methods

The material in this case comes from over 25 years of experience in working with both CA and green manure/cover crops (gm/ccs) across some 45 nations in the global south (including 21 nations in sub-Saharan Africa). The methods have been diverse. Gabino Lopez, a colleague of mine, and I have searched out zero tillage systems, mulch systems, and gm/cc systems across the world. Many of these systems are now practiced by over 10,000 farmers, and a few are practiced by well over 100,000 farmers.[i] These latter tend to be traditional zero till and gm/cc systems that farmers have used for centuries. We have interviewed thousands of smallholder farmers who have originated or adopted these systems. We have made repeated visits to the programs of EPAGRI in the State of Santa Catarina, Brazil, to learn from that extremely valuable experience.

In Honduras, we worked with over 4,000 farmers, introducing different possible zero tillage, mulch and gm/cc systems, identifying farmer experimenters, and watching which systems were adopted or disadopted by the farmers. Although most of this effort consisted of learning from others' experiences and experiments, we occasionally encouraged certain top-quality farmer experimenters to carry out specific experiments that we needed to have done in order to answer critical questions in this multi-decade search for answers. After some 14 years of using these various approaches, we organized two technical conferences, attended by selected smallholder experimenters from across the country, most of them trained by one or another of six NGOs. At these conferences over 75 star farmer experimenters were brought together and each presented their most important discoveries, much as we professionals are doing at this conference.

Results and Discussion

How well is CA fulfilling the criteria of a scalable technology? To begin, we need to look at how CA rates according to the four criteria mentioned above: does it a) significantly increase basic grain productivity, b) require less labor than do other farming systems, c) use local resources that are plentiful, and d) increase net benefits for the farm family?

a) In terms of yields, it has a spotty record. In some cases, I have heard of impressive yields of over 3 t/ha. In other cases, yields are hardly over a disappointing 1.5 t/ha.

b) In terms of labor demands, I'm afraid this is where the diagnosis starts to look a little sickly. Hauling mulch material onto fields requires a lot of work. I've seen estimates of anywhere from 5 to 12 days to gather the mulch for a quarter of a hectare. That means it would require a solid month for one person to collect enough mulch material for just 1 ha. And that's only if we make the highly optimistic assumption that one doesn't have to go a lot farther to gather the mulch for the last 3/4 ha. And if the whole community starts gathering the mulch, it could take more than twice that long to fetch it, as one may have to walk up to a km to get a decent load of grass. Furthermore, the easiest mulch material to gather is all grass, which means the farmers' young crops have a difficult first month or so. This happens because much of the nitrogen is tied up when the rains come, because the rains also increase the decomposition of all that mulched grass.

Furthermore, as we are all aware, gathering all this grass means there isn't much left for the village's grazing animals, which means that we may be reducing over-all incomes of those who have animals, because grass frequently provides more income when they feed it to cattle than when it is shielding and fertilizing the soil.

c) In terms of the use of local resources, CA also has some problems. Grass for mulching is available for the small plots of a few farmers, but if everyone in a village decides to use CA on all of his or her land, there would usually be a very serious shortage of mulch material. Also, a lot of the higher yields achieved with CA depend on the use of animal manure or compost. These resources, too, become very limiting when farmers want to expand their CA to more than a fraction of a hectare. Furthermore, the cost of making compost, from bringing the material together, making the compost pile, turning it over, transporting the material out to the field and spreading it across the land, is prohibitive for use on basic grains (except for rice). And it takes a minimum of about 20 t/ha of biomass a year to maintain yields over time.[ii] Has anyone ever seen a smallholder farmer apply 20 tons of compost to a hectare of CA?

d) Thus, the profits from CA can be very attractive for about 1/4 ha, but if we expand the use of CA to even just one hectare, the cost of mulching and enriching the soil become prohibitive. It is therefore not at all surprising that farmers usually have less than 0.5 ha of CA.

Of course, it could be possible that these problems are just part of the nature of CA. Maybe we just have to be content that farmers are planting a quarter of a hectare of CA. At least in doing so, they are probably maximizing the output of their animal manure, compost and labor, even if only on a small part of their land.

But we have incontrovertible evidence to the contrary. In southern Brazil, by far the best and most extensive example of CA anywhere in the developing world, over two million farmers are using CA. Another 1 million farmers use CA in Paraguay. Many of those farmers use CA on anywhere from 5 to 20 ha. Some wealthy farmers in Brazil use CA on literally thousands of hectares. There are much smaller instances of farmers using CA, numbering in the thousands, in Central America and Asia. Many of these people are smallholder farmers who discovered the principles of CA on their own, and have allowed the technology to spread to thousands of their colleagues.

So we need not resign ourselves to the idea that CA can only be practiced profitably on a small scale, or that its dissemination must be slow and difficult.

What Can We Do? There is one very simple and obvious difference between CA as practiced in southern Brazil, and that practiced in most of southern Africa. That is the use in CA of green manure/cover crops (gm/ccs). Most Brazilian farmers would never think of using CA without using gm/ccs along with it. In fact, in order to make their zero tillage much more productive right from the first year, they plant gm/ccs (usually intercropped with their basic grains) for a year or two before they even start using zero tillage. In this way, they fill the soil with as much as 60 t/ha of organic matter (green weight) each year for two or three years, so that when they convert to zero tillage, the soil will be soft and pliable, and their crops will produce very well from day one.[iii]

We have proven that in Africa, such a process is not necessary. Nor would it be particularly desirable in areas that are more drought-prone than southern Brazil. In droughty areas, the mulch is of tremendous importance. Operating two or three years without the mulch would not be advisable.

But the incorporation of gm/ccs into CA is of the essence. There are a good dozen very important synergies between gm/ccs and CA. In fact, gm/ccs can make tremendous strides toward solving every one of the three major problems identified above. Gm/ccs can produce prodigious amounts of *in situ* mulching material. They can greatly improve soil fertility and soil quality, so that yields in CA will rise even higher than the best yields achieved so far. And after a farmer has a handful of seed, s/he can produce all the seed s/he needs. No other local resources are essential except the land itself. Lastly, because of the reduced labor and higher yields achieved with gm/ccs, the net profit, or benefits, from CA will increase dramatically. Gm/ccs can also make farming systems completely sustainable over decades, provide high-protein food for the family, improve soil quality, reduce weed populations, and completely rid people's land of particularly noxious parasites and weeds like striga (*Striga hermonthica*) and speargrass (*Imperata cylindrical*).

All these advantages are the good news. But no cure-all like this comes free. The bad news is that we as program people will have to do a lot of learning to find the best gm/cc systems for the people with whom we are working. Incorporating the right gm/ccs into CA is not just a matter of planting a lot of mucuna (*Mucuna spp.*) or lablab beans (*Dolichos lablab*) everywhere. The best gm/cc systems have to be appropriate to the climate, the local farming system, the needs of the farmers, the topography of their land, their food preferences and their major crops, among other things. There is a lot of homework to be done.

Using Gm/ccs. First, what can we expect gm/ccs to do for CA in terms of the four criteria above?

a) Different yield increases will be achieved by different systems among the 130 or so known gm/cc systems. Nevertheless, most of us can reasonably expect that over five years, gm/ccs should raise yields of maize by at least 100% if they are presently under 1.5 t/ha, by 50% if they are between 1.5 t/ha and 2.5 t/ha and by 30% of they are higher than that.

These increases in yields will be brought by any of perhaps a dozen improvements in the farmers' production systems. Probably the most important issue here, especially for people who are as committed to mulching as CA proponents are, is the role that a mulch can play in a gm/cc system.

Many humid tropical forests inhabit some of the poorest soils on the planet, with pHs of 5.0 or less, virtually no available phosphorus, and toxic levels of aluminum. Yet they go on, year after year for millennia, producing phenomenal amounts of biomass. A smallholder farmer cuts down a piece of these forests, and within three to five years the soil has become so infertile that s/he has to let the forest grow back again to restore the soil. Why is the forest so able to do what any farmer wishes s/he could do, but can't? The answer we are given, if anyone does give us an answer, is that the farmer has used up the few nutrients left in the soil. But the nutrients used by a smallholder farmer in five years are insignificant. Furthermore, if those lost nutrients were so important, how does the forest go about restoring the fertility of the soil without them?

The trees of a humid tropical forest obtain their nutrients mostly from what foresters call the litter layer. We agronomists call the same thing a mulch. If you dig up the top 20 cm of a forest floor, you will find a mat of tree roots several cm thick. These roots are not feeding from the soil; they're feeding from the mulch. Why? The soil, with high acidity, aluminum toxicity and virtually no available phosphorus, is basically a hostile environment for plant roots. Feeder roots always go to where the environment is more favorable and the nutrients more abundant and well-balanced. In this case, that environment is the mulch.

Given two caveats, the same will happen in CA. In the mulches we maintain, there are abundant nutrients that are made available to the feeder roots of our farmers' crops over a period of just a few months. Crops will grow extremely well, but only if the mulch is biodiverse, like the litter layer of a forest, and it is moist, which also is true in a humid tropical forest. The moisture content of the mulch is an issue we will take up below when we speak of dispersed shade. The biodiversity of the mulch will be achieved when we use gm/ccs. Unfortunately, if the mulch is entirely, or is largely, composed of grasses, it will lack nitrogen (the C/N ratio will be too high), and the crops' feeder roots will not feed there very well. That is, by not including significant amounts of leguminous material in our mulches, we are denying our farmers by far the best and most efficient manner of feeding their crops. Once we do have a healthy amount of leguminous biomass in our mulches, dinner is served. Our crops will be able to take advantage of the best feeding environment this side of a scientific laboratory.

But nitrogen is not the only issue. Acid soils tie up phosphorus in minutes, and don't leave more than half a percent of the soil phosphorus in forms that are available to plants. This means that the vast majority of the generally low amounts of phosphorus we have in southern African soils is unavailable to crops. Thus, crops that feed from the soil will be starved of phosphorus, even when there is quite a bit there. In a mulch, however, virtually all the phosphorus that is not available right now, will be available sometime within the next few months, when the organic matter that contains it decomposes (ie mineralizes).

Furthermore, gm/ccs have proven that they can, like the tropical forest, produce enough biomass to maintain soil fertility for decades. The standard of 20 t/ha (green weight), which I used above, is a fairly easy target. Lablab beans, runner beans, mucuna, and many other gm/cc species can all produce more than twice that much biomass in a season.

So farmers will produce a lot more, and more sustainably, if they feed their crops through a mulch that includes legumes. In that way, millions of African farmers can do exactly the same thing a tropical forest does—produce huge amounts of edible biomass for decades, if not centuries, without in any way damaging the environment.[iv] That this can be done has been proven by a good number of gm/cc systems.[v]

b) Even when CA reduces the labor input involved in soil preparation, CA as it is practiced here in southern Africa has huge labor demands that come from hauling grass for mulching and hauling biomass to fertilize the soil, whether it is animal manure, compost, kitchen scraps or compound sweepings. Gm/ccs will produce high-nitrogen biomass that kilo for kilo fertilizes the soil roughly as well as animal manure, and can provide over 40 t/ha (green weight) of mulch material, with absolutely no transportation costs whatsoever, because it is produced *in situ*. The labor required by the gm/ccs is rarely more than that required to plant them and cut them down. Planting is a very simple operation that often can be done together with the planting of the maize or whatever species the gm/cc is intercropped with (i.e. often by throwing the gm/cc seeds in the same hole as the maize), and the cutting down of the green manure, though a major task, requires much less labor than cutting down a forest fallow, or cutting down and hauling maize stalks around to pile them up and burn them. They are also a good deal less than the labor required to haul mulch material and organic fertilizers out to the field. Thus, the labor requirements of using gm/ccs are approximately 20 to 40% less than those required by the practices presently being used for CA.

c) The materials required for most gm/cc systems are nothing more than a handful of gm/cc seeds for the first planting. After that, the farmers produce their own seed, year after year. If farmers can't easily produce their own seed from a particular species of legume, we simply don't use that species. There is no material involved in growing gm/ccs that is in short supply, that becomes scarcer if everyone in the village uses CA, or that becomes more labor-intensive if everyone decides to grow 1 ha of CA. The cost of using gm/ccs remains almost exactly the same per ha planted, whether the farmer does CA on 0.25 of a hectare, or on 25 hectares, unless s/he can mechanize, in which case the cost/ha of CA will be reduced as the size of the plot expands, rather than being increased.

d) The net profits of CA using gm/ccs will vary a good deal, but will almost always be better than the net profit of doing CA without them. This happens because, as mentioned above, yields increase and labor costs—on larger plots—decrease.

The additional benefits gm/ccs can provide for CA. In addition to those already mentioned, gm/ccs provide a huge number of additional benefits:

- Increased soil organic matter and soil nutrients. There is occurring, all around us, a crisis of soil depletion. This is occurring because of a series of unprecedented factors that are working together in a sort of "perfect storm." First, and most important, fallowing periods have now dropped in much of southern and eastern Africa from 15 years, to 8, to 4, and now down to 2 years and, unfortunately, zero, for many farmers. Since fallowing has been the primary way farmers kept their land fertile for millennia, this is a major tragedy. But at the same time, animal manure is scarcer because large amounts of common pasturelands have been turned into fields. Chemical fertilizers have more than doubled in price over the last eight years, and global warming, among other things, means that even the weeds produce less biomass. In all, soil fertility, and especially soil organic matter levels, are taking a beating that is totally unprecedented in the history of African agricultural.

Gm/ccs, by using what amounts to an improved fallow, can repair the damage done by the loss of fallowing. In traditional fallowing, farmers had to leave about 3/4 of their farms idle. Now, with gm/ccs, they can bring the fallow process right into their fields, cropping their land at the same time that they feed it with fertile leaves, creating, in a sense, a "simultaneous fallow."

- Nitrogen fixation. The most common species of gm/cc that we use—cowpeas (*Vigna unguiculata*), green beans (*V. radiata*), pigeon peas (*Cajanus cajan*), lablab beans (*Dolichos lablab* or *Lablab purpureum*), mucuna (*Mucuna spp.*), jackbeans (*Canavalia ensiformis*), tephrosia (*Tephrosia vogelii* or *T. candida*) and runner beans (*Phaseolus coccineus*)—fix anywhere from 80 to 250 kg N/ha/season.[vi] That means they can all lose even half of their nitrogen to volatilization (which will inevitably occur when they are left on the soil as part of a mulch), and still have the 40 kg N/ha/season needed to feed most African farmers' crops.

- Weed control. Another factor that occasionally causes problems in CA is that, without tillage, weeds can become a problem. Of course, CA's mulches reduce weeding labor significantly. But the "green mulches" of gm/ccs can often help reduce weed problems even more. Gm/cc species like mucuna, lablab, jackbeans and runner beans are excellent at controlling weeds, and in many cases can rid our fields entirely of very noxious weeds. Striga and nutgrass are cases of two noxious weeds that can be eliminated entirely with the proper management of gm/ccs.

- The provision of additional benefits. In addition to everything above, gm/ccs can provide high-protein food, wasteland restoration, a light shade for other crops (what we call dispersed shade), soil moisture conservation, high-quality fodder for grazing animals, a reduction in pests and plant diseases (including nematodes and corn borer worms), medicinal herbs and firewood.

Of course, there are challenges, too:

- Non-food-producing gm/ccs cannot be grown on land that has an opportunity cost. Farmers will never give a higher priority (nor should they) to gm/ccs than they do to food or cash crops. Thus, we must grow the gm/ccs on land, or at times, or in ways that the gm/ccs do not interfere with the other uses of the land. The gm/ccs have to fit into the farming system, rather than the farming system having to accommodate the gm/ccs. This sounds like it will be very difficult to achieve, but gm/ccs can be intercropped with other crops, grown during the dry season, grown when there is too much rain for other crops, or when there are frosts. They can also be grown under trees or on wastelands which are being recuperated.

- Slow results. Normally, the results of gm/ccs on increasing yields are not seen until the following cropping season. This means that in many cases, no increase in yields is observed for 15 months or longer. Farmers can lose patience with technologies that take so long. However, some of the benefits of CA were not seen for some time, either, so those farmers using CA are already accustomed to waiting to see benefits. Also, there are ways of demonstrating to farmers what gm/ccs can do. But even given all this, farmers prefer to see concrete and significant results sooner.

- Dry season problems. The most common problem with gm/ccs here in southern Africa is the problem of growing gm/ccs like cowpeas, green beans, groundnuts, or mucuna, and then letting the residues lie on the ground through an entire 6-month dry season before the rains come again in November. During six months of very hot weather, most of the nitrogen is volatilized and much of the biomass burned off, so that when the crops are planted again in November, almost nothing is left to fertilize the crop. Either we must provide shade (i.e. a cooler environment), or we must use gm/ccs, like lablab beans, jackbeans, tephrosia, late-planted mucuna or pigeon peas, that will survive the dry season and still be green when it is time to cut them down before the crops are planted. With some of these plants, like lablab beans, this means they will also provide a very good “green mulch” throughout most of the dry season.

- Difficult growing conditions. Smallholder farmers often have to work under very difficult conditions, including in drought-prone areas, on extremely acid and depleted soils, etc. These conditions affect gm/cc species just as much as they do subsistence or cash crops. Each of these problems must be solved in a different way.

- Synchronization. Often the nutrients provided by the gm/ccs are not available when farmers’ crops most need them, so they are not well-used. Sometimes this problem can be solved by changing the gm/cc system; other times it must be solved by supplementing the nutrients available to the plants, using very small amounts of foliar sprays made from plant extracts or animal manure or small amounts of chemical fertilizer.

The most promising gm/cc systems for farmers using CA in southern Africa. Choosing the right system for each situation is probably the most difficult factor in incorporating gm/ccs into CA. I have just written a book on this subject called, *Restoring the Soil, A Guide for Using Green Manure/Cover Crops to Improve the Food Security of Smallholder Farmers.*[vii] The number of different possible gm/cc systems for use in southern Africa number over 75. By far the best way of choosing the best system(s) for a given area is to study this great variety of systems before choosing any single one. Nevertheless, there are a few systems that will be of some use fairly widely.

The easiest case is that of areas above 1,500 m in elevation. In this case, runner beans (*Phaseolus coccineus*) can often be intercropped with maize. The runner bean produces a great deal of biomass, covers the soil well, can maintain the soil for 20 years of growing maize every year, and produces a bean the taste of which is preferred in most parts of the world over common beans—a fact that is usually reflected in a higher price. The only problem with runner beans is that most varieties are climbers and the bean produces so much biomass that it can cause the maize to lodge. If possible, it would be advantageous to procure seeds of bushy-type runner beans in Kenya, around the town of Thika, or in Zimbabwe. The white-seeded varieties also have a very good international market as green pods.[viii] Otherwise, this bean should be planted at a rate of only one seed for every 20 sq m of land.

For lower altitudes, the best possibilities will depend on a whole series of factors. For areas where grazing animals are not common or they are *not* allowed to graze freely during the dry season, probably the legume with the greatest potential is the lablab bean. It produces a good deal of biomass, and produces an edible bean eaten in parts of Malawi, Mozambique, Uganda and Kenya. In Kenya the lablab bean is prized in much of the country, and is sold in even the most up-scale supermarkets. It also is an excellent, palatable fodder, with the whole plant having a protein content of 23%. Lablab beans can perfectly well be intercropped with maize, and will raise maize yields quite quickly. The main problem of lablab beans is that they require a fairly fertile soil. In a poor soil, they will not grow well until the second or third year.

Where cattle roam free and CA plots are not protected, legumes that are resistant to cattle will have to be used. The best candidates for this situation will include tephrosia (*Tephrosia vogelii* or *T. candida*) and jack beans (*Canavalia ensiformis*). Both of these legumes can be intercropped with maize, and allowed to grow throughout the dry season.

In particularly difficult situations, such as drought-prone areas or where the soil is highly depleted, or even on wastelands, jack bean is by far the best species. It produces a large amount of biomass (though it does not control weeds as well as mucuna, lablab or runner beans) and usually grows clear through the dry season. It fixes around 250 kg N/ha/season in many situations, and is highly resistant to drought, even when only a few weeks old. It is also highly resistant to degraded soils, which makes it ideal for recuperating wastelands. It can be associated with maize, sorghum, millet, or even cassava, as long as we are careful only to use the bushy type. Jack bean has no other uses (except that the long pod can be used as firewood), but after two or three years it can restore even the worst land to the point that other, more useful gm/ccs can be used.

In all lowland areas (below 1,000 m in elevation), programs should also disseminate the use of fertilizer trees in what are called CA with trees (CAWT), which, in fact, are another way of incorporating gm/cc into CA. This practice is highly recommended because in the lowland tropics, the hot sun dries out the soil because it increases evaporation and transpiration rates, burns off organic matter, volatilizes nitrogen and causes crops to stop growing in the middle of the day, which just by itself can decrease crop production by 30%.

Probably the best technology to use in this case is to plant mother of cacao trees (*Gliricidia sepium*) in rows about 10 m apart, with the trees spaced each 5 m within the row. Mother of cacao is highly drought-resistant and within two years under favorable conditions will produce a large, 6-m tall tree. In poor soils with no irrigation and around 500 mm annual rainfall, it will still produce a good, 3-m tall tree in two years. The leaves are very good for fodder and for fertilizing the soil. The branches provide good firewood, the flowers are edible by humans (they are widely eaten in El Salvador and southern Honduras), and the bark can be used to kill rats and mice. It is best to plant the tree using stakes, to avoid the labor of making a nursery. Furthermore, trees planted by stakes will grow out of reach of grazing animals by the second dry season. The largest problem with mother of cacao is that it has to be treated for termites when it is planted by stakes, and it has to be protected from animals the first dry season, or maybe two dry seasons, if conditions are particularly difficult and seedlings are used.

Conclusions. A lot will have to be learned before gm/ccs will be used extensively all over southern Africa. Knowledge, on the part of extension agents, is usually the limiting factor in their spread. But once the best systems have been identified, and initial seed supplies have been secured, gm/ccs should be a major factor in motivating farmers to plant more and more of their land to CA. Even more important, the tremendous advantages of CA with gm/ccs should cause CA to spread spontaneously from farmer to farmer, just as it has done in the past in countries from Brazil to Cameroon and Kenya to Vietnam.

If we work at it, we can not only dream big, we can turn those big dreams into a very happy reality.

Best-fit residue allocation: A gate for legume intensification in nitrogen constrained cropping systems of Central Mozambique

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Key words: crop residue allocation, legume intensification, APSIM, Mozambique

Introduction

Improving legume productivity is an affordable and environmentally friendly alternative to increase soil fertility and crop productivity in nitrogen constrained cropping systems of Sub-Saharan Africa (SSA). However, poor soil fertility characterized by lower nitrogen and poor phosphorous soil concentrations of dried semi-arid regions (Giller and Cadisch, 1995; Sanginga, 2003), poor decision support systems regarding best-fit residue-fertilizer allocation and unfavorable cropping systems design (Lupwayi, 2011), are undermining legume performance in Africa. To change this situation, innovative maize-legume cropping systems designs and smart resource allocation strategies need to be tested taking into account that achieving high productivity with African legumes, is of crucial importance to strengthen legume contribution in the SSA conservation agriculture initiative. This paper presents the preliminary findings from a study aiming at identifying best-fit residue allocation strategies in maize-legume cropping systems and also test a legume intensification possibility centered in the hypothesis that sowing legumes early in the season (October-December) instead of the current mid January to February window can help improve legume performance and open the opportunity to sow a second legume crops later in the season if enough soil moisture is retained. Testing the readjustment in the Mozambican legume sowing window is sustained in a local practice of sowing small patches of legume in mixed maize-legume cropping systems at the start of the rains when maize is sown.

Materials and methods

The results here present are based on preliminary findings from combined *ex-ante* model simulations conducted with the Agricultural Production Simulator Model (APSIM 7.4) (Keating et al., 2003) and a legume intensification trial established in Chimoio, Mozambique. The *ex-ante* simulations consisted of a multi-year (61 years) simulation to assess the potential response of maize and cowpea yield to different residue-fertilizer combinations. Maize and cowpea residues were applied at 0, 2, 4 and 8 ton ha^{-1} rates at five N-levels, 0, 23, 46, 92 and 184 kg ha^{-1}. The C:N ratio of maize residues was assumed to be 80:1 and a 20:1 for cowpea. For the field trials, a maize-cowpea intercrop and a sole cowpea were sown at three residue levels, i.e., 0, 2, 4 t/ha and three N-levels, 0, 23 and 92 kg N/ha. In all systems, the legume was planted twice in a season. First legume was early sown with maize on 26th November and the second one was sown as a relay crop right after harvesting the first legume. A control maize-cowpea intercrop was sown in January 17th. Tsangano, maize OPV with 137 days to harvest and IT18, a cowpea variety with 100 days to harvest were used.

Results and Discussion

Simulations results indicated that in nitrogen depleted soils, the application of high C:N ratio residues into maize without proper N fertilization can lead to losses of up to 58.1%, 39.5% and 22.3% in maize yield, after the application of just 2 t/ha of residues at 0, 23 and 46 kg N/ha, respectively. This is because of the high N-immobilization that occurs with the application of crop residues of a high C:N ratio (maize residues) on low N soils under low levels of N-fertilization (Figure 1). In contrast, applying maize residues to cowpea sown in the Oct-Dec window, does provide moisture benefits for cowpea yields in 50% of the driest seasons at 4t/ha and in 75% of driest seasons at 8t/ha. The average yield increases are in the order of 9% at 4t/ha and 25% at 8t/ha. Applying maize mulch at the 2t/ha rate is apparently insufficient to generate consistent soil moisture benefits at this time of the season. Moreover, applying high C:N ratio residues to a cowpea crop sown in the normal Jan-Feb sowing window did not provide clear moisture benefits in the simulated cowpea yields. For the specific case of Mozambique, adjustments in the current legume sowing window need to be considered as early sowing of legumes is already a common practice across some agro-ecologies. As per the residue allocation into cowpea, this represents a shift in practice that needs also to be considered within the conservation agriculture community. Despite being the best residue option for N-constrained cropping systems, applying low C:N ratio residue will only be possible if enough biomass is produced and retained from legumes. To achieve this milestone, legume-favorable cropping systems and resource allocation strategies need to be put in place.

Legume Intensification trial results, showed that shifting legume sowing to the start of the rain season, i.e., October-December have considerably increased legume yield. The average yield obtained in maize-cowpea intercrop across the three tested N-level (0, 23 and 92kg N/ha) was 1257 kg/ha and 1328.11kg/ha at 0 and 2t/ha residue application levels. However, the yields obtained with the early-intercrop are considerably higher, i.e., about 40% more than the yield obtained in the January-February (Fp) window. In January only 681.21 and 863.81kg/ha of cowpea were harvested at the same N-levels for the 0 and 2t/ha residue application levels. Sole cowpea registered in average 1643.11 and 1647.47kg/ha yield at 0 and 2t/ha residue application at the early sowing window. The results obtained with the early sowing were in line with the ones reported in other studies (Nahardani et al., 2013; Ntare and Williams, 1992) were 30-50% increase in legume yields were obtained with early sowing. The relay legume crop yielded 302.5 kg/ha and 414 kg/ha at 0 and 2t/ha residue in the intercrop. For the relayed sole cowpea, 537.91kg/ha and 662.42kg/ha yield were obtained with the application of 0 and 2t/ha residue. Despite not obtaining significant yield increases with the application of the 2t/ha of residue, the measured yield increase with early sowing is quite encouraging considered that with early sowing comes also a high biomass production that is incorporated into the soil and contributes to the increase of residual-N. The results from the legume intensification trial showed that early sowing the legumes in Chimoio significantly increases legume yield which is positive for the system but getting benefits from the second legume crop is the challenge because yields tend to decrees as the crop grows into the drier period of season. When looking at both relays intercropped and sole legume, the last one seems to be the best intensification option (Figure 2) and having a short duration variety for the second sowing would be more beneficial for the system as a long duration variety run the risk of growing into a cooler period of the season which delays maturity.

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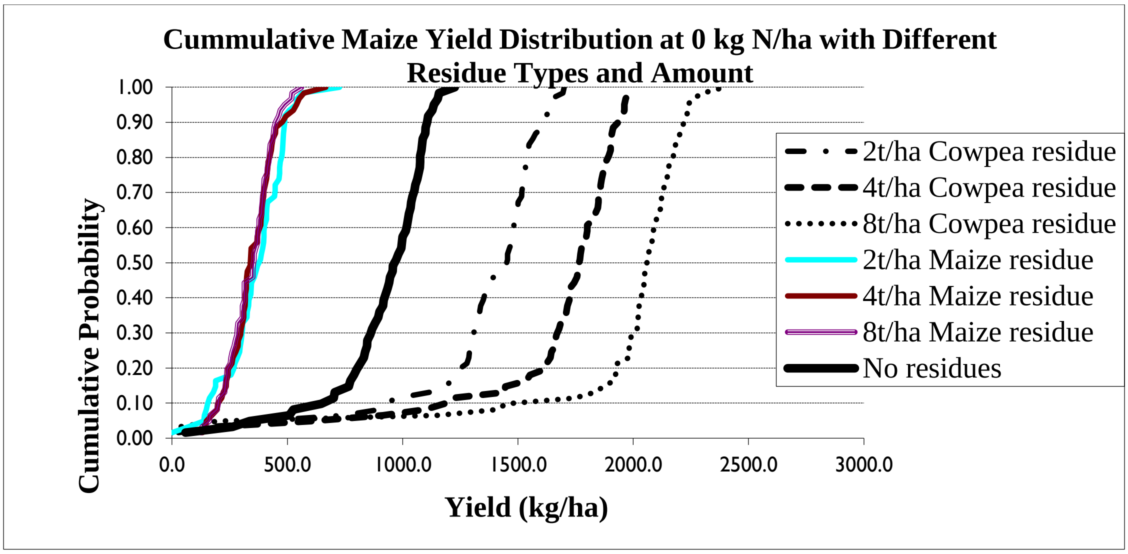

Figure 1 Cumulative probability of simulated maize yield for the period 1951 to 2012 and applications of 0, 2, 4 and 8 t ha^{-1} of maize and cowpea residues without N fertilizer inputs

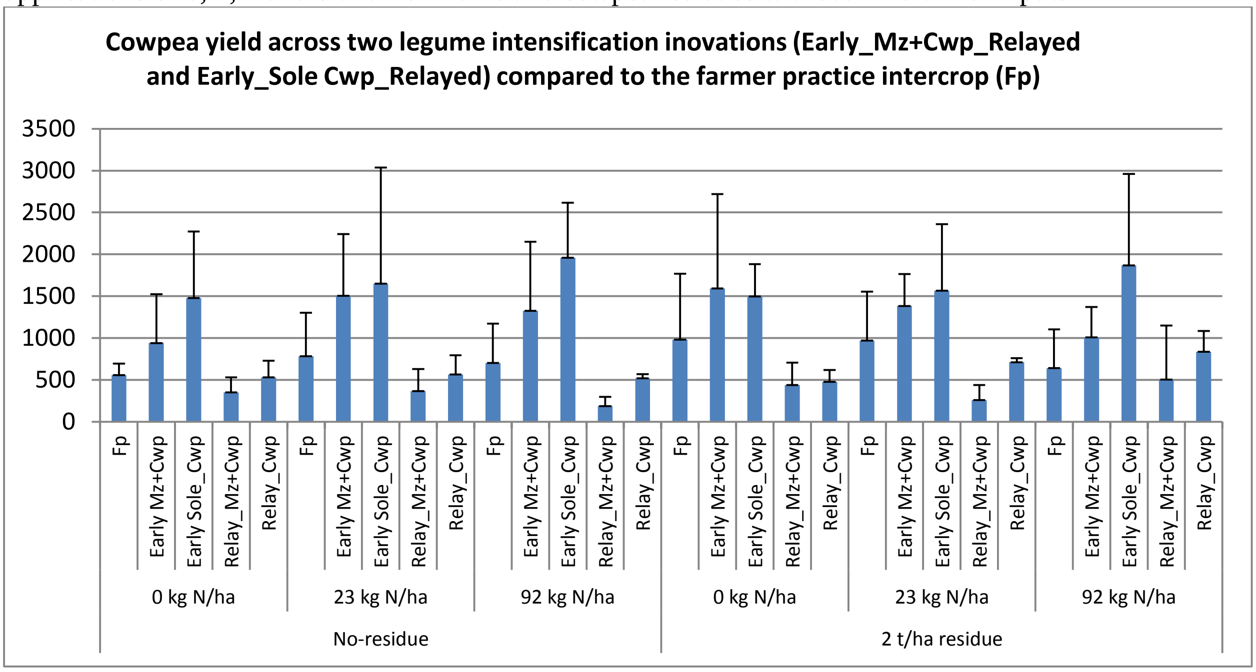

Figure 2 Cowpea yield (kg/ha) response to different sowing dates and systems: 1. Farmer practice (Fp): a maize-cowpea intercrop where cowpea was planted on 17th January; 2. Early_Mz+Cwp, a maize-cowpea intercrop where cowpea was sown in November 26th at the same time with maize; 3. Early_Sole Cwp, a cowpea monoculture where cowpea was planted on November 26th. The relay cowpea crops in both intercropped (Relay_Mz+Cwp) and monoculture (Relay_Cwp) were planted on March 2nd on the same plots as the early sown legume

Mulching effects on weed dynamics under three tillage options on a sandy clay loam soil in Zimbabwe

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Keywords: basins, conventional tillage, ripping, weed density

Introduction

Weed proliferation is probably one of the key factors hindering widespread uptake of conservation agriculture (CA) practices among smallholder farming communities in Zimbabwe. The cost of labour required to address this is often beyond the reach of many farmers (Nyamangara *et al*., 2013). While it can be argued that adoption and use of CA tillage options comes with extensive use of herbicides, the missing link may be the associated lack of technical know-how concerning herbicide use among smallholders. Poor adoption of technologies, such as herbicide use may also be linked to the general low purchasing power among this target group (Mashavave *et al*., 2013), who often opt for hand-weeding using family labour, in order to reduce costs. Mulching, one of the three principles of CA, has the potential to address the weed problem farmers face in their crop production systems. The FAO defines mulch as "material which is applied to the soil surface in order to reduce water loss, suppress weeds, reduce fruit splashing, modify soil temperatures and generally improve crop productivity" (http://www.fao.org/docrep/007/y5259e/ y5259e00.htm). However, in most CA extension in semi-arid zones including Zimbabwe, emphasis is often on reducing water loss and moderating soil temperatures (Ndah *et al.*, 2013), with little mention on weed suppression. Under smallholder farming, mulching materials often include, but are not restricted to, crop (mostly cereal) residues and grasses harvest from outside the field environment. This paper looks at the role mulch plays in weed suppression of different fertility treatment under three tillage options.

Materials and Methods

The study was conducted at Domboshawa Training Centre (17^{0}35'S, 31^{0}14'E), 30 km north of Harare. Domboshawa is in Zimbabwe's agro-ecological region (natural region [NR]) II and receives >800 mm of rainfall annually in a unimodal season between November and March. The soils at Domboshawa are granite-derived sandy clay loams commonly known as lixisols. The study was part of a multi-country '*Agro-ecology Based Aggradation-Conservation Agriculture*' (ABACO) project being led by the African Conservation Tillage Network (ACT). Three tillage options were introduced namely (i) Conventional; (ii) Ripping; and (iii) Basins in October 2011. The ABACO-Zimbabwe project has imposed eight (8) fertility treatments each planted to either maize (*Zea mays* L.), the staple cereal of Zimbabwe, or a legume, in this case cowpea (*Vigna unguiculata* L.) within each tillage option, and the project has been running for 2.5 seasons. The treatments were: 1. Fertilized maize – high rate (120 kg N; 26 kg P); 2. Fertilized cowpea – high rate (17 kg N; 26 kg P); 3. Fertilized maize – low rate (35 kg N; 14 kg P); 4. Fertilized cowpea – low rate (8 kg N; 14 kg P); 5. Maize under cattle manure + fertilizer (high rate) 7 t manure ha^{-1} + 90 kg N; 26 kg P; 6. Maize under cattle manure + fertilizer (low rate) *(*4 t manure ha^{-1}+ 35 kg N; 14 kg P*);* 7. Continuous maize (No fertilization); 8. Continuous fertilized maize – high rate (120 kg N; 26 kg P). In the second season, 2012-13, treatments 1-6 were rotated, yielding 4 maize treatments and 4 cowpea treatments, and mulch was applied on one-half of each fertility treatment. It was during this second season that weed biomass was quantified. Weed quantification was done using the quadrat method. The weed species present in each plot were counted and harvested for identification at the National Herbarium in Harare. Species dominance was done manually for the whole plot while diversity was determined by the Shannon-Wiener Index (Shannon, 1948).

Results and Discussion

Weed population dynamics under different tillage options. A total of 16 weed species were identified from the CA plots in Domboshawa. Of these, at least 11 were herbaceous annuals and perennials, while the remainder were grasses (Table 1). The weed flora under all three tillage options was dominated by herbaceous annual, *Galinsoga parviflora* (the gallant soldier) which constituted >50% of total weed populations, followed by *Richardia scarbra* (rough Mexican clover) with between 20-50%. Other less dominant annuals but prevalent across the tillage options included *Acanthospermum hispidum, Bidens pilosa* and *Commelina benghalensis* (Table 1). These results suggest that there is little impact on the weed seed-bed following conversion of tillage from conventional to CA in the short-term, although changes in tillage practices and management have been known to lead to shifts in weed species composition (Nyamangara *et al*., 2013). However, mulching appeared to affect the weed diversity of the CA tillage options of basins and ripping. This was evidenced by the differences in the Shannon-Wiener diversity indices of 2.1 for basins under mulch versus 2.8 for basin where no mulch was applied (Figure 1), although the same herbaceous annual, *G. parviflora* continued to dominate across, regardless of fertility treatments. The same trends were observed for the ripping option. Under conventional tillage, while mulching appeared not to have significantly influenced ($p<0.05$) weed diversity (mean 2.5), species richness was lower under mulched plots (4-7 species) compared to unmulched plots (6-13).

Residual fertility effects on weed dominance. Analysis of the fertility treatments impacts on species richness and weed biomass productivity within each tillage option indicated high variability among the parameters measured. Where there was high fertilizer application rates (>90 kg N ha^{-1}; 7 t manure ha^{-1}), or in plots previously planted to cowpea, *G. parviflora* and *B. pilosa* dominated, and total weed biomass were as high as 4.4 t ha^{-1}. Generally soils in Domboshawa are inherently infertile sandy clay loams and require some external nutrient application to produce any reasonable yield, thus application of such high inputs could further pose a challenge regarding weed management among smallholder farmers in similar environments. On the other hand, where there was low residual fertility, or in maize monocrop, *R. scarbra* and the two grass species, *Heteranthera zosterifolia* (Star grass) and *Cynodon dactylon* dominated. Under such plots, biomass productivity was generally low and ranged between 0.7 to 2.1 t ha^{-1}. *Richardia scarbra* and the perennial grasses are known to persist in poor infertile soils, evidently out-competing other species. It was not surprising to note a 100% coverage of *H. zosterifolia* in the low-input treatments, whether mulched or no mulch, suggesting the need for increased herbicide use to prevent infestation. Overall, least biomass productivity was evident across all mulched treatments. When no mulch was applied, the weed density increased by between 50-90% to approximately 36 plants m^{-2} under basins, and 56 plants m^{-2} under ripping.

Implications on smallholder farmers. The data imply that weed proliferation under mulch may be a question of background fertility rather than enhanced soil moisture alone. On inherently low fertility soils such as those found at Domboshawa, weed diversity and dominance is less likely to vary due to tillage, but their productivity could be a function of soil fertility management. We therefore concluded that CA results in significant reduction in weed pressure even under high rates of nutrient input. This has implications on the potential for farmers to save labour for weeding. Concentration of mulch could be a potential avenue to reduce the cost and environmental concerns associated with the use of herbicides.

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Table 1. Weed flora identified at the Domboshawa conservation agriculture field

Herbaceous weeds		Grasses	
*Species	Common name	*Species	Common name
1. *Galinsoga parviflora*	Gallant soldier	1. *Heteranthera zosterifolia*	Stargrass
2. *Richardia scabra*	Mexican clover	2. *Cynodon dactylon*	Couch grass
3. *Acanthospermum hispidum*	Bristly starbur	3. *Eleusine indica*	Wiregrass
4. *Bidens pilosa*	Cobbler's pegs	4. *Cyperus esculentus*	Yellow nutsedge
5. *Commelina benghalensis*	Tropical spiderwort	5. *Bulbostylis hispidula*	Hispidula
6. *Crotalaria cylindrostachys*	Crotalaria		
7. *Macrotylomia daltonii*	Macrotyloma		
8. *Amaranthus thunbergii,*	Thunberg's amaranth		
9. *Leucas martinicensis*	Whitewort		
10. *Hibiscus cannabinus*	Java jute		
11. *Nicandra physalodes*	Shoo-fly plant		

* - ranked in order of dominance

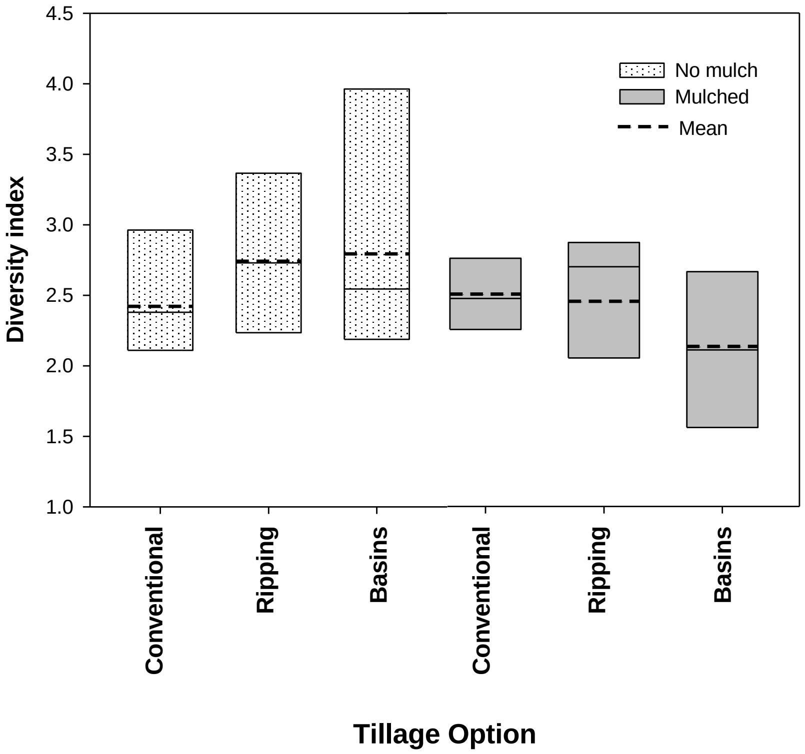

Figure 1. Shannon-Wiener diversity indices of weeds under mulch and no-mulch treatments on three tillage options in Domboshawa, Zimbabwe

Assessment of the individual contribution of each of the conservation agriculture principles to crop yield in smallholder areas of Zimbabwe

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Keywords: crop residue retention, maize-cowpea rotation, tillage

Introduction

Conservation agriculture (CA) has been proven to effectively control soil erosion and increase soil fertility and therefore may be critical in sustaining crop production in the smallholder sector in sub Saharan Africa (SSA). CA is based on three principles: (i) to minimize mechanical soil disturbance; (ii) to maintain permanent soil cover with organic mulch; and (iii) to diversify crop rotations (FAO, 2008). The strong interaction between livestock and cropping in some smallholder areas of most of SSA implies that farmers have difficulties to integrate all the three principles of CA at recommended standards, especially to maintain permanent soil cover with organic mulch during the dry season. Residues are also fed to livestock during the dry season when grazing is scarce and of low quality, and in some communities for construction of dwellings. Another social aspect is the prevalence of communal grazing rights after harvest which make it virtually impossible for an individual farmer to unilaterally decide to keep crop residues on his/her field. Therefore although CA has been widely promoted in southern and eastern Africa, smallholder farmers have largely adopted minimum soil disturbance but few have adopted soil surface mulching and/or diversified crop rotations. It is therefore necessary to determine the contribution of each of the three principles of CA to crop productivity so that farmers can anticipate the magnitude of gain or loss in yield if they omit any one of the CA principles. The research question to be addressed is: What is the relative contribution of each CA principle to crop yield? It was hypothesized that the integration of all three CA principles significantly contributed to improved crop yield.

Materials and Methods

The paper is based on findings of a trial that was set up on a sandy soil at Matopos Research station, Zimbabwe, for two seasons, 2010/11 and 2011/12. Matopos Research station lies in agro-ecological region IV which receives 450-650mm annual rainfall and is subject to frequent seasonal droughts and severe dry spells during the rainy season (Vincent, Thomas et al. 1960).The test crops were *Zea mays* (L.) (maize- variety SC513) and *Vigna ungiuculata* (cowpea - variety CBC 1). The trial was laid out in a split plot design with tillage as the main plot factor at two levels (conventional ploughing -CONV and reduced tillage using tine ripping - RIPPER) and residue retention as the subplot. The treatments were sole cereal, maize-cowpea rotation and cowpea-maize and were replicated four times. The plots measured 30 m^2 each. To imitate smallholder conditions no residues were applied in the first season but were retained after harvesting and applied to the soil at 0 and 3 t ha^{-1} for maize residues and 1.5 t ha^{-1} for legume residues. Fertilizer was applied to both crops at 100 kg ha^{-1} basal fertilizer (7%N: 6%P: 6%K) and 90 kg ha^{-1} top dressing (Ammonium nitrate, 34.5% N). Weeds were controlled manually using hand-hoes. Before establishment of the experiment, soil samples were collected for characterization to assess the baseline fertility status and uniformity. Daily rainfall, and grain and stover yield data was collected.

Results and Discussion

Maize yields

The 2010/11 season was wetter than 2011/12 as such yields for both maize and cowpea were lower in the latter season (Figure 1). In both the 2010/11 and 2011/12 seasons, tillage typehad a significant effect on maize grain yield ($P < 0.05$) with conventional tillage giving the highest grain yield compared with reduced tillage (Table 1).These grain yields averaged 1.06 and 0.86 t ha^{-1} for reduced tillage and 2.2 and 1.3 t $ha^{-1}$for conventional tillage in the 2010/11 and 2011/12 seasons respectively.Grain yields between tillage treatments were not different when rotation was applied with grain yields and in the range920 – 960 kg ha^{-1}. When both mulch and rotation were applied, differences in maize grain yields were observed between the two tillage treatments. Similar trends were followed by the stover yields although differences were only significant for tillage typeonly and the interaction between tillage + mulch in the 2011/12 season (Table 2).

Cowpea yields

There were no significant differences in cowpea grain yields in both seasons as affected by tillage type or the interaction between tillage type and mulch (Figure 2). Cowpea yields ranged between 0.78 – 1.6 t ha^{-1} in the 2010/11 season and 0.28 – 1.10 t ha^{-1} in the 2011/12 season.

Tables and figures

Table 1: Maize grain yields for the 2010/11 and 2011/12 seasons at Sandveld, Matopos Research Institute, Zimbabwe.

	2010/11			2011/12		
	CONV	**RIPPER**	**SED***	**CONV**	**RIPPER**	**SED**
Tillage only	2218	1059	358.5	1675	811	125.6
Tillage+Mulch				1383	798	177.6
Tillage+Rotation				921	956	177.6
Tillage+Mulch+Rotation				1383	895	251.2

*SED – standard error of the difference of the means

Table 2: Maize stover yields 2010/11 and 2011/12 cropping seasons at Sandveld, Matopos Research Institute, Zimbabwe.

	2010/11			2011/12		
	CONV	**RIPPER**	**SED**	**CONV**	**RIPPER**	**SED**
Tillage only	4347.2	3928	556.2	2963	1512	193.4
Tillage+Mulch				2840	1636	273.5
Tillage+Rotation				1821	1636	273.5
Tillage+Mulch+Rotation				2099	2346	386.8

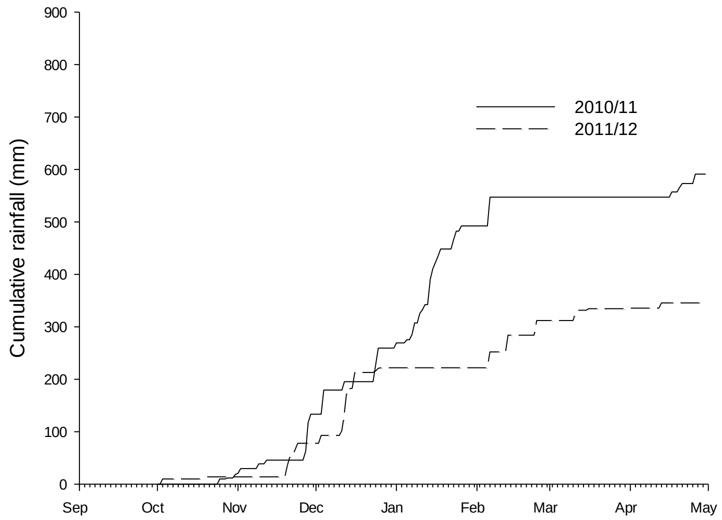

Figure 1: Cumulative rainfall at Sandveld, Matopos Research Institute, Zimbabwe for the 2010/11 and 2011/12 seasons.

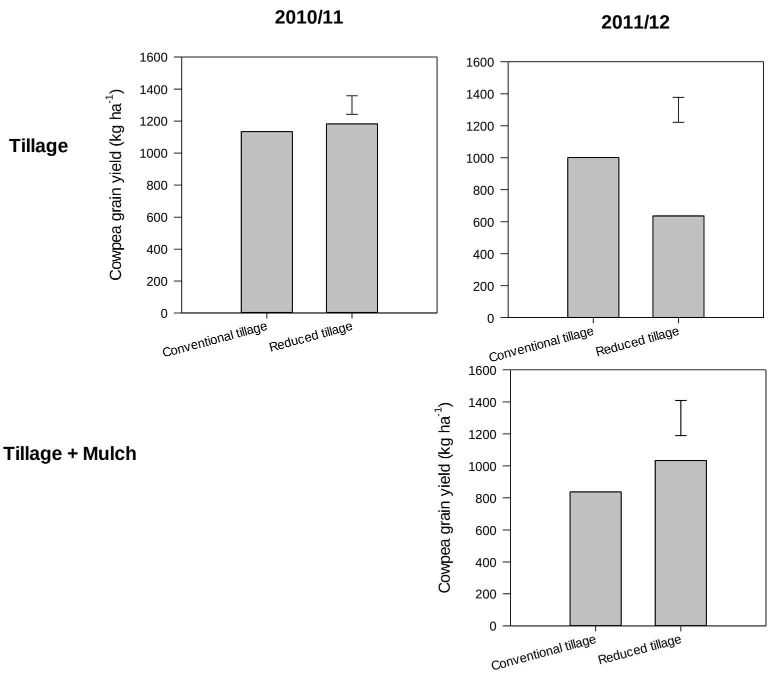

Figure 2: Cowpea grain yields for the 2010/11 and 2011/12 seasons at Sandveld, Matopos Research Institute, Zimbabwe. Bars present standard errors of the difference of the means.

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Assessment of maize productivity under Conservation Agriculture with Tephrosia

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Key words: Conservation agriculture, Agroforestry, Tephrosia, Fertilizer trees.

Introduction

Malawi’s current cropping systems are largely characterized by continuous monoculture of the staple crop, maize, with annual tillage practices involving the construction of planting ridges using a hand hoe. Tillage as commonly practiced among smallholders in Malawi involves clearing and burning of crop residues, weeds and debris followed by ridging. A shift towards more sustainable agricultural systems such as conservation agriculture (CA) and agroforestry is believed to provide alternatives in reversing soil degradation, reducing labour and improving production (Giller et al., 2009). Individually, these practices have shown potential to increase agricultural production, food security and incomes within a context that ensures sound management of natural resources. The question at hand remains whether integration of agroforestry technologies and CA offer opportunities to improve crop productivity or not. The aim of the study was to assess the effect of integration of Tephrosia with conservation agriculture in a maize production system.

Materials and Methods

On-farm trials were conducted in both Kasungu and Lilongwe districts for 3 consecutive growing seasons between 2011 and 2013. The two districts are at an altitude of 800-1600 m-asl and on average receives 1000 mm rainfall. Soils are predominantly sandy loam with pH range of 5.5-6.5. The National Smallholder Farmers Association of Malawi (NASFAM) field officers and lead farmers facilitated the selection of participating farmers in their operation areas in Kasungu (Chamama, Chulu, Chipala) and Lilongwe (Mpenu, Mlodzedzi). Willing farmers were identified and requested to commit their plots for 3 years without changing the land management regimes.

A total number of 9 treatments combinations were assessed including conventional tillage, basin planting, old ridge planting in combination with under sowing of Tephrosia and fertilizer application. Under conventional tillage the farmer constructed ridges at spacing of 75cm and planted 1 maize seed per planting station at a spacing of 25cm. Planting basins were constructed at a spacing of 75 cm within the row and 75 cm apart from another row. Each planting basin measured 30 cm long, 30 cm wide and 20 cm deep. Three seeds were planted in each basin. In the old ridge plots, farmers did not split the ridges during land preparation in the first year and in the subsequent years the farmers maintained the ridges and maize was planted as in the conventional tillage. *Tephrosia candida* was under sown at the spacing of 150cm between rows and 60cm between planting stations. Two seeds were planted not later than two weeks after planting maize. Tephrosia litter and harvested leaves were incorporated between the ridges or in the planting basins during land preparation period. Both basal application of 23:21:0+4s and top dressing of CAN or Urea fertilizers were done in all fertilizer treated plots at the rate of 200kg/ha. Hand hoe weeding and all other cultural practices were carried out.

The treatments were replicated 3 times on-site by either the same farmer or 3 farmers within area. Treatment combinations included: conventional tillage + fertilizer (CF), conventional tillage + Tephrosia (CT), conventional tillage + fertilizer + Tephrosia (CFT), basin planting + fertilizer (BPF), basin planting + Tephrosia (BPT), basin planting + fertilizer+ Tephrosia (BPFT), old ridge + fertilizer (ORF), old ridge + Tephrosia (ORT), and old ridge + fertilizer + Tephrosia (ORFT). CF, the farmers' practice, was used as a control. Treatments were laid out in a Complete Randomized Block Design (RCBD) with 3 replicates.

Maize yield data were collected and p*lanned comparisons* were conducted to compare mean yields. *Planned comparisons* provides a better alternative to *post-hoc* tests and increases the statistical test power due to the limited number of comparisons related to a clear hypothesis about the effect size. Dunnetts method of pre-planned mean comparison was applied to compare all treatments with the control "CF". Additionally, the yields stability across sites/years and the improvement relative to the conventional farmers' practices are important characteristics to be considered when assessing the value of a cropping system in comparison to others, especially with the advent of climate change (Sileshi et al., 2011; 2012). The coefficient of variation (CV) and formal stability analysis have been widely used to quantify and compare variability in crop yields (Sileshi et al., 2011; 2012). For this preliminary analysis, the CVs were calculated to determine yield stability over time and across sites for various treatments.

Results and Discussion

In the 2010/11 growing season, the treatment combination CFT gave the highest yield (5777 kg/ha) followed by BPF (5573 kg/ha) across sites (Table 1). The percentage increase with CFT is 3.5% higher than the CF. ORFT gave 8.6% increase over the CF. The lowest yield (3182 kg/ha) was recorded in BPT, which was 46.1% lower than the CF. In the second season (2011/12), the highest yield (6149 kg/ha) was recorded in the CF followed by CFT (5581 kg/ha) and the lowest was in BPT (1977 kg/ha). In the third season (2012/13), ORFT gave the highest yield (5641 kg/ha) followed by CF (4540 kg/ha), ORF (5311 kg/ha) and CFT (4926 kg/ha).

Across years, comparison of treatments using Dunnett's test indicated that most of the treatments gave yields comparable with the control (CF). Treatments CT, ORT and BPT produced significantly lower yields relative to the control. In terms of yield stability [$CV_{(\%)}$], CFT was the best followed by CF. The least stable yields were recorded in BPT and ORT. Site productivity (Figure 1) showed relatively higher maize yields at Lilongwe sites (Mpenu in 2011 and Mlodzedzi in 2013) while in Kasungu; Chulu (2011, 2013) and Chamama (2012) were the least productive sites. Overall, the study shows that with or without Tephrosia, CA treatments that included inorganic fertilizer (BPF, BPFT, ORF and ORFT) gave better and more stable yields than those without (BPT, ORT). A study by Munthali et al. (2014) found significantly increase in maize grain yield when N and P fertilizers were applied to maize planted after Tephrosia fallows at Chitedze in Malawi. These finding highlights the benefits of fertilizer amendment of CA or CAWT plot. Since soil productivity in smallholder systems is generally poor, adding the appropriate use of fertilizer as a fourth principle of CA has recently been proposed by Vanlauwe et al. (2014) to increase crop residue production.

The recent studies in Kenya suggest that minimum tillage and crop residue retention may be unprofitable on poor sites and emphasizes that rehabilitation of such soils is critical. In addition, CA does not necessarily improve crop yields and soil C in the short term. Since minimal tillage without mulch commonly results in depressed yields, the use of inorganic fertilizer to enhance crop productivity and organic residue availability is essential for smallholder farmers to engage in CA (Vanlauwe et al., 2014). Thus, in as much as the soil pH for Kasungu and Lilongwe sites are within a good range; the soils being sandy loam remains poor for maize production without inorganic fertilizers and adequate organic residues. Fertilizer trees when integrated with CA practices are hoped to ensure better soil cover and increase availability of organic residues. In that sense, CAWT should be conceived first and foremost as a sustainable land management approach for rehabilitating degraded soils (Akinnifesi et al., 2010). It has also been widely advocated that applying combinations of mineral and organic fertilizers, using green manures, agroforestry leguminous fertilizer trees, and returning residues to the soil, using improved CA practices can restore soil health and increase crop yields at sustainable levels (Akinnifesi et al., 2010).

It is concluded that the integration of *Tephrosia vogelii* undersowing with conventional tillage combined with fertilizer application gives stable and high yields. In the absence of fertilizer application, basin planting and undersowing of Tephrosia alone may not achieve yields comparable with the farmers' conventional practice.

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Table 1. Average maize grain yields (kg/ha) over a three year period (2011 - 2013).

Treatment code	**Treatment description**	**Maize yield (kg/ha)**			**3 Years average**	**CV (%)**
		2010/11	**2011/12**	**2012/13**		
CF	Conventional tillage + fertilizer	5553.8	6378.6	5449.9	5801.0	59.5
CFT	Conventional tillage + fertilizer + Tephrosia	5776.6	5581.4	4926.3	5484.8	29.9
CT	Conventional tillage + Tephrosia	4135.3	2862.2***	2571.9***	3294.0***	44.1
ORF	Old ridge + fertilizer	5252.4	5694.3	5311.1	5415.3	73.3
ORFT	Old ridge + fertilizer + Tephrosia	5631.6	5710.9	5641.1	5662.6	38.4
ORT	Old ridge + Tephrosia	3451.2*	1705.9***	2177.2***	2529.7***	44.4
BPF	Basin planting + fertilizer	5572.7	5234.3	3792.2	4985.1	70.4
BPFT	Basin planting + fertilizer + Tephrosia	5363.4	5025.1	3630.1	4788.4	37.9
BPT	Basin planting basin + Tephrosia	3181.4**	1977.4***	1786.1***	2408.0***	31.2

*, ** and *** represent significant difference between the treatment and control (CF) according to Dunnett's test of planned comparison at 5%, 1% and 0.1%, respectively.

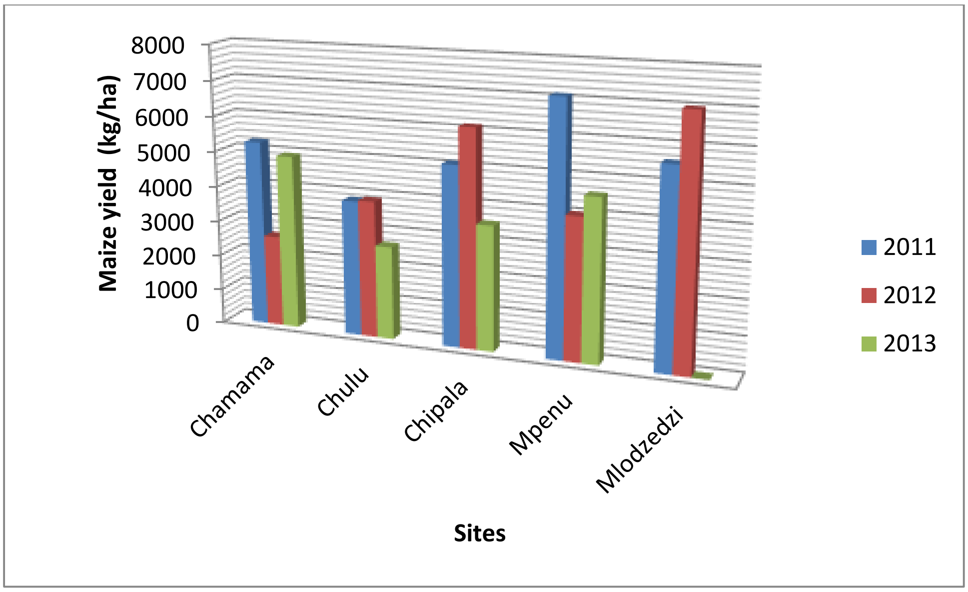

Figure 1. Maize grain yield (kg/ha) at different sites in Kasungu (Chamama, Chulu and Chipala) and Lilongwe (Mpenu and Mlodzedzi) Districts, over 3 years time period.

Effects of Conservation Agriculture based cropping systems and herbicide use on maize yields in Malawi and Mozambique

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Keywords: conservation agriculture, crop rotation, intercropping

Introduction

Food security among smallholders in Southern Africa remains precarious due to low uptake of improved technologies such as fertilizer, maize and legume varieties and soil degrading cropping practices (Thierfelder *et al.*, 2013). Conservation Agriculture (CA) based Sustainable Intensification (Garnett *et al.*, 2013) technologies have been under evaluation in the last three cropping seasons through the programme '*Sustainable Intensification of Maize legume systems in Eastern and Southern Africa* (SIMLESA) under different agro-ecologies in Malawi and Mozambique. On-farm exploratory trials were established in both countries with the objective of testing the yield impacts and feasibility of various cropping systems following consultations of local stakeholders. This paper presents maize yield results from both countries and preliminary conclusions from three cropping seasons since 2010.

Materials and Methods

In Malawi 5 treatments were tested in the mid-altitude high potential areas while 6 treatments were tested in the low-altitude low potential areas with legume rotation and intercropping combinations. In Mozambique 6 manual traction treatments involving maize cowpea or common bean rotations and intercrops were also established in districts with contrasting agro-ecologies. In both countries, CA crop establishment techniques involved dibble stick inserted 3-5 cm holes, jab planter and 15 cm diameter x 15 cm deep hoe prepared holes commonly known as CA basins. These were compared to local conventional farmer practices. In each location the control treatment was the local farmer practice using locally recommended fertilizer rates. Newly released improved maize and legume varieties in each country, were used as test crops in the trials. Key measurements included rainfall, maize yields and in-season farmer evaluations to generate farmer feedback on the technologies. Measurements were made from 6 replicates (farmers) per site.

Results and Discussion

Within site, maize yield differences between conventional farmer practices and CA based systems were mostly not significant in the first two seasons in Malawi mid-altitude agro-ecology sites (Lilongwe, Kasungu and Mchinji but became significant on two of the latter sites (communities) in 2012/13. Also in the same sites, although herbicides were a major incentive to farmers, no significant differences were obtained from systems employing herbicides and those in which weeds were controlled mechanically. In the Malawi lowlands, significantly higher yields were obtained from CA hoe prepared basins in the first year in Balaka while no apparent differences were noted in the other two lowland communities Ntcheu and Salima, with tendencies for lower yields from these basins (Figure 1). In Mozambique, a similar pattern of yield trends was observed in Sussundenga and Gorongosa districts with mostly no apparent differences in yields within site for each of the 3 seasons. However, CA basins performed relatively better in Mozambique compared to Malawi's lowlands.

For each country's agro-ecology, *combined analyses of variance across sites* was carried out using pooled mean yields by treatment for each site and season and using *site and season* as blocks (replicates). Overall 3-yr results from each of the two countries showed significantly higher yields from maize-legume rotation CA systems compared to the farmer check across all agro-ecologies (Table 1). However, the other systems such as maize sole with basins plus herbicide and intercrop systems superiority depended on site and season (Table 1).

Testing for yield stability across environments and seasons, linear relations between site mean and cropping system were not significantly different by treatment for the mid-altitude regions of Malawi. However, in the Malawi lowlands, significantly higher yield responses (steeper gradient) from the maize-groundnut CA rotation systems across locations compared to the ridge and furrow farmer practice, were observed (Figure 1). Overall basins had the tendency of occasionally depressing maize yields over the three lowland sites and seasons, but were not significantly different from the ridge-furrow farmer practice. In Mozambique (Gorongosa and Sussundenga sites), the maize cowpea rotation system also showed significantly higher maize yield advantages compared to the farmer check over time and locations (Figure 2).

The three seasons results of this ongoing work suggest that maize yield differences between CA based and conventional farmer practices, generally depended on season quality in terms of rainfall amount and distribution., Systems involving legume rotations more often and increasingly resulted in superior maize yields compared to the farmer practice over time. Similar results regarding rotation benefits have been reported in Malawi (Thierfelder *et al.*, 2012).

Despite relatively lower maize yields from intercrops compared to rotations in Mozambique, farmers preferred mostly the maize-cowpea intercrop system as it allowed two crops output per given area despite the higher maize yields from rotations obtained in the third year. Results from Malawi mid-altitude regions also suggest that CA can also be successfully implemented without herbicides with no yield penalties at all although herbicide use proved to be popular with farmers in both countries. Results from both countries also show that of the crop establishment methods tested, the performance of the commonly used CA basins (15x 15 cm) may be inconsistent and risky under Malawian lowland conditions while at the same time being advantageous under Mozambique's conditions in the central zone.

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Table 1. 3-yr mean maize yields (kg/ha) by cropping system in contrasting agro-ecologies of Malawi and Mozambique between 2010 and 2013.

Malawi Mid-Altitude Regions

Cropping system	3yr mean Maize yield (kg/ha)
Conventional Farmers check	3743^{a}
CA Dibble stick maize sole no herbicide	3867^{ab}
CA Dibble stick maize sole+ herbicide	4303^{bc}
CA Dibble stick maize-soya rotation	4524^{c}

Note: *N=36, df=24, LSD*$_{(0.05)}$*=529kg/ha*

Data from Kasungu, Mchinji and Lilongwe

Malawi Lowland Region

Cropping system	3yr mean Maize yield (kg/ha)
Conventional Farmers check	3034^{a}
CA Basins Maize/p.pea intercrop	3295^{ab}
CA Dibble stick Maize sole	3807^{bc}
CA Dibble stick Maize-p.pea intercrop	3824^{bc}
CA Dibble stick Maize-g/nuts rotation	4267^{c}

Note: *N=36, df=24; LSD*$_{(0.05)}$*=757*

Data from Ntcheu, Salima and Balaka districts

Mozambique Central Region

Cropping system	3yr mean Maize yield (kg/ha)
Farmers check	1487^{a}
CA maize-cowpea intercrop	1686^{ab}
CA Matraca maize sole+ r/up	1734^{bc}
CA basins maize sole +r/up	1812^{bc}
CA maize-cowpea rotation	1972^{c}

Note: *N=30; df=20; LSD*$_{(0.05)}$ *=233kg/ha*

Data from Sussundenga and Gorongosa

N.B. Means in the same column followed by the same letter are not significantly different at $p<0.05$

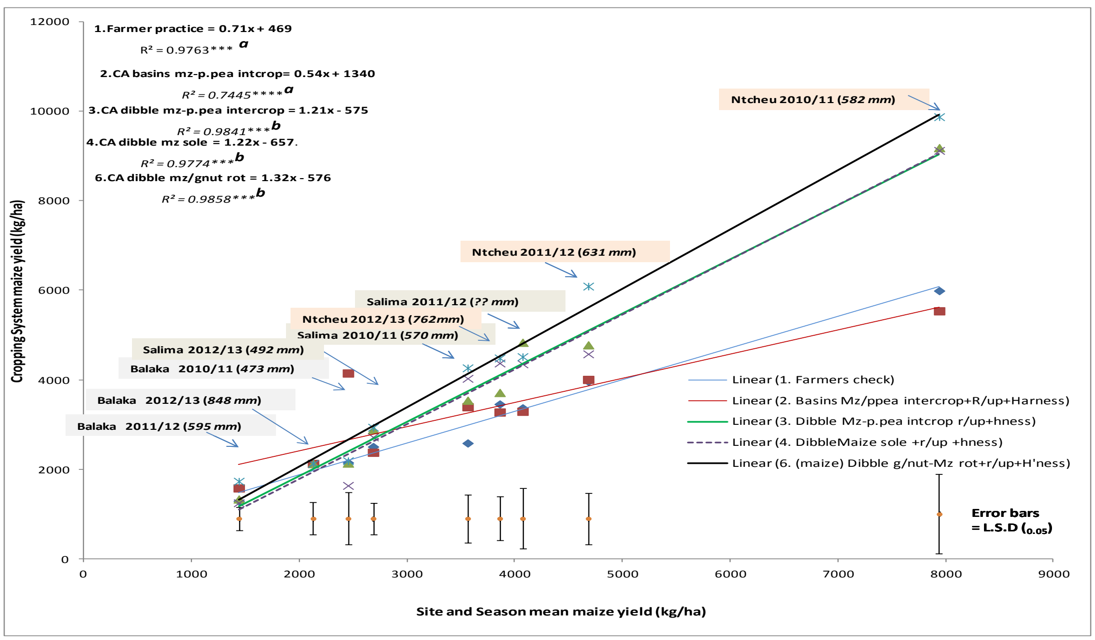

Figure 1. Linear regressions of cropping system maize yields against Site and Season mean in Malawi lowland region sites from 2010/11 to 2012/13. N.B Error bars denote lsd $_{(0.05)}$ for separation of means from each site and season. Labels for each site show season and total rainfall in mm. Treatment regression equations followed by the same superscript letter are not significantly different at $p<0.05$

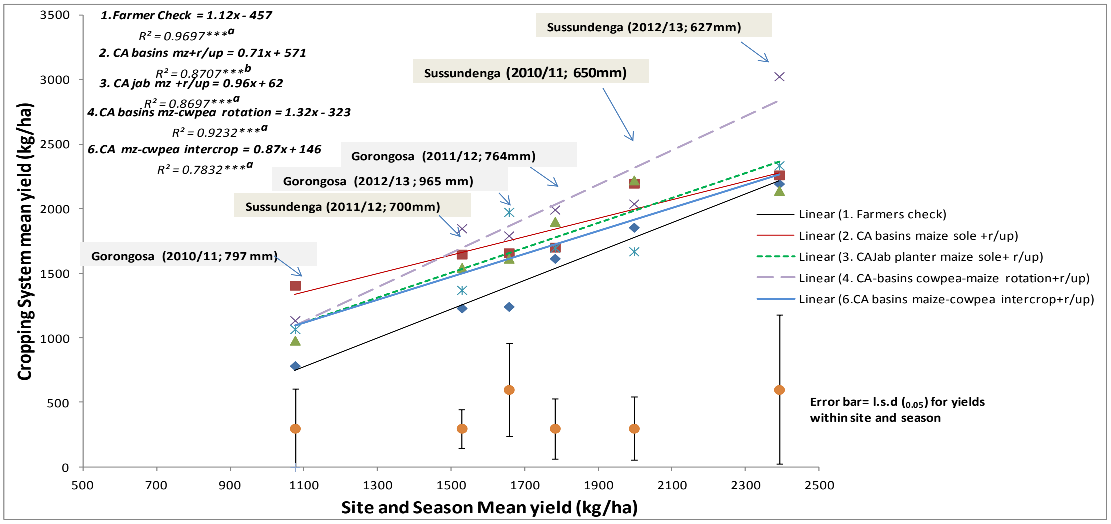

Figure 2. Linear regressions of cropping system maize yields against Site and Season mean in Mozambique's central region sites from 2010/11 to 2012/13. N.B. Error bars denote lsd $_{(0.05)}$ for separation of means from each site and season. Labels for each site show season and total rainfall in mm. Treatment regression equations followed by the same superscript letter are not significantly different at $p<0.05$.

Crop yield responses to conservation agriculture practices in sub-Saharan Africa: a meta-analysis

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Keywords: no-tillage, mulch, crop rotation, conventional tillage

Introduction

In recent years a growing number of studies have been carried out comparing the practices of conservation agriculture (CA) to conventional tillage (CT) in Sub-Saharan Africa (SSA). The studies have been conducted under a range of conditions (climate, soil, management, cropping system). In general, the effects of CA on crop yield compared to CT in these studies are diverse, which makes it very difficult to draw general conclusions. The general aim of this study is to contrast and combine results from different CA experiments through meta-analysis in the hope of identifying patterns among study results, sources of disagreement among those results, or interesting relationships that may come to light in the context of the different studies. More specifically, a meta-analysis of the existing data can help in better understanding crop responses to CA and in identifying the agro-ecological and management conditions that favor positive crop responses to CA practices in SSA. This latter can contribute to better targeting the investments with CA development and research.

Materials and Methods

Data was collected from scientific literature on the effects of the CA principles (no-tillage, crop residue mulching and rotations) on crop yields in SSA. A comprehensive literature search was conducted for peer-reviewed publications. In total 42 papers were selected for the final dataset with 61 independent studies. The CT treatment was set as a control to compare it with CA treatments. In our analysis, we used the mean difference in yield between the CA treatment and control (CT) because of its ease of interpretation. To obtain overall treatment effects across studies, the differences between treatment and control were weighted. The weight given to each study was calculated as the inverse of the variance. The random effects model was the most appropriate model to calculate effect sizes as it assumed that studies were drawn from different populations. Soil texture, years under CA, nitrogen fertilizer input, and amount of seasonal rainfall were chosen as covariates and their effect tested on the magnitude of response (mean differences). The StatsDirect statistical software version 2.7.2 (StatsDirect, Ltd., Cheshire, UK) was used to perform the effect size meta-analysis.

Results and Discussion

Summary statistics of weighted mean difference

The results of the summary statistics of weighted mean differences of crop grain yields between CT and no-tillage without mulch and rotation (NT), no-tillage with mulch application (NTM) and no-tillage with mulch and rotation (NTR) are shown in Figure 1. NTM had the largest range with the largest positive mean (378 kg ha^{-1}) followed by NT with a negative mean (- 24 kg ha^{-1}) and then NTR with a positive mean (142 kg ha^{-1}).

Effects of no-tillage

There was a change in the weighted mean difference of crop grain yields between NT and CT practices with time. When NT is practiced over a period of time less than 3 years the overall effect in terms of yield benefit is positive (88 kg ha^{-1}) compared with CT (Table 1). The opposite occurs when NT is practiced over a period of more than 3 years, with an overall negative effect (-227 kg ha^{-1}). This result indicates that in the longer term no-tillage without crop residue mulching triggers negative impacts on crop production, which may be mainly due to a soil compaction or soil surface crusting (Baudron et al., 2012).

Effects of no-tillage with mulching

Weighted mean differences of crop grain yield between NTM and CT tend to be higher when mulching is practiced over a longer period of time: 294 kg ha^{-1} for less than 3 years versus 487 kg ha^{-1} for more than 3 years (Table 1). The positive yield response under NTM indicates that mulch application is a major factor influencing the success of CA systems. Mulching is known to have a positive short-term effect on crop growth and productivity through increased soil water conservation, and a positive long-term effect through enhancing soil carbon levels and soil fertility in general.

Effects of no-tillage with mulch and rotation

The weighted mean difference between CT and NTR was 166 kg ha^{-1}. In about 90% of the studies, where crop rotation was practiced, maize was cultivated in rotation with a grain legume. Higher crop grain yield observed under NTR relative to CT can be attributed to combined effects of multiple factors like increased nitrogen inputs from biological nitrogen fixation in case of legumes, enhanced water infiltration, increases of soil carbon and macro-faunal activity leading to better soil structure and suppression of crop specific pests (e. g. Thierfelder et al., 2013).

Effects of seasonal rainfall

Crop grain yields were overall significantly higher under CA treatments compared to CT in all of the seasonal rainfall categories (Table 1). Overall, crop grain yields were 143, 161 and 348 kg ha^{-1} higher under CA compared to CT when growing season rainfall was < 600 mm, 600-1,000 mm and > 1,000 mm, respectively.

Effects of soil texture

Crop grain yields on sandy and clayey soils under CA were not significantly different than yields under CT (Table 1). The weighed mean differences were 72 and 45 kg ha^{-1} for the sandy and clayey soils, respectively. In contrast, on loamy soils crop yield under CA treatments was overall significantly higher than that of CT, as indicated by the weighted mean difference of 299 kg ha^{-1}.

Effects of nitrogen fertilizer application

Weighted mean differences in grain yields were significantly higher (391 kg ha^{-1}) than zero when nitrogen fertilizer input was higher than 100 kg ha^{-1}, but not (85 kg ha^{-1}) when N fertilization was lower than 100 kg ha^{-1} (Table 1). These results indicate appropriate use of fertilizer is necessary in SSA for increasing crop productivity and the availability of crop residues for mulching (Vanlauwe et al., 2013).

Conclusions

Crop grain yields were significantly higher in no-till treatments when mulch was applied and/or rotations were practiced in comparison to only no-tillage/reduced tillage without mulch and/rotation. The results from this meta-analysis thus suggest that for farmers to benefit from CA they should be able to keep their crop residues as mulch on the soil surface. Additionally, rotation should be an integral component of their cropping practice. A clear response of crop yield to CA with N fertilizer application leads to the conclusion that farmer's ability to use fertilizer in sufficient quantities and correct proportions is needed for CA.

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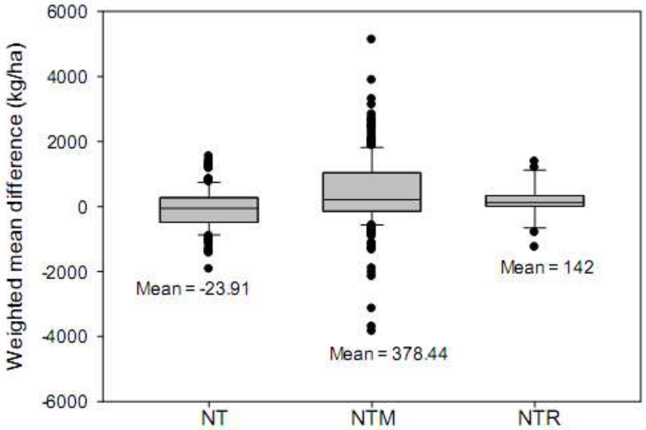

Figure 1. Weighted mean difference in crop grain yields between the conventional tillage treatments and the CA treatments used in the meta-analysis. The middle lines represent the median values with upper and lower 25th percentiles. NT = no-tillage/reduced tillage, NTM = no-tillage with mulch and NTR = no-tillage with mulch and rotation

Table 1: Overall weighted mean difference between CA and CT under different conditions

Treatments	Pooled weighted mean difference (kg ha^{-1})
No-tillage ≤ 3 years	87.76 (36.62, 138.91) *
No-tillage > 3 years	-226.77 (-366.07, -87.46) *
No-tillage with mulch ≤ 3 years	294.21 (217.03, 371.39) *
No-tillage with mulch > 3 years	487.14 (380.62, 593.67) *
No-tillage with mulch and rotation	165.61 (25.74, 305.48) *
Growing season rainfall < 600 mm	143.32 (88.98, 197.67) *
Growing season rainfall 600 – 1,000 mm	160.99 (80.78, 241.20) *
Growing season rainfall > 1,000 mm	348.44 (120.21, 576.67) *
Nitrogen fertilizer input ≤ 100 kg/ha	85.52 (-33.50, 204.55)
Nitrogen fertilizer input > 100 kg/ha	390.62 (243.39, 537.85) *
Loamy soil texture	299.33 (257.92, 340.73) *
Sandy soil texture	71.26 (-65.78 , 208.29)
Clayey soil texture	44.69 (-95.04, 184.42)

Values reported are overall effect size weighted mean gains (positive values) or loss (negative values) generated by bootstrapping, with 95% confidence interval in parentheses. Confidence intervals that do not overlap with zero were considered significantly different (*)

Sub-Theme 2: Weather proofing agriculture - the adaption of farming practices to address climate variability and change

Building resilience to climate change in Malawi: Trends in crop yields under Conservation Agriculture and factors affecting adoption

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Keywords: minimum tillage, soil cover, productivity, labor savings, CA adoption

Introduction

Smallholder farmers across Malawi and the region face similar challenges and have similar ambitions: They all want to improve their livelihoods, produce enough food to feed their families, and earn cash to meet basic needs and send their children to school. These ambitions are becoming more elusive as farms shrink in size, soils become exhausted, and the ability to purchase inputs decreases. Although Malawi's input subsidy program has helped greatly to improve smallholder crop yields, its long term sustainability and impact on productivity are major concerns, especially with looming reductions in the scale of the program. While improved seed and fertilizer has potential to increase returns, the attendant costs are often beyond the reach of many farmers. With the growing threat of climate change, the challenge today is to find sustainable ways to increase agricultural productivity to meet the demands of a growing population. In this context, conservation agriculture (CA) is attracting attention based on claims that it offers opportunities for farmers to mitigate the impacts of climate change on farm productivity, to reduce the loss of valuable rainfall and top soil, to adapt more effectively to adverse weather conditions, to improve the health of their soils, and to reduce labor and input costs. The focus of this paper is two-fold: 1) to compare maize and groundnut yields under CA with conventional ridge tillage based on long term on-farm trials in different parts of Malawi, and 2) to evaluate smallholder adoption of CA over time and related challenges.

Materials and Methods

Assessments of crop yields are based on a joint program between Total LandCare (TLC), the Ministry of Agriculture (MOA) and CIMMYT to establish and evaluate on-farm trials with farmers in Central and Southern Malawi to compare CA with conventional ridge tillage. The number of on-farm trials and sites increased with time and each has been monitored annually from the date established. All on-farm trials were managed by farmers with technical support from TLC and MOA staff. Each trial included 3 plots of 0.1 ha each: 1) conventional ridge tillage (CRT) with maize which involves removing residues (traditional practice), 2) CA with maize with retention of residues, and 3) CA with maize and a legume intercrop with retention of residues. In later years, groundnut yields were also evaluated in rotation with maize by splitting the original plots into two. After the required land preparation according to the practice, each plot was treated in the same manner in terms of planting time, crop variety, spacing, and fertilizer application to enable valid comparisons of yields. The plots were kept weed free by hoe weeding in the CRT plots while the CA plots also included use of herbicides as follows: The CA treatment with sole maize received an initial spray of glyphosate followed by a residual herbicide (initially Bullet® which was later replaced by the more environmentally benign Harness®). The CA maize-legume plot received glyphosate only as initial weed control.

Based on the positive results from early on-farm trials, TLC began promoting CA in 2006/07 using the lead farmer approach and TLC's network of field extension staff across Malawi. In most cases, a basic input pack was provided on loan to interested farmers after making an upfront deposit. The aim is to instill ownership and commitment by farmers to undertake CA based on TLC's philosophy of "giving a hand-up not a hand-out". Payments go into a revolving fund to reach more farmers in subsequent years. Input packs also help to avoid compromising a new technology due to planting poor seed on exhausted soils with no inputs. Results on "farmers trained" and "practicing CA" are compiled annually into a database across all sites. Surveys are undertaken to assess the reasons for and against adoption of CA by farmers across the country.

Results and Discussion

Comparison of yields under CA vs. CRT

Results from these on-farm trials clearly show the superiority of planting crops under CA (Figure 1). From the second cropping season, significant differences in maize yields were recorded for all sites between both CA treatments and CRT. Planting an intercrop showed no impact on maize yields and provided multiple benefits to the land, soil and household. Yield increases of maize varied from 11 and 70% across years (Figure 1), with greater differences in years of low rainfall. Farmers also realized benefits of rotating groundnuts after maize under CA. This allowed halving the row spacing which is clearly not possible with ridging. The results in 2012/13 increased groundnut yields by 37-350% relative to the CRT plots. It also doubled the ground cover which reduced the risk of runoff and rosette disease. Greater and more stable yields of cereals and legumes will benefit households in terms of improved food security, nutrition and income from the increased productivity of CA.

Adoption of CA and challenges

Results of trainings, field days, study tours and on-farm demonstrations by TLC have led to a steady increase in the area and number of farmers practicing CA from 14 ha and 46 farmers in 2005/06 to 5865 ha and 17,797 farmers in 2012/13 (Figure 2). Farmer surveys revealed several key benefits, including increased yields, especially in years of poor rainfall; reduced loss of top soil; and significant savings in labor. However, adoption has been lower than expected due to two major factors: 1) confusion of farmers caused by the delivery of inconsistent technical messages on CA by different organizations; and 2) perceptions by both farmers and extension staff that specific inputs and/or tools are needed before CA can be undertaken. While certain inputs and tools help to implement CA, they are not a pre-condition to the practice. In order to accelerate the adoption of CA, there is an urgent need to harmonize technical messages among implementing organizations, to strengthen the knowledge base of CA among farmers and staff, and to facilitate access to basic inputs and tools by farmers.

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Figures:

Figure 1: Maize grain yields on two CA treatments as compared to a conventionally ridged practice on initially 24 farmers' fields in 2005/06 and up to 72 farmers' field in 2012/13.

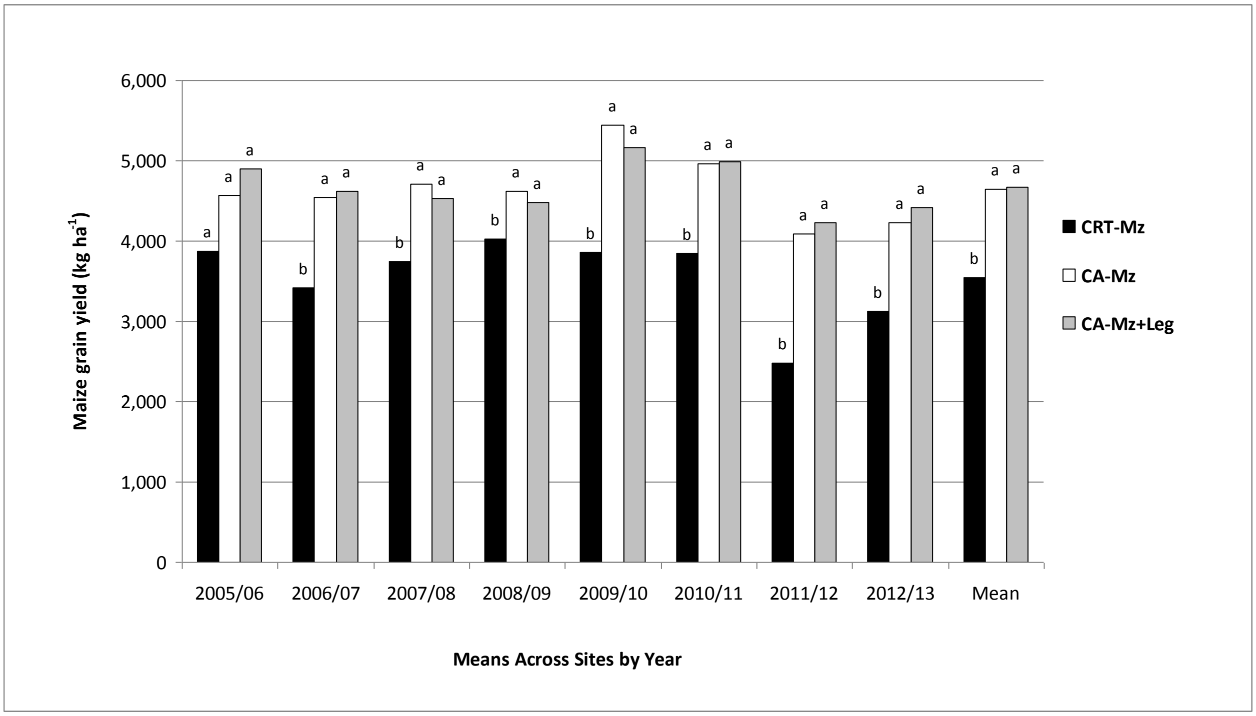
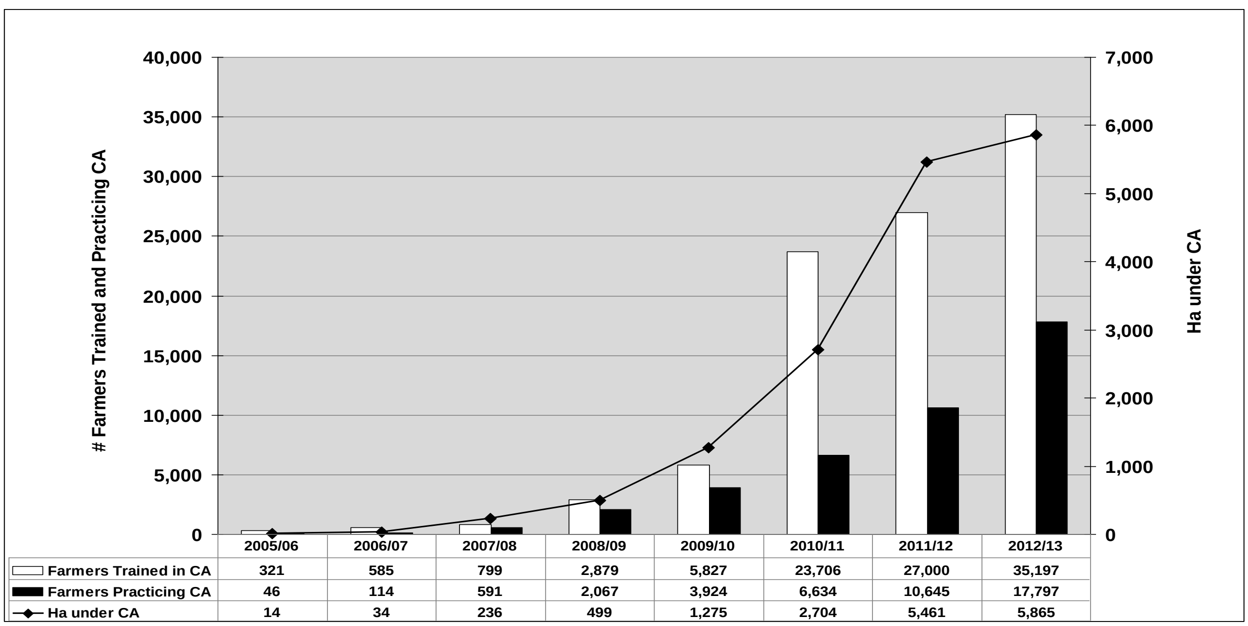


Figure 2: Farmers Trained and Practicing CA under TLC Programs, 2005/06 to 2012/13



	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
Farmers Trained in CA	321	585	799	2,879	5,827	23,706	27,000	35,197
Farmers Practicing CA	46	114	591	2,067	3,924	6,634	10,645	17,797
Ha under CA	14	34	236	499	1,275	2,704	5,461	5,865

Climate-Smart push-pull--A conservation agriculture technology for food security and environmental sustainability in Africa

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Introduction

Developing adaptable, productive agricultural systems that are resilient in the face of the risks and shocks assciaoted with long-term climate variability is essential to maintaining food production into the future (Pretty, 2011, Khan, et al. 2014). But resilience is not enough. Climate-smart agricultural systems also need to protect and enhance natural resources and ecosystem services in ways that mitigate future climate change (Tittonel and Giller, 2012). The International Centre of Insect Physiology and Ecology (ICIPE) and partners developed a conservation agriculture intercrop technology, push-pull, which responds to these needs in mixed farming systems practiced in Africa.

Africa's challenge of low productivity and poverty

Africa faces particular problems in feeding its population and it is the only continent in which per capita food production has been on the decline over the past two decades (World Bank, 2008). In Africa agriculture still accounts for over 65 per cent of full-time employment in Africa, 25–30 per cent of GDP and over half of total export earnings (IFPRI, 2004; World Bank, 2008). It underpins the livelihoods of over two-thirds of Africa's poor because smalholder agriculture remains the main source of household incomes. Although some improvements have been made in African agriculture, high population growth pressure on land and resources have reduced the per capita availability of domestically grown food has not changed at the continent scale for 50 years and has fallen substantially in three regions (Pretty, 2011). As a result, hunger and poverty remain widespread because of low agricultural productivity. It is estimated that 265 million people in sub-Saharan Africa face hunger (FAO, 2009b).

In sub-Saharan Africa (SSA), land degradation, pests and weeds hamper efficient production of cereals, particularly maize, the main staple and cash crop. Low and declining yields are affecting food security, nutrition and income, trapping farmers in poverty and poor health. The resource-constrained smallholder farmers living in the arid and semi-arid regions who practise mixed crop–livestock systems are particularly badly affected (Khan, et al. 2014, FAO, 2004). Indeed, projections indicate that unless drastic steps are taken, SSA will have more than 500 million food insecure people by 2020 (USDA, 2010).

In addition to widespread poverty (with more than 60% of the SSA population living on less than $40 per month), population pressure on land is high. Landholdings commonly amount to just one hectare or less. Soils are severely degraded and have low organic matter as a result of continuous monocropping (Sanchez, 2002; Oswald, 2005; Rodenburg et al., 2005). Many fields are heavily infested with parasitic striga weeds, while insect pests – principally stemborers – devastate cereal

crops, commonly causing over half the harvest to be lost (Maes K. 1998, Kfir R, Overholt WA, Khan ZR, Polaszek A. 2002). And now, farmers are facing unpredictable rainfall and rising temperatures. Many families remain trapped in a cycle of diminishing yields and deepening poverty. Food insecurity is common, with a critical shortage of cereals in almost 70% of rural households. These constraints are expected to increase during the next few decades as agriculture intensifies to meet the extra food demand from a growing population and as a result of climate change (DeLucia et al., 2008; Fischer G, Shah M, Tubiello F, van Velthuizen H.
2005).

The compounding effects of climate change

Climate change is anticipated to have far-reaching effects on the sustainable development of SSA and global efforts to achieve the Millennium Development Goals (MDGs) and post-MDG targets (IPCC, 2007; Khan et al., 2013). Studies have predicted the effects of climate change on Africa's major cereal-growing regions by calculating the percentage overlap between historical growing-season temperatures (for 1960–2002) and the values projected for 2025, 2050 and 2075 (IPCC, 2007). The results indicate that temperatures will overlap, on average, by 58% with the historical observations by 2025, 14% by 2050 and 3% by 2075. This suggests that, within two decades, growing-season average temperatures will be warmer than those of 1960–2002 for four years in ten for the majority of Africa's maize area by 2025, growing to nearly nine years in ten by 2050 and nearly ten out of ten in 2075. Similar trends are likely to affect millet and sorghum (Burke et al., 2009).

Furthermore, climate predictions indicate that rainfall will become progressively more unpredictable, with a decline in yearly totals and an increasing incidence of floods and droughts. Together with the rising temperatures, this will lead to worsening land degradation and pest and weed pressure, with crop failure occurring more often, exacerbating food insecurity. To adapt to these adverse conditions, resource-constrained smallholder farmers will need to change their systems to incorporate cereal crops with greater drought resistance (e.g. sorghum and millet), and replace cattle with small ruminants for dairy production (Khan et al., 2013; Pretty J, Toulmin C, Williams S. 2011).

Holistic agricultural intensification

There is thus an urgent need for a significant, and sustainable, increase in grain yields and animal production. The need for sustainability requires ecologically sound ways of managing weeds and pests with a strong focus on maintaining soil, crop and water resources. Therefore the solution lies in sustainable agricultural intensification that maximizes soil quality and crop productivity, adopting a systems approach (social, economic and environmental) to agricultural development, and making specific recommendations based on integrated analyses of specific agro-ecologies, locations and cultural preferences (IAASTD, 2009; Pinstrup-Andersen, 2010). Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services (Royal Society, 2009; Conway and Waage, 2010; Godfray et al., 2010).

Sustainable agriculture in this context will require a more holistic approach, reflecting the multi-functionality of agriculture, promoting value chain approaches, improving market access, and developing the rural non-farm sector. Integration of a variety of packages of resource-conserving technologies and practices – integrated pest management (IPM), integrated nutrient management (ISFM), conservation tillage, agro-forestry, aquaculture, water harvesting, and livestock integration are likely to increase productivity significantly and sustainably (Pretty et al., 2006).

Push–pull: a broad-based conservation agriculture solution

The push-pull technological innovation, developed by the International Centre of Insect Physiology and Ecology (*icipe*) (http://www.icipe.org), Rothamsted Research (www.rothamsted.bbsrc.ac.uk) in the UK, and partners in East Africa addresses smallholder agricultural constraints, food security, environmental degradation, loss of biodiversity. *icipe* and partners recognized that addressing the interrelated problems of soil degradation, high temperatures and water stress, and reduced yields due to biotic constraints, notably pests and weeds, through improved management strategies would significantly increase farm productivity, resulting in better nutrition and alleviating poverty for millions of farmers in SSA.

Push–pull (www.push-pull.net) is a complex technological innovation that holistically combines multi-functional resource-conserving Integrated Pest Management (IPM) and Integrated Soil Fertility Management (ISFM) methods. The technology combines integrated soil and pest management strategies and makes efficient use of natural resources to increase farm productivity. It has already proven successful as a holistic technology that addresses most aspects of smallholders' constraints (Hassanali et al. 2008; Cook et al., 2007). The technology effectively controls the major insect pests of cereals in SSA, i.e. lepidopteran stemborers, and the devastating parasitic striga weeds, both of which can cause total yield loss to cereals. Furthermore, it improves soil health and conserves soil moisture. The technology involves use of inter- and trap crops in a mixed cropping system (Khan, et al., 2006, 2008, 2013). These companion plants release behaviour-modifying stimuli (plant chemicals) to manipulate the distribution and abundance of stemborers and beneficial insects for management of the pests (**Figure 1**). The system relies on an in-depth understanding of chemical ecology, agro-biodiversity, plant-plant and insect-plant interactions (http://www.push-pull.net/publications.shtml) and is well suited to African socio-economic conditions.

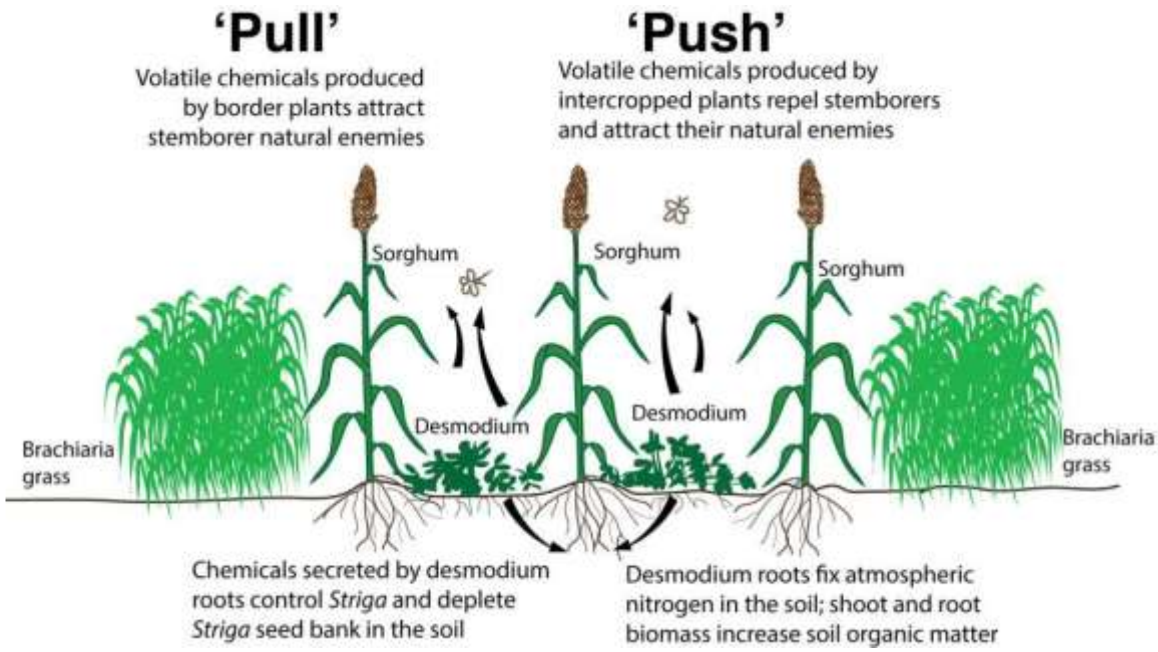

Figure 1. How the push–pull technology works. Aerial responses are mediated by volatile organic compounds produced by companion plants. In the rhizosphere, chemicals secreted by desmodium roots inhibit attachment of germinated striga seeds to cereal roots and cause rapid depletion of striga seed bank in the soil.

The main cereal crop is planted with a repellent intercrop such as desmodium (push) and an attractive trap plant such as Napier grass (pull) planted as a border crop around this intercrop. Gravid stemborer females are repelled from the main crop and are simultaneously attracted to the trap crop (Cook et al., 2007). The companion plants are valuable themselves as high quality animal fodder thereby facilitating livestock integration.

The Napier grass trap crop produces significantly higher levels of volatile cues (stimuli), used by gravid stemborer females to locate host plants, than maize or sorghum (Birkett et al., 2006). There is also an increase of approximately 100-fold in the total amounts of these compounds produced in the first hour of nightfall (scotophase) by Napier grass (Chamberlain et al., 2006), the period at which stemborer moths seek host plants for oviposition (Päts P., 1991), causing the differential oviposition preference. However, most of the stemborer larvae, about 80%, do not survive (Khan et al., 2006, 2007) as Napier grass tissues produce sticky sap in response to feeding by the larvae which traps them causing their mortality. The intercrop, legumes in the *Desmodium* genus (silverleaf, *D. uncinatum* and greenleaf, *D. intortum*), on the other hand produce repellent volatile chemicals that push away the stemborer moths. These include (*E*)-*β*-ocimene and (*E*)-4,8-dimethyl-1,3,7-nonatriene, semiochemicals produced during damage to plants by herbivorous insects and are responsible for the repellence of desmodium to stemborers (Khan et al., 2000). Desmodium also effectively controls striga weed, resulting in significant yield increases in maize from 1 to 3.5 t/ha per cropping season (Khan et al. 2006, 2008).

In the elucidation of the mechanisms of striga suppression by *D. uncinatum*, in addition to benefits derived from increased availability of nitrogen and soil shading, an allelopathic effect of the root exudates of the legume, produced independently of the presence of striga, was found to be responsible for the dramatic weed reduction in an intercrop with maize. Presence of blends of secondary metabolites with striga seed germination stimulatory, 4″,5″,-dihydro-5,2′,4′-trihydroxy-5″,-isopropenylfurano-(2″,3″;7,6)-isoflavanone, and post-germination inhibitory, 4″,5″-dihydro-2′-methoxy-5,4′-dihydroxy-5″-isopropenylfurano- (2″,3″;7,6)-isoflavanone, activities in the root exudates of *D. uncinatum* which directly interferes with parasitism was observed (Tsanuo et al., 2003). This combination thus provides a novel means of *in situ* reduction of the striga seed bank in the soil through efficient suicidal germination even in the proximity of graminaceous host plants. Other *Desmodium* spp. have also been evaluated and have similar effects on stemborers and striga (Khan et al., 2006) and are currently being used as intercrops in maize, sorghum and millets.

Extensive research and development (R&D) efforts revealed that not only were stemborers and striga effectively controlled by the technology under farmers' conditions, but farmers also reported additional benefits such as increased soil fertility, up to three-fold increases in grain yields, and improved availability of animal fodder resulting in increased milk production (Khan et al., 2008a, 2008b). All these gave significantly higher economic returns to the farmer, with cost-benefit analyses showing significantly higher returns to both land and labour than conventional farmers' practices. Desmodium also fixes atmospheric nitrogen (110 kg N/ha) (Whitney, 1966), adds organic matter to the soil, conserves soil moisture and enhances soil biodiversity, thereby improving soil health and fertility. Additionally, it provides ground cover and, together with the surrounding Napier grass, protects the soil against erosion. It therefore improves agro-ecosystem sustainability and resilience, with great potential to mitigate the effects of climate change. Both desmodium and Napier grass provide valuable year-round quality animal forage whilst the sale of desmodium seeds generates additional income for the farmers. So far, on-farm uptake by over 70,000 farmers in East Africa has confirmed that the technology is very effective and has significant impacts on food security, human and animal health, soil fertility, conservation of agro-biodiversity, agro-ecosystem services, empowerment of women, and income generation for resource-poor farmers (see **figure 2** below).

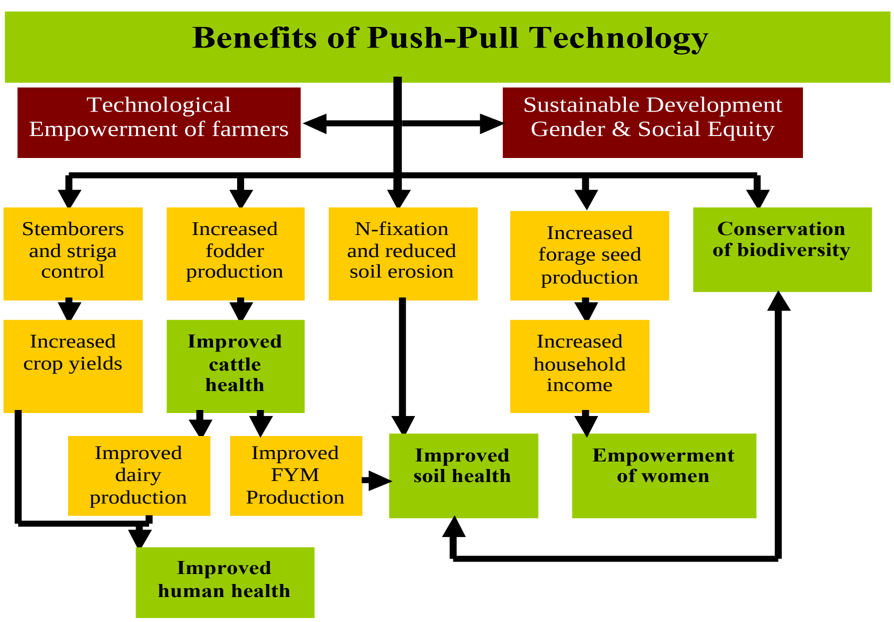

Figure 2. Schematic presentation of the benefits of the push-pull technology

A number of studies have demonstrated that push-pull is more profitable than farmers' own practices, and some of the practices designed to improve soil fertility. Significantly higher benefit: cost ratio was realized with push-pull compared with maize monocrop and/or use of pesticides, posting a positive return on investment of over 2.2 compared with 0.8 obtained with the maize monocrop, and slightly less than 1.8 for pesticide use (Khan et al., 2001). Additionally, push-pull with no additional fertilizer had the best gross returns while less profit were recorded with the use of fertilizer, implying it was economically propitious for poor smallholders who could not afford external inputs to invest in push-pull. In a more detailed economic analysis utilizing data of over 7 cropping seasons, returns to investment for the basic factors of production under push-pull were significantly higher compared to those from maize-bean intercropping and maize monocrop systems (Khan et al., 2008). Positive total revenues ranged from $351/ha in low potential areas to $957/ha in the high potential areas, with general increases in subsequent years. The returns to labour which were recovered within the first year of establishment of push-pull ranged from $0.5/man day in the low potential areas to $5.2/man day in the higher potential areas, whereas in the maize monocrop, this was negligible or even negative. Furthermore, the Net Present Value (NPV) from push-pull was positive and consistent over several years. A more recent study (De Groote et al., 2010) that used discounted partial budget and marginal analysis corroborated these findings and concluded that push-pull earned the highest revenue compared to other soil fertility management technologies, including green manure rotation.

Climate-smart technological innovation

Furthermore, the new 'climate-smart' adaptation of the technology has unrivalled potential to equip farmers with the resilience and adaptability they need to deal with the additional problems associated with climate change (Khan et al, 2014). With rising uncertainties in the region's rain-fed agriculture due to the continent's vulnerability to climate change, there was a demand and need to adapt conventional push-pull to withstand increasingly adverse and changeable conditions. With farmers facing rising uncertainties of rain-fed agriculture, there was an urgent need to adapt the conventional push–pull to withstand increasingly hotter and drier conditions. The trap and intercrops used in conventional push-pull were rainfall and temperature limited as the initial system was developed under average rainfall (800-1200mm) and moderate temperatures (15 to 30C°). In order to ensure that push–pull continues to affect food security positively in Africa over the longer term, new drought-tolerant trap (*Brachiaria* cv mulato) and intercrop (drought tolerant species of desmodium, e.g. *D. intortum*) plants have been selected from research undertaken with funding from the EU. The new companion plants also have the appropriate chemistry in terms of stemborer attractancy for the trap component, and stemborer repellence and striga suppression, and ability to improve soil fertility and soil moisture retention, for the intercrop component (Khan et al., 2013). Both trap and repellent plants provide high quality livestock fodder over long periods of drought. In addition, they provide other ecosystem services such as biodiversity improvement and conservation, and organic matter improvement.

Identification of drought and temperature tolerant trap and repellent plants

icipe, Rothamsted Research and national partners in Ethiopia, Kenya, and Tanzania identified and selected new drought and temperature tolerant trap and intercrop plants suitable for drier agro-ecologies. From a total of 400 grasses previously identified under different agro-ecologies in those countries an initial 21 candidate drought tolerant trap plants were selected. *Brachiaria* cv. mulato was chosen as the trap plant for the climate adapted push-pull given also its ability to attract stemborers, farmers' preference for it as livestock fodder, and commercial availability of its seed that would allow faster dissemination and up-take. Additionally, it allowed minimal survival of stemborer larvae, a suitable characteristic of a trap plant that would support populations of natural enemies within season and when the cereal crop is not in season.

Desmodium species that are drought tolerant and emit volatiles that repel stemborers, fix nitrogen to improve soil fertility, produce high biomass but have low growth habit that cover the soil and improve soil health were identified. Forty-three accessions of 17 *Desmodium* species initially collected from dry and hot areas in Africa and other arid environments were obtained from germplasm repositories[2] and from field survey samplings. Greenleaf desmodium (*D. intortum*) was observed to be more drought tolerant compared to silverleaf desmodium (*D. uncinatum*) and was chosen as the intercrop species for immediate integration into a climate adapted push-pull. Greenleaf desmodium was chosen given its known ability to control striga and stemborers (Khan et al., 2007) coupled with commercial availability of its seed that would enable its wider testing by farmers within the project target areas. The work to isolate and purify all the active compounds in the desmodium root exudates and fully elucidate their effects on striga suppression is ongoing at *icipe* and Rothamsted Research. Similarly, the full mechanism of stemborer control by the new companion plants is currently being elucidated with the aim of providing both sustainability and quality assurance as more companion plants are selected for new agro-ecologies.

Field implementation of climate-smart push-pull technology

Currently over 18,000 smallholder farmers in drier parts of Kenya, Tanzania and Ethiopia have taken up the climate-smart push–pull and have reported effective control of stemborers and striga weed resulting in significant increases in grain yields of both maize and sorghum. In both maize and sorghum trials the yield increase was fivefold compared to the corresponding control plots (see **figure 3**).

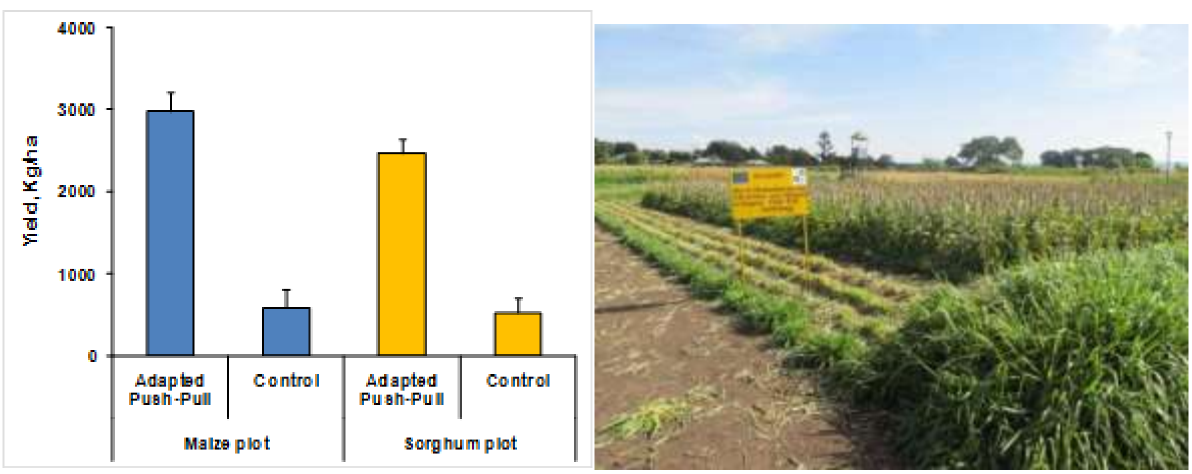

Figure 3. First season on-farm results of maize and sorghum yields from push-pull plots planted with the drought tolerant companion plants: *Brachiaria* cv. mulato as the trap plant and Greenleaf desmodium as the intercrop plant.

[2] Desert Legumes Program (DELEP) at the University of Arizona-USA; ILRI forage plants gene bank in Ethiopia; and the United States Department of Agriculture (USDA), Agriculural Research Service (ARS) Plant Genetic Resources Conservation Unit (PGRCU).

The new companion plants were also assured availability of high quality fodder at the farms. This increased the productivity of livestock fed on the fodder while the surplus fodder was preserved as hay. Validation of gross return from the adapted climate-smart push-pull showed $1075.8/ha and $1289/ha gross benefits and a marginal rates of return (MRR) of 109% and 143% for sorghum and maize respectively, implying that the net increase in benefits of climate-smart push-pull outweighed the net increase in costs compared to farmers' practices. Additionally, over 80% of the interviewed farmers (350) reported effective control of striga and stemborers, improvement in soil fertility and improved grain yields. Other benefits mentioned included increases in fodder and milk production.

Climate-smart push-pull thus opens up significant opportunities for smallholder growth in drier areas and represents a platform technology around which new income generation and human nutritional components, such as livestock keeping, can be added. It therefore affords the smallholder farmers in these areas an opportunity to enter into cash economy. The technology can also be tailored to specific farmer needs. Smallholder farmers in SSA typically practice multiple cropping, where cereals are intercropped with food legumes. Therefore, the technology has been adapted to the farming systems by incorporating edible beans, planted either in the same hole with maize or in between maize plants within a row. This has increased the technology's appeal to the farmers as it guarantees an additional protein source in the diet (Khan et al., 2009), resulting into higher technology adoption rates in the region.

Maintaining push–pull's multiple benefits

The new trap plants and intercrops have met the farmers' and the scientists' expectations, giving effective control of stemborer and striga weed. As a result, yields of maize and sorghum have increased significantly, with an amazing up to five-fold increase over control plots (**Figure 3** above). The new companion plants have also provided ample, good-quality livestock fodder, producing enough to allow farmers to make hay for the dry season. And the better-fed dairy animals have produced more milk. In all, the system gives significantly higher economic returns to the farmer.

On-farm uptake by nearly 70,000 farmers in eastern Africa has confirmed that push–pull has significant impacts on food security, human and animal health, soil fertility, income generation, empowerment of women, conservation of agro-biodiversity and provision of agro-ecosystem services. Climate-smart push–pull will spread these benefits wider, conferring the benefits to additional crops and agro-ecologies.

Food security, diet and health

Dealing with striga and stemborer means healthier, more productive maize plants. Farmers who have adopted conventional push–pull reported steady increases in the amount of grain they harvested in the first and second seasons after planting. On-farm research has confirmed yield increases, with conventional push–pull routinely producing more than double the amount harvested from an equivalent area of monocropped maize across twelve districts of Kenya. Climate-smart push–pull has a similar positive impact on yield, but achieves this in a single season after planting, thanks to the rapid action of the greenleaf desmodium in dealing with striga.

In many cases, push–pull farmers say that their health and that of their families has improved since adopting the technology, because it has resulted in an improved diet, particularly through drinking more milk. Dietary diversity has also increased. Thanks to increased income from the sale of push–pull products and by-products, many farmers report that they are in a better position to purchase foods that they are not able to produce for themselves.

Protecting the soil

Push–pull farmers in Kenya, Uganda and Tanzania all describe improvements in soil fertility after adopting push–pull. Protected from erosion by the trailing, low-growing stems and leaves of the desmodium intercrop, this soil is one of the keys to the increased grain yields that farmers experience. The majority of adopters incorporate the technology into an integrated crop–livestock production system. This close association with livestock means that farmyard manure can be added to the soil, increasing the fertility benefits already gained from the fixation of nitrogen by the desmodium intercrop. Most push–pull farmers notice an improvement in their soil within a very short time of adopting the technology.

Providing nutritious fodder

Livestock fulfil many purposes in the livelihood systems of farming households. They provide milk, meat, manure and draught power. Their outputs become goods for sale and exchange, and the animals themselves represent a form of savings. Keeping animals well fed and healthy is often pivotal in maintaining soil fertility, paying school fees and eating a nutritious, balanced diet.

Push–pull farmers use their fodder crops to feed goats, sheep, cattle, pigs, poultry and even rabbits. Many farmers report positive changes in the health and productivity of their animals, particularly thanks to the nutritional qualities of desmodium. Because it is rich in protein, desmodium fodder often has a positive effect on milk yields, frequently doubling or even tripling them. Greenleaf desmodium appears to be even better than silverleaf.

Generating income

There are a number of ways that push–pull generates cash income, including the sale of cereals, milk and fodder. Increased income is often spent on school fees, home improvements or invested in diversifying livelihood enterprises. But there are also many examples of income being invested in the community and upholding of social safety nets to protect the vulnerable.

Gender equity

Once established, push–pull reduces the drudgery of digging and weeding, a task performed most often by women, freeing up their time and labour for more productive tasks like selling milk or starting a poultry enterprise. Diversified farm income means there is more money available to buy medicines, household goods and other essentials. Stall-feeding dairy cattle also frees the women and children from the task of herding cattle to graze.

More stable and resilient agro-ecosystems

As far as possible, climate-resilient agro-ecosystems maintain the functions and services provided by natural systems. This means integrating instead of segregating, closing water and nutrient cycles, increasing biological and genetic diversity, and regenerating instead of degrading bio-resources. Push–pull technology contributes to stable and climate-resilient agro-ecosystems

by providing farmers with a tool for on-farm diversification which is in line with these underlying principles.
Smallholder farmers in SSA typically practise multiple cropping, where cereals are intercropped with food legumes. Therefore, the technology has been adapted to the farming systems by incorporating edible beans, planted either in the same hole with maize or in between maize plants within a row. This has increased the technology's appeal to the farmers as it guarantees an additional protein source in the diet, resulting in higher technology adoption rates in the region.

Producing a good grain harvest is increasingly becoming a question of gambling with the weather as climatic patterns become more unpredictable. Farmers have for many years habitually diversified the crops they plant as an insurance strategy against climate uncertainty. Push–pull reinforces this strategy, because it can equally usefully be applied to maize, sorghum, millet and rice. Furthermore, having both conventional and climate-smart variants widens the range of planting material that farmers can use to tailor their cereal cropping practices to local climatic conditions.

Partnerships in implementation

The push–pull development programme has brought together a wide range of contributors from disciplines as diverse as chemical ecology, organic chemistry, socio-economics and weed science to develop a systemic approach to solving the problems of stemborer and striga that works for farmers.

While push–pull is in many ways an elegantly simple technology, it is based on a set of complex ecological and chemical relationships between plants, insects and soil. Scientists at *icipe* have found that it works best in practice when farmers understand clearly why it works, and what each component in the system contributes to its overall success. This means that disseminating push–pull has been a knowledge-intensive process, with a strong emphasis placed on building farmers' capacities.

As well as being fully trained in all aspects of push–pull, farmers have been involved at every stage of the research and dissemination over the past 15 years. The result is a cohort of farmers who understand basic agro-ecology, supported by a vibrant network of farmer leaders and farmer-teachers who have become experienced peer educators. Most of them have visited the push–pull garden at *icipe's* Mbita Point research station, and many have taken part in technology development trials.

The district-based *icipe* field workers usually work with farmer groups set up for mutual support and self-help, and these have become a well-established medium for delivering agricultural extension and other development interventions. In some places, push–pull triggers the formation of new farmers' groups, while in others existing groups incorporate push–pull into their own portfolio of activities.

One hallmark of the successful spread of push–pull has been *icipe*'s capacity to identify and work in harmony with the groups and organizations it meets in the field. Exploiting synergies with other active research and development organizations has created new channels for sharing knowledge. Particularly important is *icipe*'s partnership with Heifer Project International (HPI), an NGO whose livestock-focused work has proved to be a good fit with push–pull. In 2011, a strong informal partnership was cemented when HI formally became the implementing partner for climate-smart push–pull in Kenya and Tanzania.

Looking ahead

One of push–pull's strengths is the way the programme has been managed as a learning process. Because farmer participation is built in to the processes of research and dissemination, contextual changes encountered in the field can be communicated, discussed and responded to. Achieving this level of reflexivity to contextual change is a vital aspect of the climate-smart qualities of push–pull, and is thanks in no small part to the flexible approaches of the many donor organizations that have funded its development and spread. Both the technology and its model for dissemination represent a substantial resource for the future.

The development of climate-smart push–pull has made it possible for the technology to be implemented in new areas with less rainfall, and to increase the potential number of farmers who might find it a useful and profitable addition to their livelihood strategies. Work has begun to extend climate-smart push–pull in Tanzania, Uganda and Ethiopia, trials are being carried out in Nigeria, and the technology has been adapted for use in South Africa. The push–pull technology is expanding to a broader range of agro-ecosystems and farming practise in Africa.

The need for adaptive agricultural practices that can cope with increasingly variable climatic conditions and still produce food for people and livestock has never been greater; neither has the need for development pathways that respect ecological limits and restore ecosystem health. Experiences with push–pull offer important lessons about developing and implementing the kind of climate-smart technologies that are needed to meet these challenging goals.

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Improved plant water availability on soils under NT variants in semi-arid districts of South Africa

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Keywords: plant available water capacity, final water infiltration, soil water level, crop water productivity (CWP)

Introduction

Farmers in the semi-arid region of the Eastern Free State and southern Lowlands of Lesotho need to "harvest water". The water-use efficiency of conventional farming practices can be questioned. Fallow, as part of the crop rotation, is common in the eastern Highveld area of South Africa in order to store pre-plant water quantities and breaking pest cycles. This method of using fallow as part of a crop production system is contested by McNee et al. (2008). Bare fallow, as part of a crop production system is contested as it leads to a reduction in soil organic matter (and soil carbon), is prone to erosion and scores low on agronomic productivity.

Soil water levels can be measured by the different levels of precipitation utilization of different production or management practices for dry land crop production or rangeland utilization. Hellegers et al. (2009) used the concept of crop water productivity (CWP) which has also been described as “the value of water” or “net return to water” (Young 2005). Different trials were conducted measuring soil wetness, final water infiltration rates and crop water productivity.

Conventional NT (CNT) (NT without adequate levels of soil cover and sound crop rotations) is practiced among commercial NT pioneers in the Eastern Free State of South Africa. CNT (primarily ‘*likoti*’[3]) is also practiced among the smallholder and subsistence farmers in the Maphutseng valley, Lesotho. This paper addresses the importance of adherence to the three key CA principles (i.e. especially soil cover) for improved soil water use efficiency. This data is crucial for crop production against changing climatic conditions, fluctuating annual rainfall and variability in the annual rainfall distribution.

Materials and Methods

The minimum data set on soil structure, for soils under different production systems, for this paper used the following indicators: (1) plant available water capacity. Sub indicators for the latter are: (1a) soil final water infiltration rates, (1b) soil water levels and (1c) crop water productivity.
On farm trials were conducted in Ladybrand were three variables were being compared: NT, NT with mulch and NT with cover crops. The trials included four treatments, each with four repetitions. Treatment blocks were 3.6m wide (width of the NT planter) and 40m long. The blocks were randomly selected. The first treatment was NT wheat followed by maize. This reflects the conventional NT farming operations past 2004. The main crop rotation under conventional farming (CV), before converting to NT, was wheat followed by maize. NT has initially been implemented without significant soil cover (40-50%) and sound crop rotations (2 grain crops). Treatment two was the NT maize-wheat rotation with grass mulch after planting maize. Treatment three and four referred to the maize-wheat rotation including cover crops. Treatment three’s cover crop mix was oats *(avena sativa)* /grazing vetch *(Vicia dasycarpa)* /fodder radish *(Raphanus sativus)*. Treatment four’s cover crops included stooling rye *(Secale cereal)* / grazing vetch /fodder radish).

Final water infiltration rates were measured as an indicator for pore size distribution as indicator of pore size distribution represented by soil structure and biopores. The final water infiltration rates were measured by using a double ring infiltrometer. The infiltration studies were conducted in September 2011 and 2013 prior to planting the cash crop.

Soil moisture levels were initially measured at a depth of 100cm and 50cm. Watermarks were installed by snug fitting them into pvc pipes. An irrometer moisture reader was used giving readings between 0 and 199 where 0 is wet and 199 is dry. Readings were taken weekly and occasionally bi-weekly. There were insignificant differences in soil moisture readings in 2011 at 100cm and 50cm depth and therefore the pipes were re-installed after maize planting at a depth of 50cm and 30cm. Some watermarks became defective during the years and were replaced.

Results and Discussion

Plant water availability

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[3] plant basins

Final water infiltration rates

The displayed some variability, but the highest final water infiltration rates were found in the two cover crop treatments, followed by the NT mulch treatment and lowest under the conventional NT treatment (see graph 1). The final water infiltration rates improved over time under NT cover cropping (T3 and T4).

Soil water levels

The soil under all four treatments was more or less equally wet at the beginning and at the end of each season i.e. at planting time of main cash crop. We see a variability of soil wetness during the season. T1 (conventional NT) is driest for most of the seasons, especially during the active growth of the maize crop. The grass mulch treatment (T2) is stable throughout the season with no sudden peaks i.e. slow change in soil wetness, indicating wet soils under cover. All the treatments follow more or less the same pattern: soil drying off when there is no or little rainfall, but the highs and lows differ. The CC treatment T3 and T4 are driest in the cover crop stage, but are wettest (lowest figure) after a significant rainfall event. This implies highest infiltration rate for the cover crop treatments and water losses by overland flow and run off from the other treatment

Crop water productivity

The CWP was highest under the two CC treatments (T3 and T4) followed by T2 and T1. The total beneficial biomass (Y_i) accrued over the 3 years was 5,491, 6,342, 13,940 and 15,482 kg ha^{-1} for treatment 1-4 respectively.

The CWP_i was 2.70, 3.12, 6.87 and 7.62 for treatment 1-4 respectively. Double cropping i.e. higher crop intensity or agronomic productivity, was possible under T3 and T4 without jeopardizing cash crop yields, which were in fact highest under T4 followed by T3. The maize yields under the CC treatments T4 and T3 were 1.23, 1.19 and 2.35, 1.54 times higher than the conventional NT maize yields for the 2011/12 and 2012/13 seasons respectively.

It can be concluded therefore that CA, as an improved variant of NT cover cropping, is a climate change mitigation strategy as compared to CNT. CA reduces the risk of farming against the background of increased rainfall variability i.e. quantity as well as seasonal distribution as a result of climate change

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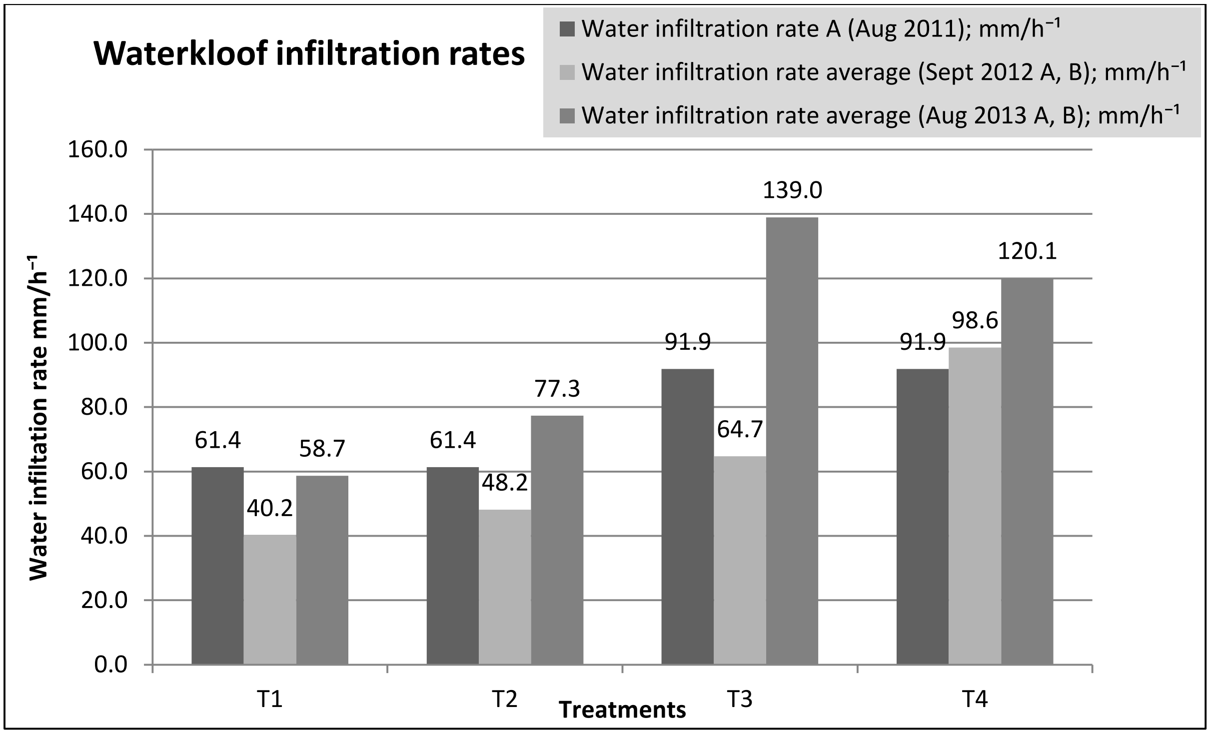
Figures and Tables

Graph 1: End-of-season soil final water infiltration rates under four different NT treatments in 2011-2013



Effect of conservation tillage on soil moisture and crop yields in Mwala District, Kenya

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Key words: tillage systems, cropping systems, soil water conservation, yields

Introduction

Semi-arid areas are characterized by temporal and spatial variability of rainfall. In Kenyan semi-arid areas, the rainfall is usually low and unreliable. The timing and relative lengths of each growing period vary substantially with location and this leads to reductions in yields by 75%

when they occur. The deficit of soil water in these areas is also attributed to low infiltration rates (due to surface sealing and crusting and low organic matter content) and subsequent high runoff rates. The conservation of soil water in semi-arid areas requires appropriate tillage practices that not only improve rain infiltration but also conserves adequate soil moisture for plant growth. Conservation tillage practices such as tied ridging, subsoiling and ripping have the potential of soil moisture retention and mitigation of intra-seasonal dry spells that often result in low productivity and crop failure . Although conservation tillage is highly advocated, there is strong evidence that this kind of tillage may not be good with soils prone to surface crusting and sealing, a characteristic of most of the soils in semi-arid areas of Kenya. This study was conducted to quantify the comparative effectiveness of selected tillage practices in conserving soil moisture and improving crop yields in Mwala District, Eastern Kenya.

Materials and Methods

The trials were established during the long rains (LR), short rains (SR) of 2012/13 in Mwala District, Kenya. Six tillage systems; Disc plough (MB), Disc plough and Harrowing (MBH), Ox-ploughing (OX), Hand hoe and Tied Ridges (HTR), Hand hoe only (H) and subsoiling - ripping (SR), three cropping systems namely, sole maize, sole bean and maize-bean intercrop were investigated in a split-plot design with four replications. Data on soil moisture content was monitored at different weeks after planting (WAP) and the crop yields at end of each growing season. The recommended agronomic practices were observed.

Results and Discussion

Moisture trends as affected by tillage methods: When the amount of soil moisture content for each tillage method was averaged for the three seasons, a seasonal difference was found ($p < 0.001$) and a trend of OX > H > MB > MBH > HTR > SR observed. This shows that the conventional tillage practices had the highest soil moisture content as compared to the conservation tillage methods.

Moisture trends as affected by cropping systems: A three - season moisture average as affected by cropping showed that sole bean had higher moisture (12.8 %) followed by sole maize (12.66 %) and the intercrop (12.62 %). This confirms that increased plant population density per plot result in higher moisture extraction within the plots.

Maize grain and biomass yields: In LR, 2012, the highest grain yield (5.35 Mg/ha) was observed in MBH and the lowest (3.99 Mg/ha) in HTR. For the SR, 2012, the highest grain yield (8.93 Mg/ha) was observed in the case of MBH and the lowest (3.33 Mg/ha) in OX plots. In LR, 2013, the highest grain yield was in MBH (2.59 Mg/ha) and lowest in HTR (1.81 Mg/ha).

In LR, 2012, the highest stover yield (14.44 Mg/ha) was observed in MBH and the lowest (10.04 Mg/ha) in H. For the SR, 2012, the highest biomass (8.93 Mg/ha) was observed in the case of HTR and the lowest (5.72 Mg/ha) in subsoiling – ripping (SR) plots. In LR, 2013, the highest stover yield was in MBH (5.42 Mg/ha) and lowest in OX (4.28 Mg/ha). There was a gradual decrease in the biomass from LR, 2012 to LR, 2013 and this is due to variation in rainfall differences which influenced soil moisture availability at the different stages of crop growth. Intercropping significantly reduced the three-season mean yields by 11 % (from 3.71 – 3.31 Mg/ha) in maize grain and 7.3 % (from 8.19 – 7.59 Mg/ha) in biomass respectively Higher yields in sole crops indicate the relative competitive effect of intercrops compared to sole cropping.

These yield variations also show that by rainfall differences in the long and short rains influenced soil moisture availability at different stages of crop growth.

Bean grain and biomass yields: The biomass yields were affected by tillage with a trend of MBH > HTR > SR > OX > MB > H while for grain yield, MBH > MB > HTR > SR > OX > H. In LR, 2012, the highest grain yield (0.57 Mg/ha) was observed in MBH and the lowest (0.21 Mg/ha) in handhoe (H). For the SR, 2012, the highest grain yield (1.096 Mg/ha) was observed in the case of HTR and the lowest (0.76 Mg/ha) in handhoe (H). Mean seasonal grain yields was at 0.43 Mg/ha in LR, 2012 and 0.92 Mg/ha in the SR, 2012. No bean yield data was recorded in LR, 2013 due to poor rainfall distribution and prolonged drier conditions in the growing season.

In LR, 2012, the highest biomass yield (1.15 Mg/ha) was observed in MBH and the lowest (0.556 Mg/ha) in H. For the SR, 2012, the highest biomass (3.27 Mg/ha) was observed in the case of HTR and the lowest (2.23 Mg/ha) in handhoe (H). There was a gradual increase in biomass production from one season to the next indicative of variability in seasonal rainfall patterns. Sole bean produced an average grain yield of 0.69 Mg/ha and biomass of 1.9 Mg/ha as compared to 0.7 Mg/ha and 1.87 Mg/ha of the intercrop respectively. Yield advantages from intercropping as compared to sole cropping are often attributed to mutual complimentary effects of component crops, such as better total use of available resources.

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Figures

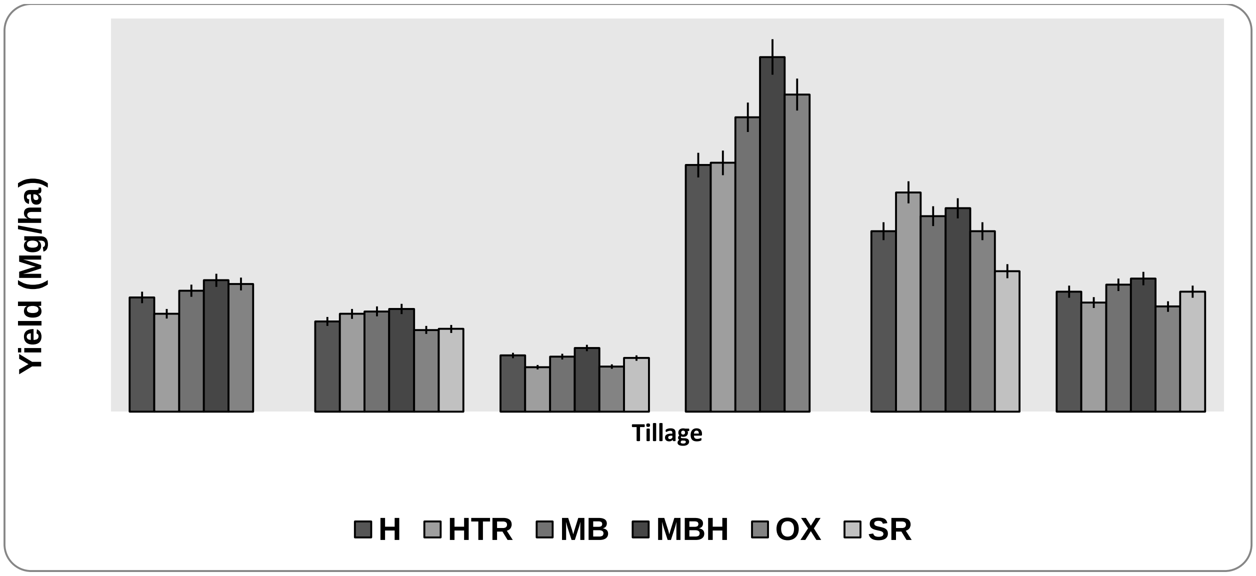

Figure 1: Effect of tillage methods on maize grain and biomass yields

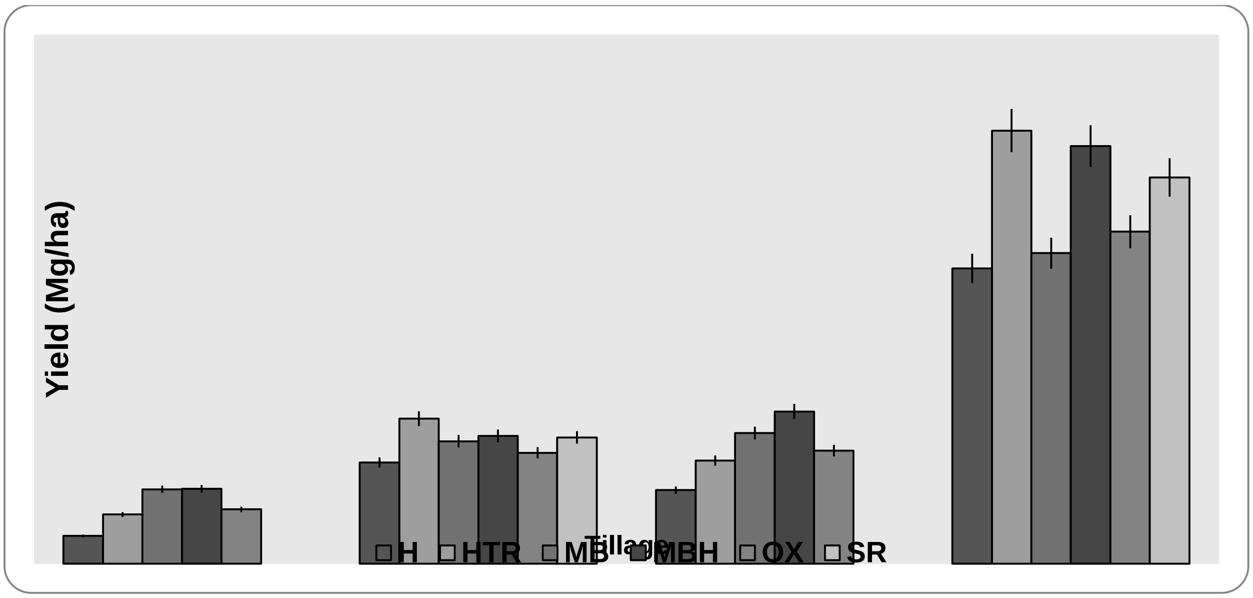

Figure 2: Effect of tillage methods on bean grain and biomass yields

Food security and adaptation impacts of potential climate smart agricultural practices in Zambia

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Keywords: Climate smart agriculture, minimum soil disturbance, crop rotation, legume intercropping, inorganic fertilizer, improved maize

Introduction

The impacts of climate change on food security have been (and continue to be) discussed in many international policy and academic circles. Based on global climate models we know that Sub-Saharan Africa will be one of the most affected regions, with expected productivity decreases of up to 20%, and stubbornly high levels of poverty and food insecurity (Cline 2008). Within SSA, Zambia is projected to be one of the countries most affected by climate change.
In the past 30 years, frequent rainfall anomalies and droughts have been observed in Zambia – especially in the southern and central regions – with resulting decreases in maize yields (Jain 2007). Although urban poverty has decreased in the last 20 years, rural poverty has stayed around 80% and the proportion of the population which is malnourished has increased by 23% since 1990 (Chapoto et al. 2011). Most of the rural poor (75% of total farming population) are subsistence farmers that rely on rainfall for production (Jain 2007) making the need for adaptation and resilience imperative in the fight to achieve food security. Climate smart agriculture (CSA) seeks to achieve this by sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change and reducing and/or removing greenhouse gases emissions relative to conventional practices (FAO, 2013).
A better understanding based on evidence and sound analysis would greatly increase identifying site specific synergies and tradeoffs. Most of the studies on climate change and productivity in Zambia up to date have been based on simulations lacking significant details at the household level or on cross sectional data missing relevant climate variables, whereas large scale panel studies with detailed geo-referenced data on climate and soil characteristics have been absent from the literature. This paper fills this gap by using large scale household panel data combined with geo-referenced data on historical rainfall and temperature as well as with soil characteristics to assess the impacts of potential CSA practices on maize productivity in Zambia. The CSA practices considered are: minimum soil disturbance (MSD), crop rotation (CR), and legume intercropping (LEGINT). The impacts of the use of inorganic fertilizers (INOF) and improved maize seeds (IMPSEED) on productivity are also considered. While the latter two practices may not be considered as part of CSA per se, they are also analyzed given their widespread promotion and use, making it necessary to understand how they interact with other practices.
Most of these practices have the potential to decrease the variability of production over time through improvements in the capacity to deal with extreme weather events (e.g. droughts or late onset of rains) and therefore on the probability of disastrously low productivity on which

empirical evidence is rather weak to date. This paper addresses this gap in the literature trying to identify potential synergies between food security and resilience to extreme weather events.

Material and Methods

Our main data sources are two rounds of Rural Incomes and Livelihoods Surveys (RILS) conducted in 2004 and 2008 (CSO 2004, 2008). These surveys are the second and third supplemental surveys to the nationally representative 1999/2000 Post-Harvest Survey (PHS). The supplemental surveys, were carried out by the Central Statistical Office in conjunction with the Ministry of Agriculture, Food, and Fisheries and commissioned by the Food Security Research Project of Michigan State University, to study options to improve crop production, marketing, and food consumption among small scale farmers. Figure 1 shows the distribution of standard enumeration areas in the RILS across the 4 agro-ecological regions in Zambia.

RILS data was merged with historical rainfall and temperature data at the standard enumeration area level to control for the effects of the levels and variations in rainfall and temperature on maize productivity. Rainfall data come from the Africa Rainfall Climatology version 2 (ARC2) of the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA-CPC) for the period of 1983-2012.[4] The temperature data are surface temperature measurements at 10 day intervals for the period of 1989-2010 obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF). Harmonized World Soil Database (HWSD) was also used to control for the effects of soil nutrient availability and soil pH levels on productivity.[5]

Using the ARC2 data, the following variables relevant for productivity were created: total rainfall, average and maximum temperatures during the growing seasons covered by the RILS, the coefficient of variation (CoV) of rainfall in the growing season since 1983, and indicators for false onsets and too hot seasons.

This rich data set is used to analyze the determinants of the CSA practices as well as the climate variables on maize productivity, the probability of low yields and yield shortfall in Zambia. The estimation strategy controls for potential bias by using a fixed effects model, which also addresses potential endogeneity of the adoption of these practices to the extent that the endogeneity is caused by time-invariant unobserved heterogeneity.

Results and Discussion

Table 1 summarizes the most robust findings of our analyses as the direction of change in outcome variables associated with selected variables in the first column.[6] Controlling for a large set of variables that affect production, results show no significant impact of MSD, positive impact of LEGINT and a negative impact of CR on maize yields. The positive impact of LEGINT is robust to climatic shocks, while the negative impact of CR is off-set by a significantly positive impact under highly variable rainfall conditions. The average positive impacts of modern input use are found to be conditioned by climatic variables: INOF has a much

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[4] ARC2 data are based on the latest estimation techniques on a daily basis and have a spatial resolution of 0.1 degrees (~10km) . See http://www.cpc.ncep.noaa.gov/products/fews/AFR_CLIM/AMS_ARC2a.pdf for more information on ARC2 algorithms.

[5] The HWSD has a resolution of 30 arc-seconds and combines existing regional and national updates of soil information worldwide. See http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/ for more information.

[6] All other socio-economic and agro-ecological variables controlled for are not shown here in the interest of space.

smaller impact under false rainfall onsets, and IMPS has a yield decreasing impact under very high growing season temperatures. Finally, LEGINT, INOF and IMPSEED all significantly decrease yield shortfall. INOF increases the probability of obtaining low yields and yield shortfall significantly under high rainfall variability, whereas IMPSEED increases low yield probability and yield shortfall in locations where growing season maximum temperatures exceed 28°C. In addition to conditioning the impacts of CSA, too high temperatures during the growing season increases the probability of low yields and decreases yield shortfall significantly.

One of the most robust findings shows that having timely access to fertilizers increases maize yields, and decreases low yield probability and yield shortfall significantly in all specifications, as in Xu *et al.* (2009). This result indicates that improving the efficiency of fertilizer distribution systems is one of the key policy entry points to improve food security in Zambia.

This paper demonstrates that rigorous analyses with rich agricultural household as well as geo-referenced climate data are needed to identify the real impact of agricultural practices on yields and their resilience to climatic shocks. The oft-mentioned positive impacts of modern inputs on yields decrease and/or disappear once their interactions with various climate shock variables are taken into account. Crop rotations are found to significantly increase yields under rainfall variability, whereas the positive impacts of legume intercropping are robust to various shocks considered here. Given the challenge of addressing food security under the projected impacts of climate change that is expected to increase the frequency of climate shocks, agricultural development policy would be more efficient if targeting pays attention to how impacts of various practices interact with each other and vary by climatic conditions as demonstrated in this paper.

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Figures and Tables

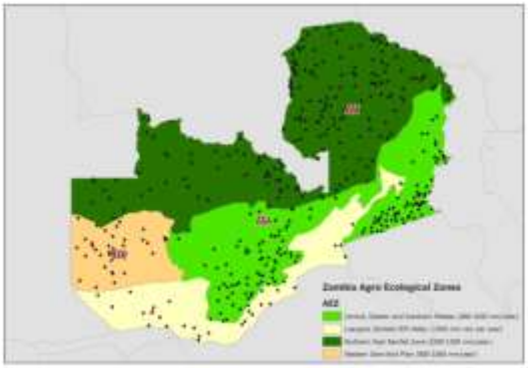

Figure 1. Agro-ecological regions of Zambia and RILS survey sites (Standard Enumeration Areas)

Table 1. Summary of robust findings

	Yield	p(low yield)	Yield shortf.
MSD			
CR	-		+
LEGINT	+		-
INOF	+	-	-
IMPSEED	+	-	-
CR*CoV Rain	+		
INOF*CoV Rain		+	+
INOF*False onset	-	+	+
IMPS*False onset	+		-
IMPS*tmax ≥28°C	-	+	+
Fertilizer on time	+	-	-
Rainfall	+		-
Max temp ≥ 28°C		+	-

Are Conservation Agriculture practices reducing impact of seasonal climate variability in Ethiopia? *Hae Koo Kim*[1], *Solomon Admassu*[2], *Feyera Merga Liben*[3], *Solomon Jemal*[3], *Fred Kanampiu*[4]

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Keywords: rainfall, maize, legume, rotation, intercropping, agroecology, sustainability

Introduction

Sub-Saharan Africa is particularly vulnerable to effects of seasonal climate variability due to land degradation and increasing population pressure. In this context, adoption of Conservation Agriculture (CA) in Eastern Africa is not yet as successful as countries of Latin America or South Asia (Giller *et al.*, 2009). In Ethiopia, smallholder farmers rely mainly on rainfed agriculture, and land degradation due to soil erosion and declining soil fertility represent a major challenge to sustainable intensification (Rockstrom *et al*., 2003). Such degradation is generally attributed to exploitative farming practices that include plowing, removal of crop residues, mono-cropping which have detrimental effects on soil structure and soil organic matter content. Climate change with higher rainfall variability is believed to worsen this trend leading to serious consequences on crop yield in many African countries including Ethiopia. Coupled with poverty and growing population, land degradation poses a serious threat to national and household food security (Temesgen *et al*., 2012). CA practices might provide long-term alternatives to reduce the detrimental effects of soil erosion and water stress (Aikins *et al*., 2012). The objectives of this study were to: (i) evaluate the performance of maize-bean cropping systems under CA and conventional farming practices across several seasons; and (ii) identify which cropping systems under CA can reduce adverse effects due to the high seasonal climate variability.

Material and Methods

Field experiments under rainfed conditions were conducted in representative agroecologies of the Ethiopian Rift Valley between 2011 and 2013 main cropping seasons. In research managed experiments (i.e., Melkassa and Hawassa research stations), four different maize-bean cropping systems (i.e., sole maize, sole bean, rotation and intercropping) were evaluated both under CA and conventional agricultural practices (CP) using a randomized complete block design with three replications. Each replication consisted of six rows of 5.1 meter long plot. Maize was planted at a spacing of 75 cm inter-row and 30 cm intra raw while bean was planted at 40 cm between rows and 10 cm inter-plant density. In on-farm trials across four different districts, the four different maize-bean cropping systems under CA were compared to the CP (e.g., sole maize). The most commonly used maize and bean varieties used were for each location. In the CA practices (started in 2010), narrow rows were opened with a hand-hoe to a depth of about 10 cm to plant seeds and for fertilizer application without any prior tillage and all crop residues were retained in the field. The CP plots were managed similar to the common farmers' practice, and crop residues were cut and carried to the farmers' house for feed and fuel immediately after harvesting. Crop phenology and the major agronomic data including yield and biomass were collected during the cropping season. In case of on-station trials, soil moisture content was measured at harvest for each plot.

Results & Discussion

Effect of climate. Seasonal climate variability is very high in the Ethiopian Rift Valley with recurrent low rainfall every three to four years (e.g., 2000, 2003, 2009 and 2012) during the past decade (Fig. 1a). The detailed analyses across four different districts of the Central Rift Valley show that the variability in rainfall amount and distribution was particularly very high during the cropping season (up to two fold) including early or late drought periods (Fig. 1b).

Limited effect of tillage. Difference in tillage practices did not have a significant effect on yield reduction due to rainfall variability. Over the last three years, maize yield for both CA and CP varied up to four times from one season to the next, while bean yield was relatively stable (Fig. 2).

Effect of CA on soil moisture. Although the effect on overall yield was not significant, the impact of CA practices on soil moisture content at harvest during an above average rainfall season (2011) was significant in case of maize sole and maize-bean rotation cropping systems (Fig. 3). In such context, it appears that maize-bean intercropping under CA can be more advantageous in locations with higher average rainfall, but also why relaying cropping or double cropping systems can be other alternatives to use the residual moisture left under CA.

Recommended CA technologies. To benefit of the residual moisture at the end of the season under CA practices, maize-bean intercropping might be a better option in locations where there are sufficient rainfall. Rotation might be a better option in locations with higher frequency of drought; however, smallholder farmers should be able to make higher benefits from legumes. Higher adoption of CA technologies requires better characterization of the best options in each agroecology. Besides, the socio-economic context including market for cash crops and livestock components must be considered in addition to agronomic practices which can limit the risks of seasonal climate variability.

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Graphs

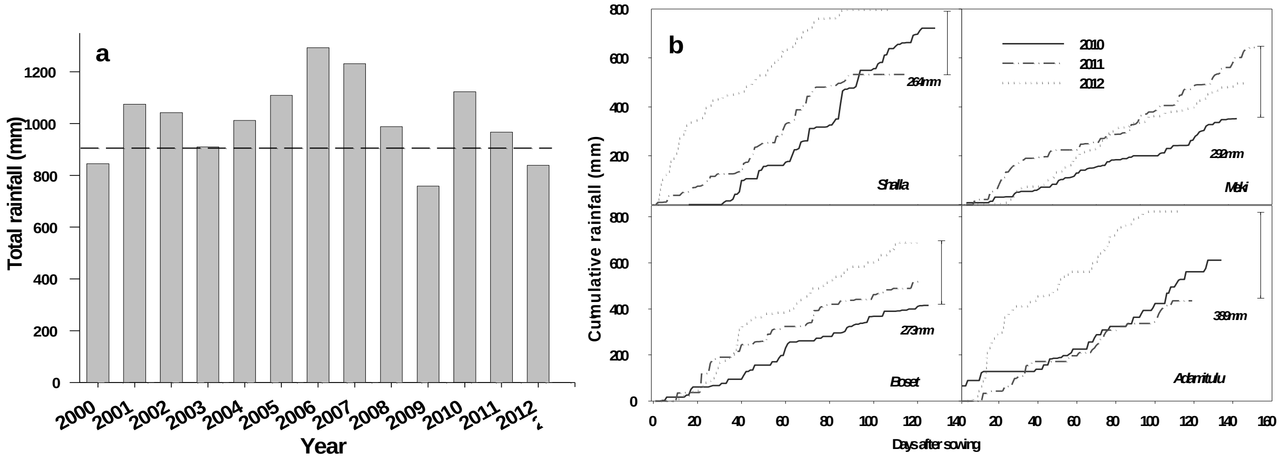

Fig. 1a: Rainfall variability in the Rift Valley (Hawassa research station) between 2000 and 2012 (dashed line representing average rainfall); **b:** Cumulated rainfall from sowing to harvest in 4 different locations (Shalla, Meki, Boset, Adamitulu) of the Central Rift Valley between 2010 and 2012 (vertical line representing the maximum rainfall difference across the different seasons).

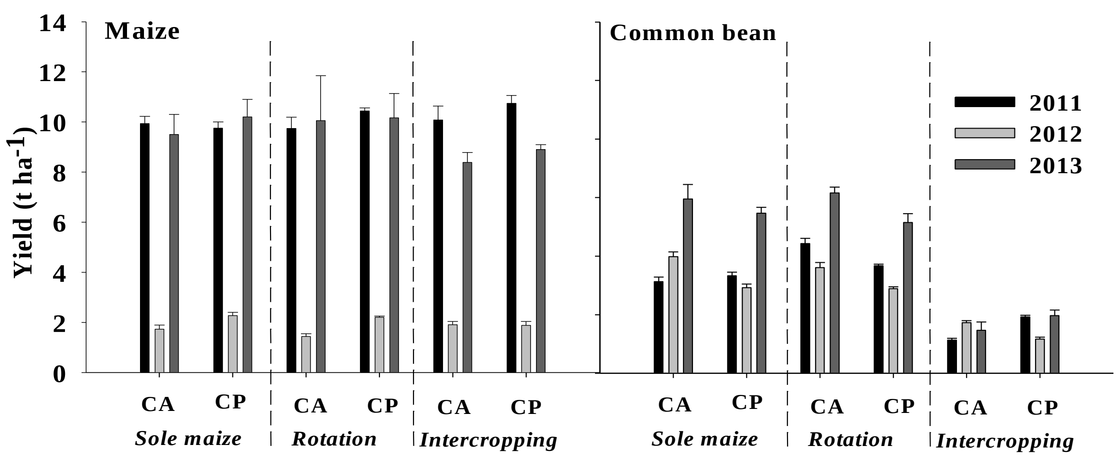

Fig. 2 Effect of seasonal climate variability on maize and common bean grain yield grown under different cropping systems and tillage practices in Hawassa

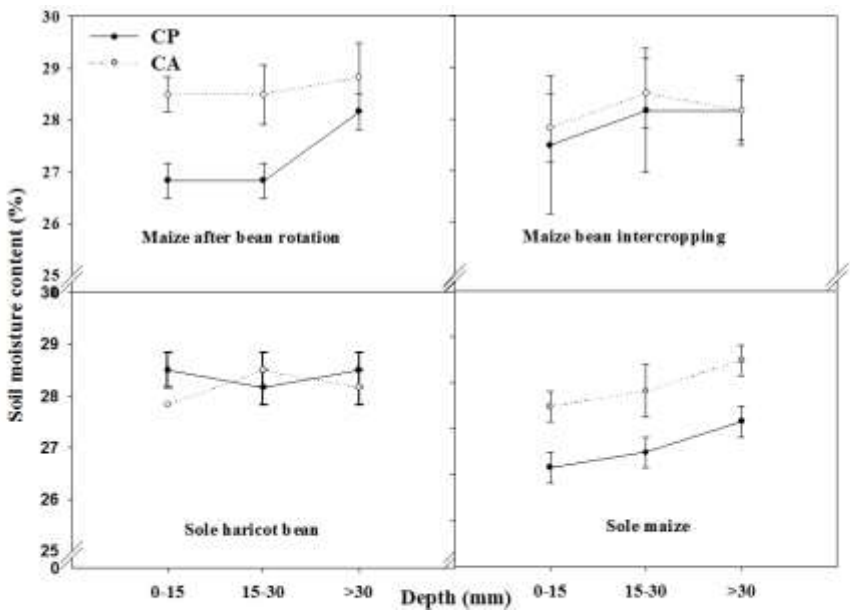

Fig. 3 Pairwise comparison of CA or CP tillage effect on soil moisture content at harvest in 2011 between the different cropping systems

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Conservation Agriculture performance during the 2011/2012 maize cropping season dry spell in the Lake Chilwa Basin

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Keywords: Climate change and variability, water stress, smallholder farmer, rainfall

Introduction

Climate change and variability have made agricultural production especially for food crops such as maize unpredictable (Tadross, et al., 2005). Conservation Agriculture (CA) practice in Malawi has the potential for an increased soil, water and nutrient buffer capacity for a sustained stable productivity of rain fed crops such as maize. In this regard CA offers an opportunity to mitigate the effects of climate change and variability. The main decisive factor being the provision of an optimal environment in the root-zone to a maximum depth (Kassam, *et al*, 2009). Increases in mean dry spell length and reductions in rain day frequency have been experienced in Lake Chilwa Basin and across Malawi during the past rainfall season based on planting date and rainfall cessation. This suggests that changes are occurring at the start of the season, reinforcing the evidence that the start of reliable rainfall for planting has been getting late over the country (Hewitson and Crane, 2006). CA in the context of Lake Chilwa Basin Climate Change Adaptation Programme (LCBCCAP) is regarded as a timely intervention to be undertaken especially with the aim of improving productivity both on the farm and time management while at the same time protecting the environment. The study aimed at assessing the performance of CA in the wake of prolonged dry spell to spur adoption among farmers.

Materials and Methods

This paper is based on the findings from respondents who were randomly sampled from a listing of CA farmers being supported by LCBCCAP within an extension planning area (EPA). The other respondents who are not practicing CA were randomly selected from a village listing and purposely from an EPA as a control in order to compare the perceived field performance of existing farming practices especially when fields have not received a minimum moisture of 25mm of cumulative rainfall in 10 consecutive days required to sow and grow maize. Thus, a total of 106 farmers were interviewed across the basin: 85 CA practicing farmers (who also practice conventional farming) were randomly sampled from 267 CA farmers that were then being supported by LCBCCAP. Twenty one (21) conventional farmers were randomly sampled from the entire basin community and this was used as a control group. Interviews were conducted from 6 to 10 February in all the hotspots. Rainfall data from October 2011 up to February, 2012 was collected from records maintained at the EPA. This rainfall data is from standard rain gauges installed in the EPAs within the Lake Chilwa Basin. The rainfall data has been used to determine the extent to which soil moisture became limiting for maize planting and growth. Field observation was also used to assess how CA was faring under moisture stress condition.

Results and Discussion

CA performance during the dry spell. Most respondents (83.9%; n=106) noted that CA fields survived the water stress condition that was created due to the dry spell that was experienced for the minimum period of 10 days after planting maize. Some respondents (52%) attributed this to CA farming technology being resilient while others cited soil type that could retain little moisture available for crop use (16.1%; n=106) and time of planting that coincided with the next rains within 10 days of planting (25.5%; n=106). Field observations too confirmed that CA fields, though in the first year of practice had survived the dry spell although the impact of the dry spell could not be completely eliminated.

CA in the wake of dry spell. The survey revealed that 81.4 % (n=106) of farmers that were interviewed practice CA. It further showed that 31.4% of respondents planted their maize in December with the majority (94.1%; n=106) using hybrid seed. Most respondents (61.3%; n=106) indicated that it took two weeks before the next rains came after planting. The dry spell was seriously felt in October and November because towards the end of December the rains had resumed normally. In this case 37.3 % (n=106) of the respondents indicated that maize crop was showing signs of water stress through wilting at the onset of the second rains after planting. The study observed that CA farmers (77.1%; n=106) did not bother to uproot or replant their fields since the state of the maize crop was not worrisome and the crop was able to gain vigor thereafter. According to Thierfelder and Wall (2009), one of the benefits of CA in water stressed condition is improved rainfall-use efficiency through increased water infiltration and reduced evaporation from the soil surface.

Rainfall trend over the dry spell. Cumulative rainfall data recorded from October to early February across the basin EPAs show that the year did not receive good rains when it was expected. All the EPAs under study, did not receive minimum moisture of 25 mm of cumulative rainfall in 10 consecutive days required to sow and grow maize. This meant that October and November was not the right time to plant maize as the months experienced dry days where observed rainfall did not exceed 2 mm in the following 20 days.

Maize production prospects from the study. The study revealed a mean maize yield prospect of 550 kg from 0.2 ha which was found to be an average land holding size for the respondents. The distribution of the yield results (Figure 1) is positively skewed (Skewness = 2.3; Kurtosis = 7.13). The mean maize yield prospects translate to maize production of 2.9 t/ha which is an increase gain from the recorded 1.5 t/ha that smallholder farmers normally harvest. This supports findings from a study by Kassam *et, al*., (2009) in which CA was able to withstand water stress conditions through strict application of the three principles to sustain stable yields.

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Figure

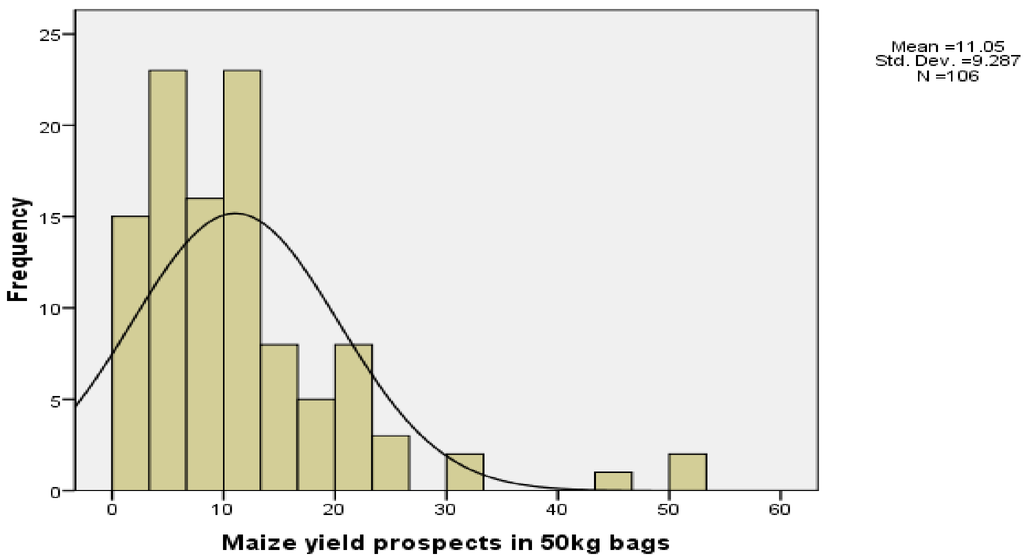

Figure 1: Maize yield prospects in 50 kg bags

Maize yield and greenhouse gas emissions potential of Conservation Agriculture at Kolero, Tanzania

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Keywords: Agroforestry, CAWT, Climate change mitigation, Double digging, and Soil fertility

Introduction

Conservation agriculture (CA) has been found to increase crops yields, carbon content in soils, and maintain soil moisture suggesting it can improve soil fertility and enhance resilience of farming system by improving soil health and minimizing drought related impacts on crops yields (Goddard et al. 2008). When CA is integrated with soil and nutrient management techniques on highland areas like Kolero, it can enhanced further crop production even in highly degraded soils due to the interactive effects of improved plant nutrition and soil moisture relations. In this way CA may be considered ‘climate-smart’, i.e., the agricultural practice which produces triple wins: improve livelihoods, mitigate greenhouse gas emissions (GHG), and increase adaptive capacity of farmers and agro-ecosystems. However, there is limited information on the mitigation and/or emission potential of CA-based farming systems in SSA. The objective of this study was therefore to examine soil nutrient dynamics, maize yield and GHGs emissions in CA within the project on Mitigation for Climate Change in Agriculture (MICCA) in Kolero, Tanzania. Besides food crop production, this work will contribute to understanding of mitigation and/or GHG emissions potential of CA.

Materials and Methods

This study was conducted at the Centre for Sustainable Living (CSL) in Kolero, Tanzania, located in the Southern Uluguru Mountain Range (37°48' E, 07°015' S). Temperature varies between 22 and 33°C and annual precipitation is 1800 mm. Precipitation falls in a bimodal pattern. The long rains start in early to mid-March to June. The short rains start in October to December. The experiment was laid out in a randomized completely block (RCBD) design with three replications. Treatments were: 1) conventional farming practices (Cultivation), as a control, and CA-based treatments, i.e., 2) double digging + mulching along maize rows only (Mulching), 3) double digging + Lablab as a cover crop (Lablab), 4) double digging + *Gliridia sepium* (Gliridia), and 5) double digging + N-fertilizer (Fertilizer). Double digging is a form of reduced tillage which involves cultivating to twice the depth reached by a hand hoe (Ca. 30cm). The CA plus *Gliricidia* treatment is also known as Conservation Agriculture with Trees (CAWT), a form of climate smart agriculture practice combining the advantages of CA and agroforestry to sustain agricultural productivity (Garrity et al., 2010). Treatments were selected to reflect practices currently being used (#1, 2), how CA is largely being implemented (#2), how CA is being promoted (#3, 4), and general recommendation based on research across Sub-Saharan Africa (#5).

The site was prepared according to the prescribed treatments. Double digging was conducted along the maize planting row. Maize seeds were planted at a spacing of 30 cm by 75 cm in 3m x 5m-plots. The plots were separated by the 2-m unplanted buffer strips. In each season, Lablab was intercropped between rows of maize 2 to 3 weeks after maize planting. Seedlings of *G. sepium* were planted at a spacing of 1 m x 1m. The shrub was regular pruned (approx. at 2 weeks interval) during the growing seasons to minimize aboveground competition. The foliage biomass was sub-sampled for dry matter and nutrient analysis and then evenly spread in the plots as green manure. Similarly, crop residues after harvesting from each plot were retained on-farm and evenly spread as mulch according to the prescribed treatments; except for cultivation (no mulch was applied). For the mulching in row treatments, mulching was confined to maize rows only. Soil samples were collected at random locations within each plot for site characterization. Maize grain samples were harvested from the net plot areas matter (1.5 cm by 4.5 m), oven dried at 70^0C to constant weight, and the results expressed in Mega gram per ha (Mg ha^{-1}). Gas was sampled using a syringe from the pre-installed chambers stored in the vials and shipped for CH_4 and N_2O analyses using Gas chromatography (GC). The dynamic chamber technique was used for carbon dioxide (CO_2) and nitric oxide (NO) gas sampling. All GHGs measured were expressed in carbon dioxide equivalent (CO_2e) to compare treatments and quantity the global warming potential of treatments.

Results and Discussion

Maize grain yields are shown in Fig. 1. Overall CA improved maize grain yield compared to the conventional cultivation using a hand hoe in all seasons, except for the short rains in 2012. Significantly different, however, were in CA treatments where CA (double digging) was complemented with either N Fertilizer or *Gliricia sepium* as noted for the long rains of 2012 and 2013 seasons. Relative to the control, percentage maize grain yield across the three seasons averaged 26 % for *Gliricidia* and 44 % for fertilizer compared to 3 % and 6 % for Mulching and Lablab treatments, respectively. These results suggests that maize grain yield were driven more by nutrient inputs from the CA treatments than biophysical advantages (e.g., improve soil moisture and root proliferations) of the double digging. Recent review also suggest that in a shor-term, effects of CA on crops yield may be masked by other biophysical factors like soil compaction and completion from weed (Broudera and Gomez-Macpherson, 2014). The CSL site at Kolero is located at the bottom value which may have masked the moisture effects of the double digging since the soil remains relatively high in most of the maize growing period during the season. The CA-based treatments also showed variations in the GHGs emission (Table 1) with the lowest GWP obtained by CA + Fertilizer (11.1 Mg CO_2e/ha/0.5yr) and the highest obtained by Gliricidia (15 Mg CO_2e/ha/0.5yr) and Mulching (14.1 Mg CO_2e/ha/0.5yr). Both *G. sepium* and lablab are nitrogen fixing plants used as cover crops to provide mulch for the CA. Thus higher GWP possibly reflect microbial conversion of fixed N and organic matter into N_2O CO_2 and other gases in these treatments. Fertilizer treatments on the other had had not additional mulch apart from maize stover from the same plot. Lower GWP is therefore may reflect of low microbial activities in this treatment because of low residue quality of plant material.

This paper demonstrate that CA-based practices in Kolero improved maize yield by up to 44 % when integrated with N fertilizers and leguminous trees/shrubs or cover crops like *G. sepium* and lablab. However, the effects reduced tillage may have limited advantages on this site as maize yields in the double digging treatments were similar to the control (conventional cultivation or farmers practice). As noted by the highest response in CA practices amended with *N-fertilizer* or G. *sepium*, maize yield trend reflected the nutrient response. Comparatively high GHGs emissions potential of *G. sepium* and lablab based CA practices may suggest that one need to consider the GHGs emissions potential of leguminous trees and/or herbaceous legumes integrated in CA for building soil health and/or nutrients.

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Figures and Tables

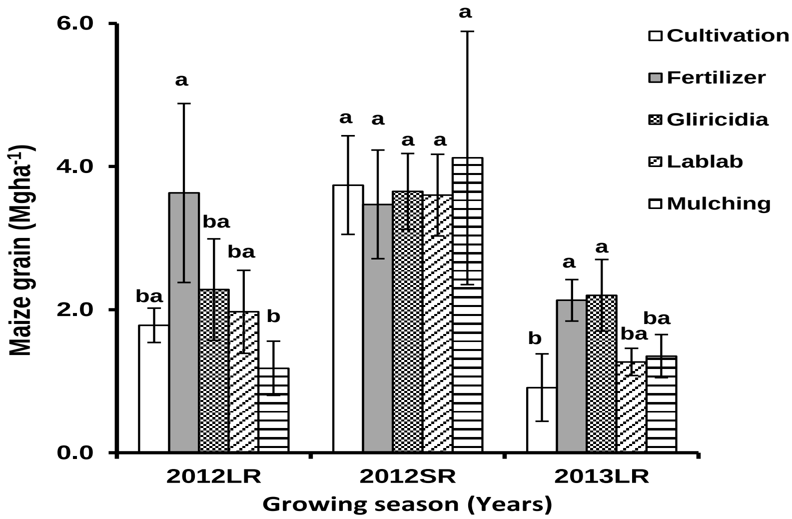

Figure 1: Maize grain yield under various conservation agriculture based practices at Kolero, Tanzania for the long rainy (LR) and short rainy (SR) seasons in 2012 and 2013 growing seasons. Means within a season followed by the same letter are not significantly different at α = 0.05 according to Tukey's Studentized Range (HSD) Test. Vertical bar indicate standard deviation (SD) of the mean (n = 3)

Table 1: Global warming potential (GWP) for CA-Based Practices in Kolero, Tanzania in the 2013 Long rain season

Treatment	GWP (Mg CO_2e/ha/0.5yr)
Cultivation	13.5*
Fertilizer	11.1
Gliricidia	15.0
Lablab	14.1
Mulching	13.2

*Mean value based on the descriptive analysis of preliminary data

Sub-Theme 3: CA for sustained wealth creation – unlocking barriers to entrepreneurship along the value chains

Conservation Agriculture as a commercialisation tool for smallholder farmers

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Keywords: small holder commercialisation, increased income, market links

Introduction

Smallholder farming in Africa is largely subsistence based, with little or no market integration for most farmers and very few farmers generating income from their farms. As most small holder farmers do not generate sufficient income from their farming activities they are not able to invest much in farm inputs, infrastructure and this keeps productivity at subsistence level. Due to the low and unreliable production of the smallholder (one word) sector, the private sector has no motivation to invest in it. Overall farmers stuck at subsistence level as investments for improvements are not generated and various input support programs may increase production (not productivity) in the short term, but have no long term impact on productivity and viability. Farmers have no funds and/or access to funds for mechanization, irrigation, improved inputs as no funds are available.

However, many smallholder farms have the potential to generate income, if they would be utilized efficiently, (repetition) Interventions which do not require major investments can improve productivity and break this cycle. Conservation Agriculture (CA) in the right context will improve production and productivity, as farmers are able to be timely and precise, significantly, without capital requirements, therefore provides the perfect basis for increased productivity. The use of CA will not only increase the crop outputs through improved agronomy, but also offers an opportunity for many small- holder, resource-poor farmers to enter into market linkage arrangements, as production becomes more reliable[7].

In this context CA offers a reliable low costs (as initially it can be done without any capital investments) entry into precision farming, improving productivity and reducing production risks, without the need for capital investments (specially: machinery like tractors harrows and ploughs), giving small holder crop farmers and ideal opportunity to commercialize their farming. CA for small holder farmers is a relatively new intervention; it was introduced in the southern African region initially, complementing humanitarian (food security) input programs from the mid-2000, to enhance the impact of seed and fertilizer support. The intention was to improve agricultural productivity, improving the livelihoods and smallholder farm-based food security. Additionally CA was (is) pushed as a drought mitigation strategy for farmers in dry areas and as a method to improve small holder ability to produce more food (cereals) for their own consumption, but not for its commercial potential[8].

CA is an efficient and cost effective technique also for resource-poor crop farmers, to prepare and manage their lands, mechanised or manual, effectively, economically and timely. Also farmers can utilise high standard, without depending on third party support or expensive equipment. CA is enabling farmers through the use of good farming practices and being able to improve on timing and precision to reduce risks and use resources more efficiently thereby increasing productivity, yields and income in a sustainable way, through improved timing and

[7]Small holder maize and cotton project in Zambia and Zimbabwe confirm this.
[8] FAO Zimbabwe and southern Africa

precision, which are the most important aspect for improving and maintaining productivity. Through the CA introduction on the back of humanitarian food security interventions to resource poor and food insecure farmer's, 'better of' farmers were excluded, further diverting from the economic value.

Material and Methods

The paper is a summary of CA work in Zimbabwe, Zambia, Swaziland and Kenya, since 2004

Results and Discussion

With the currently very low productivity and small farm areas it will be impossible to achieve surplus production and commercialize for most farmers, leaving millions of households and ha specifically in Africa extremely underutilized. Additionally weak organizational structures of small holders, poor infrastructure and perceived huge investment requirement and high risks hamper private sector and small holder partnership.

However, production potential of many small holder farmers is much higher than current levels indicate if farmers could without major investments achieve cereal yields of 3 or more MT/ha of cereals these farmers would not be food secure, but able to sell and generate incomes from their farms. With increased cereal production many small holders could produce sufficient food from a part of their land could use some of their lands for cash crops. This would result in market integration and better interaction with markets, some farmers would eventually produce exclusively for markets and buy food crops from markets or neighbours. Also the increased income generation and circulation in the farming communities would generate spill off income.

In order to realize this, interventions would need to be modified and stakeholder involvement (specifically private sector) broadened. However funding and investment requirements would be enormous, unless options for improving productivity with low investments are utilized.

Sustainable productivity improvements would need to address all bottlenecks affecting farming simultaneously and the involvement of all stakeholders including the private sector and farmer organizations. Intervention focus has to be on farmers' training and improved farming standards (management/agronomic practices), on input and output markets, while at the same time policy lobbying for incentives and an enabling environment is critical.

In order to accomplish this:

- Farmers would need to improve yield levels swiftly, sustainably and without major capital investments.
- Farmers need to be integrated into input and output markets
- Farmers need to be organized into groups to utilize (exploit) economies of scale and improve bargaining power and easy interactions with partners
- Farmers would need to have access to funding (credit) systems
- CA is being promoted throughout sub-Saharan Africa as a response to low productivity levels and as an alternative to traditional tillage practices, which have kept small holder farmers out of commercial production as investment and maintains costs for traditional tillage are unaffordable.
- CA is also reducing smallholder farmers' vulnerability to climate risks as timely and precise planting reduces climate risks. CA is enabling farmers to circumvent low

draught power ownership levels, and combating increasing levels of soil degradation and loss of fertility.

  - The above is resulting in increased productivity and reduced yield fluctuation, both increasing profits and reducing risks for private sector. With this in combination with specific support improved buy-in of the private sector will offer farmers the opportunity to integrate into markets and generate income.
  - In this context the appropriate use of CA offers many farmers to option to generate income from their farms and contribute to the economies.
- Given the vast potential of small holders in Africa, adaption and adoption of CA offers a very good tool to unlock huge farming potentials in the region

Due to rather large scale CA interventions with parallel input (seed & fertilizer) support, CA was 'taken up' swiftly, by those farmers as they wanted access to inputs, rather than seeing the benefits of CA. As to whether the uptake of CA would have been as fast without inputs remains questionable, also the real benefits (timing and precision, drought tolerance due to timely planting and mulch) were not the main value to farmers, but access to input. The exclusive focus of CA roll-out on poor households and exclusion of perceived better of (productive farmers) did certainly hamper uptake and adoption, as CA is now seen by many as 'poor farmer's technology', not to be done by good farmers (Where did this happen?). Also now farmers seen in the fields doing planting holes by hand are seen as backward and some policy makers tend to see this CA moving farmers backwards from advanced technology. Additionally poor and resource constraint farmers are not seen as role model to follow for others and do not have the capacity, status and resources to convince others, often farmers with more resources stay away from the poor farmers. How widespread is this perception?

However as CA is resulting in increased productivity and reduced yield fluctuation, both increasing profits and reducing risks (cite reference), a rebranding and refocus on commercial potential will be needed. This would need to be specifically targeted to the private sector and policy makers demonstrating the immense potential of small holder farming with CA forming the basis for improved agricultural practices. The appropriate use of CA offers many farmers to option to generate income from their farms and contribute to the economies.

Given the vast potential of small holders in Africa, adaption and adoption of CA offers a very good tool to unlock huge farming potentials in the region.

Table 2: Increase in income of sorghum through reduced land preparation and planting costs and increased precision through CA

	Conventional			CA		
	yield target			yield target		
	0.5	1	2.5	0.8	1.5	3.0
Ploughing (animal drawn)	75	75	75			
Discing (animal drawn)	50	50	50			
Planting (hand)	25	25	25			
Spraying (x 1, conv, x 2 CA)	25	25	25	50	50	50
Harvesting	50	75	75	50	75	75
Direct seeding (animal or 2 wheel tractor)				60	60	60
Costs to planting, spraying , harvesting	**225**	**250**	**250**	**160**	**185**	**185**
Insurance (weather based index, 13% of input value	1	7	14	2	7	14
Labour (other)	20	40	80	20	40	80
Planting , spraying harvesting	225	250	250	160	185	185
Packing, 50kg bags @ 0.45/bag	5	10	20	5	10	20

Transport of produce	5	10	20	5	10	20
Inputs (seed fertilizer etc.)	10	50	110	15	50	110
Total Cost/ha	266	367	494	207	302	429
Return (@ $400/MT)	200	400	1000	320	600	1200
Profit, Loss/ha	**-66**	**34**	**506**	**113**	**299**	**771**

Table 3: Increase in income of Maize (fully mechanised) through reduced land preparation and planting costs.

	conventional			CA		
	yield target			yield target		
	3.5	5	6	3.5	5	6
Ploughing	150	150	150			
Discing	100	100	100			
Planting	50	50	50			
Spraying (x 2, conv, x 3 CA)	50	50	50	75	75	75
Harvesting	150	150	150	150	150	150
Direct seeding				100	100	100
Costs to planting, spraying , harvesting	**500**	**500**	**500**	**325**	**325**	**325**
Insurance (weather based index, 13% of input value	53	68	85	53	68	85
Labour	130	130	130	130	130	130
Planting , spraying harvesting	500	500	500	325	325	325
Packing, 50kg bags @ 0.45/bag	32	45	54	32	45	54
Transport of produce	35	50	60	35	50	60
Inputs (seed fertilizer etc.)	408	523	653	408	523	653
Total Cost/ha	1158	1316	1482	983	1141	1307
Return (@ $300/MT)	1050	1500	1800	1050	1500	1800
Profit, Loss/ha	**-108**	**184**	**318**	**67**	**359**	**493**

Sub-Theme 4: Food sovereignty – integrated CA based systems and family farms

Ecological organic agriculture and conservation agriculture: Harnessing the synergies and opportunities for enhanced family farming in Southern Africa

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Key Words: organic farming, ecology, family farming

Introduction

More than 60% of the population in Southern Africa rely on agriculture for their livelihoods and the majority farm in generally marginal areas. Despite recorded increases over the years, e.g. in Malawi and Zambia, statistics (FAOSTAT, 2014) show that mean maize (*Zea mays* L.) yields have generally remained low compared to global levels. The low and fluctuating yields are attributed to poor soil fertility (Bationo et al., 2012), poor rainfall, biological, and technological as well as socio-economic constraints faced by most smallholder family farmers. This negatively impacts on household food and nutrition security and national development: stunting is highly prevalent (~33% in Zimbabwe, ~45% in Mozambique and Zambia, and >45% in Malawi) among children under the age of five (UNICEF-www.childinfo.org/country_list.php) while chronic hunger prevails in some areas. National and regional efforts are underway to increase and stabilize yields using various climate-smart and other technologies in the region. Conservation agriculture (CA)[9] and to some extent organic agriculture (OA)[10] has been promoted in Southern Africa by NGOs, farmer organizations, governments, parastatals, researchers, development partners and intergovernmental institutions. The goal for both is to ensure sustained food, nutrition and income securities of family farming households while conserving natural resources and contributing to national development. Currently global scientific evidence on the effectiveness of reduced tillage in organic systems is limited (Gattinger et al, 2011). To date, CA and OA have largely been promoted in Southern Africa with little integration and potential benefits of an integrated CA-OA approach remain largely untapped.

Objectives

[9] According to the Food and Agriculture Organization of the United Nations (FAO), the principles of CA are i) minimized mechanical soil disturbance, ii) practicing crop rotations or mixtures, and iii) maintaining an organic soil cover

[10] According to the International Federation of Organic Movements (IFOAM), 'Organic Agriculture is a production system that sustains the health of soils, ecosystems and people and relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects'. Organic Agriculture in this paper is interchangeably used with ecological organic agriculture (EOA), as endorsed by the African Heads of State and Government in 2011 in support of OA promotion

The objective of the present review is to identify and highlight potential complementarities, synergies and challenges which could emanate in as far as productivity, profitability, as well as food, nutrition and income securities, and environmental services are concerned if smallholder family farms in Southern Africa applied OA and CA principles and practices concurrently.

Approach

Literature, particularly published documents involving meta-analyses or reviews on OA and CA, was reviewed. The personal experiences of the authors were also applied in the review synthesis.

Results and Discussion

Potential synergies exist for an integrated CA-OA production system as follows:

i) *Risk mitigation and addressing food insecurity, poor soil fertility and soil degradation:* Both CA and OA have led to some yields increase (Tables 1and 2) or guaranteed some harvest under challenging growing conditions (Baumhardt, 2003; UN Report, 2008; Twomlow et al., 2008; Haggblade and Tembo, 2010; Chikowo, 2011; Marongwe et al., 2011; Arslan et al., 2013; Ndlovu et al. 2013; FAO, 2013; Rodale Institute Report, 2013; IFOAM, 2013). From 114 organic and 'near organic' projects in Africa, average yield increases of 116% were reported, with up to 179% increase reported for Kenya (UN Report, 2008). In semi-arid Namibia, higher organic matter content, better infiltration and substantial yield increases of up to 3,000 kg ha^{-1} have been recorded under CA compared to the conventional average of <300 kg ha^{-1} (Smith, 2014, unpublished). In his review on CA, Dubreil (2011) concluded that reduced tillage seemed to have greater impact on soil moisture and erosion control than soil chemical fertility. Enhanced soil fertility through rotations with N-fixing food and non-food legumes led to higher yields under CA+legumes systems (Dubreil, 2011; Lubozya, 2013). Seven-year long case studies from Tigray, Ethiopia, and four-year long studies from Kouaré, Burkina Faso, confirmed the benefits of applying compost or manure to degraded fields in comparison with chemical fertilizers alone (Edwards et al., 2007; Bationo et al, 2012) whose efficiency is low in highly degraded soils. Soils managed organically have a good structure with 20-40% higher aggregate stability (Mäder et al., 2002) and 15-20% higher infiltration rates (Rodale Institute Report, 2013), and are better able to support plant growth and other processes. CA resulted in higher infiltration rates in Zambia and Zimbabwe (Thierfelder and Wall, 2009). Organic CA could help to arrest or reverse degradation and restore future productivity in arable soils of Southern Africa.

Yield gains alone do not fully depict the potential benefits from CA and OA and their integrated scenarios. Forster et al. (2013) reported higher economic returns from organic cotton-cereal based systems in India despite the lower yields and Mazvimavi (2011) reported similar findings for CA. The prevailing high levels of stunting in children under the age of five in Southern Africa partly highlight the underlying long-term problems of inadequate consumption and low dietary diversity among other constraints. CA and OA potentially diversify family diets from own produced legumes, fruits, root and other crops in space and time, livestock integration, and through income generated from market oriented production. Chances of higher dietary diversity and food intake can be speculated under integrated CA-OA while reduced use of synthetic chemicals could help to increase food safety and to reduce accidental direct and indirect poisoning to humans and animals.

ii) *Ecological and environmental services and functions:* In their meta-analysis involving 94 studies, Tuck et al. (2014) found 34% higher species richness in organically managed systems with higher diversity recorded in landscapes where land-use intensity was greater. An integrated CA-OA system could help to conserve beneficial insects (pollinators, biological control agents, etc) while enabling smallholder farmers to harvest a diversity of crops as part of risk mitigation strategy. Weed suppression through green manures in an ongoing trial (TILMAN-ORG)[11] shows promise and under organic management in temperate conditions (Cooper et al, 2013, unpublished).

Soil organic matter, soil organic carbon (SOC) and greenhouse gas (GHG) fluxes: A recent meta-analysis based on 74 published long-term system comparisons revealed higher SOC stocks and higher C sequestration (0.55 Mg C ha^{-1} yr^{-1} compared to 0.090 Mg C ha^{-1} yr^{-1} in non-organic systems) in organically managed soils (Gattinger et al., 2012), Table 3. An earlier meta-analysis of C stocks under reduced tillage conditions by Gattinger et al. (2011) showed positive C gains only in the top 10-20 cm of the soil possibly due to poor incorporation of organic matter into the soil when tillage is reduced. In their 2009 review, Niggli et al. showed that properly managed organic systems had positive impacts on soil carbon. It can be speculated that SOC stocks could be higher in top and sub soil horizons under an integrated CA-OA.

Meta-analyses of the non-CO_2 emissions from soils under organic and non-organic management showed lower nitrous oxide (N_2O) emission per hectare and higher methane (CH_4) uptake rates in organically managed soils (Skinner et al., 2014), Table 4. Expressed in yield terms, the N_2O emissions were higher under organic management. The authors attributed this to the yield gap under organic management, which if reduced to only 17 % for productive regions (and to 16% in developing countries – de Ponti et al. (2012)), would balance out the yield-based emissions to current non-organic levels provided emission factors do not change much. An integrated CA-OA could help reduce emissions through a reduction in the yield gap (Skinner et al., 2014) and lower overall system GHG emissions as supported by findings from a long term research trial at Rodale Institute, USA.

iii) *Potential market integration through integrated CA-OA:* Both CA and OA bring together farmers, public and private value chain players through the vertical and horizontal integration created in the agro- input, services, and output markets. The availability of output markets promotes increased CA and OA adoption as would happen under conventional. Arslan et al. (2013) found higher probability of CA adoption and practice intensity in Eastern Zambia in villages with a higher number of produce selling points. Smallholder farmers engaged in certified organic export production in East Africa had higher net farm income earnings compared to those in conventional (IFOAM, 2013). In eastern Zimbabwe, unpublished information from smallholder organic CA farmers indicates greater crop diversity, better access to niche markets, and improved soils. In Namibia, e.g., as of February 2014 certified organic producers required 60 tons of organically produced feed for dairy and chicken production and more for human consumption. One could ask: Could future organic CA farmers produce for niche organic markets and potentially obtain premium prices? For example, could surplus cereals and legumes, together with suitable agroforestry species from future organic CA farmers be used to produce organic livestock feed in Namibia and other countries while the animal manure generated helps to boost crop yields?

[11] A research project conducted by an European consortium funded by the EU core organic program..

Potential challenges of an integrated CA-OA approach have been identified and are as follows:

i) Yield gaps: Contrary to some yield increases reported in organic and CA case studies from Africa discussed in the preceding sections, cases of lower yields have been recorded in transition and established OA and CA phases. For example, results from three independent meta-analyses reflect lower mean yields in organic systems compared to conventional: -20% (de Ponti et al., 2012), -25% (Seufert et al., 2012), and -26% (Skinner et al., 2014) although variable, Table 5. Smaller (-17%) yield differences recorded under rain-fed compared to irrigated (-35%) conditions indicated better performance of organic under fluctuating moisture regimes (Seufert et al., 2012). Under CA-OA, one could speculate that yields will be higher due to better nutrient management and other synergies, but whether this can lead to overall efficiency of family farming in southern Africa is not clear: Ndlovu et al. (2013) concluded that increased CA yields from 15 districts in Zimbabwe did not seem to translate into increased system efficiency.

ii) Management of weeds and aggressive pests and diseases: Reduced tillage under large scale CA is often associated with increased use of herbicides for more efficient and effective weed control, Figure 1 (Gattinger et al., 2011) with potential negative environmental effects if the smallholder farmers use less degradable types. Giller et al. (2009) indicated that labour requirements for weeding in CA are higher without herbicides. In a study analysing 25 experiments, Farooq et al. (2011) concluded that CA can compare well with conventional systems but that more research was required to overcome CA limitations such as weed management. Initial findings from a project comparing tillage and green manures under organic and conventional management suggest that crops tolerated higher weed densities in organic plots (Cooper et al., 2013). Controlling some aggressive pests such as the African armyworm *(Spodoptera exempta),* African bollworm *(Helionthis armigera)* and certain diseases could be another potential challenge. This then raises the questions: How can smallholder farmers efficiently and sustainably manage weeds and aggressive pests/diseases under organic CA where both mechanical and chemical weed control as well as synthetic pesticides are restricted? Could this see an upsurge demand for genetically modified crops developed to tolerate certain harsh conditions? Or could this lead to development of more and greater use of technologies like the push-pull pest control system developed by the International Centre of Insect Physiology and Ecology (icipe) to control Stemborers and Striga?

iii) Managing organic sources of nutrients (manure, compost) and phosphorus: With most soils in Southern Africa being inherently deficient in key nutrients and the tendency of some to bind soil P, nutrient availability and management could be one of the major challenges under an integrated CA-OA system as supported by findings of Seufert et al. (2012) and dePonti et al. (2012). The observed poor performance of organic systems in more acidic conditions by Seufert et al., (2012) points to problems associated with availability, imbalances, and toxicities of nutrients. De Ponti et al. (2012) also concluded that yield gaps between organic and conventional systems arising from nutrient related constraints could be much larger at farm and regional levels than the 20% they reported from plots. Liming would be an integral part of the CA-OA system and so would be innovative methods and devices of effectively and economically applying and incorporating manure/compost into the soil under larger scale production. What would happen to poorly incorporated compost or manure – would significant N losses occur from the soil surface and would GHG emissions be higher under organic CA systems if on-site organic fertiliser and residue management is poor?

iv) Ensuring adequate quantities of organic sources of nutrients: Obtaining adequate quantities of soil organic inputs could be another challenge of an integrated CA-OA system in Southern Africa where biomass availability is limited by the unimodal rainfall pattern, frequent droughts, competition as livestock feed and fuel, termite attack, and other constraints. There are, however, opportunities to augment plant residues with household waste while also making more efficient use of animal manure. In Ghana, for example, municipal waste processing into compost reduces pollution and enhances availability of high quality organic fertilizers for peri-urban and urban agriculture.

v) Costs of certification: Would the need for certification, as required for some organic markets, potentially reduce CA-OA integration by some smallholder family farmers? Would the produce volumes under CA-OA warrant investments into certification by the farmers, or would Participatory Guarantee Systems (PGS), a form of certification for some local markets, suffice for most of them?

Conclusions and recommendations

While a considerable number of potential benefits exist from an integrated CA-OA scenario, there are also potential integration 'incompatibilities' between the two systems arising partly from their respective core principles. Strengthened efforts to combine CA and OA should be made to harness the collective benefits and explore how to minimize the potential conflicts and incompatibilities at farm level. Many questions remain unanswered as to the full extent of benefits and challenges which would be experienced by smallholder farming families in southern Africa under an integrated CA-OA system. All these questions could benefit from further dynamic research which is more objective and endeavours to address different and emerging challenges faced on smallholder family farms.

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Figures and Tables

Table 1: Maize yields from farms practicing conventional (CT), OA and CA in Zambia

Farming Methods	**OA**	**CT with <50% N**	**CT with >50% N**	**CA**	**CA+Legumes**	**CA+Herbicides**
Mean Yield (kg/ha)	**2,748.65**	1,295.12	2,667.96	2,175.64	3,519.17	2,903.44
Difference in relation to OA	—	-1,453.53	-80.69	-573.01	**+770.52**	**+154.79**

Source: Lubozya, 2013: *A bold positive value indicates that the method resulted in a higher average yield than that from OA*

Table 2: Yields and some economic benefits from CA and conventional production (CT), Zambia and Zimbabwe

Country	Source of Data	Enterprise	Season	Parameter	CA (Basin)	CA (Ripper)	CT
Zambia	Haggblade and Tembo, 2003	Cotton	2001/02	Yield (Kg/ha)	1,278	557	818
		Maize	2001/02	Yield (Kg/ha)	3,054	1,727	1,339
	Haggblade and Plerhoples, 2010	Farm level profitability		Gross Margins (US$/ha)	44	104	19.28
				Returns to labour ($/day)	1.32	2.65	1.28
				Returns to labour (kg/day)	20.27	47.61	30.27
Zimbabwe	Mazvimavi et al. 2010	Maize from 16 districts	2006/07	Yield (Kg/ha)	1,570		765
			2007/08	Yield (Kg/ha)	1,114		407
			2008/09	Yield (Kg/ha)	1,540		970
	Mazvimavi and Twomlow, 2009; Mazvimavi, 2011	Farm level profitability		Gross Margins (US$/ha)	213		61.22
				Returns to labour ($/day)	2.74		1.8
				Returns to labour (kg/day)	14.56		11.22

Table 3: Soil organic carbon (SOC) in organic compared to conventional production systems

Attribute	**SOC concentration (%)**	**SOC Stocks** (Mg C ha^{-1})	**C sequestration** (Mg C ha^{-1} yr^{-1})
With no soil bulk density measurements			
Overall comparisons	0.18 ± 0.06 higher (***)	3.50 ± 1.08 higher (***)	0.45 ± 0.21 higher (***)
Zero net input systems	0.13 ± 0.09 higher (**)	2.16 ± 1.65 higher (*)	0.27 ± 0.37 higher (ns)
Zero net input + annual external inputs	0.07 ± 0.05 higher (*)	1.83 ± 1.44 higher (*)	0.16 ± 0.25 higher (ns)

Source: Gattinger et al. (2012) based on a meta-analysis involving 74 studies

Table 4: Soil derived GHG emissions (nitrous oxide (N_2O) and Methane (CH_4)) from arable and grasslands

Basis for measurement	**Parameter**	**Organic Management**			**Non-organic Management**		
		Arable	Grassland	Rice paddies	Arable	Grassland	Rice paddies
Area based fluxes	kg N_2O–N ha^{-1} yr^{-1})	2.58	3.22	0.89	2.97	5.64	2.28
	kg CH_4–C ha^{-1} yr^{-1})	- 0.61	*	180.68	- 0.54	*	145.70

Source: Skinner et al. (2014) based on meta-analysis involving 12 studies

Table 5: Relative yields (OA as a % of conventional) reported for selected crops from selected meta-studies

Source	**Crop**	**Relative yield (%)**
Seufert et al. (2012). Meta-analysis using 62 scientific studies worldwide with 316 organic-to-conventional yield comparisons on 34 different crop species	Overall average	75
	Cereals	74
	Oilseeds	89
	Vegetables	67
	Fruits	97
de Ponti et al. (2012). Using a meta-dataset of 362 published organic–conventional comparative crop yields	Overall average	80
	All Cereals (range 40-145)	79
	Maize (range 60-141)	89
	Soybean (range 74-126)	92
	Potatoes (range 37-114)	70
	Other root crops (sweet potato, etc) (range 89-114)	105
	Tomato (range 21-140)	81
Skinner et al. (2014) : meta-analysis from 12 studies	Overall average yield	74

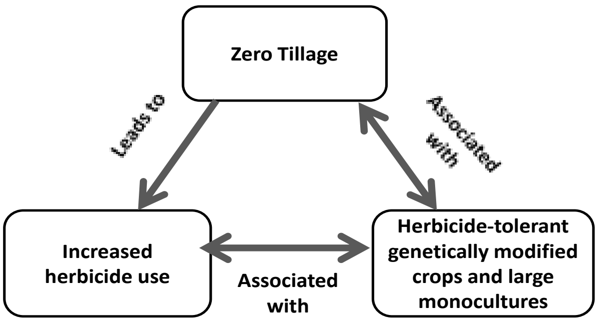

Figure 1: Interactions between zero tillage (= no-till) and increased herbicide use, herbicide-tolerant genetically modified crops and large-scale mono-cropping systems (Source: Gattinger et al., 2011)

Youth engagement in Conservation Agriculture and contribution towards sustainability in Zimbabwe

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Introduction

The youth population of Africa continues to grow unabated fueling hope that this young generation is the center of the continent's future. When youths address societal issues including agriculture and food systems, land tenure, markets and support systems, and environmental sustainability they create own businesses and worldview in the process. Both within and outside Africa, the question of how to feed an increasing population is fast becoming insignificant. The pre-occupation in food issues now is how to ensure consumers select and utilize food choices, rights, and sovereignty against a background of food abundance and food losses, even in smaller communities. This food abundance is necessitated by the growing access to global markets and food trade dynamics. Sustainable development (or sustainability) calls for a convergence between the three pillars of economic development, social equity, and environmental protection (Murphy and Drexhage, 2012). A new fourth pillar is good governance and personal security. Traditionally, sustainability programs were donor driven but this is rapidly changing given the emergence of savvy young people from Africa. There is a need for emphasis on opening young minds to new ideas and images, rather than on the accumulation of facts and information (Odhiambo, 1993). Young minds in Africa should be integrated in general problem-solving and learning processes. Problem-solving and learning processes foster the build up local intelligence, creativity, and innovation. The article investigates youth engagement in conservation agriculture (CA) and contribution towards sustainability in Zimbabwe. The premise is that immediately once any African nation has useful knowledge it has the capacity to solve pressing societal issues.

Rationale and frameworks for youth engagement in Africa

Current and proposed modalities. Farming must become more attractive and profitable for all who are involved in the different value chains, but particularly also for the hundreds of millions of small scale farmers and small to medium-size entrepreneurs in the developing world (UNSDSN, 2013). In Africa the population is predominantly an agrarian and rural one (70-80 percent), and over 85 percent of the rural dwellers can be classified as poor (earning less than US$ 370 annual income per capita). Most of them depend on agriculture for their livelihoods (Kruijssen, 2009). Furthermore, these people have little access to land or credit, and are served by inadequate infrastructural, educational and health facilities (Odhiambo, 1993). Agriculture is the backbone of Southern Africa's economies and at least 65 percent of the region's citizens live in rural areas and rely on rain fed agriculture. However, the sector's performance is adversely affected by climate change (Shumba et al, 2012). Agriculture thus remains vital for sustainable development, poverty reduction, and food security (Kruijssen, 2009). In particular, smallholder agriculture is pivotal for economic development (Chakeredza et al, 2008). The energy, resourcefulness and enthusiasm of the young people have the potential to lift the continent from its current challenges towards increasing socio-economic development (Gambari, 2013). Africa cannot fail the aspirations and hopes of its youth; rather it will have to build them through empowerment and full participation. Today's young people are considerably more educated and much more aware of global opportunities than was the case a decade or so ago, giving them high expectations of a better life (UNECA, 2011). Investing in creating and retaining a new generation of agricultural scientists and professionals including more women and young people will be vital for achieving any of the post-2015 agricultural development goals (UNSDSN, 2013; Pretty et al, 2010). Huge human resources gaps persist in many developing countries, particularly in Sub-Saharan Africa, but, with the exception of perhaps China and India, also in most countries of Asia (UNSDSN, 2013). The Pan-African Youth Strategy on Learning for Sustainability spearheaded by the World Wide Fund for Nature takes cognizance of other initiatives targeted at youth development across the African continent. The initiatives include the African Union Youth Charter and its accompanying African Youth Decade (2009-2018) Plan of Action – Accelerating Youth Empowerment for Sustainable Development (AU, 2011). The strategies and action plans must be developed, owned and driven by African youth themselves. They are the ones who will inherit whatever problems as well as opportunities that the current generation of decision-makers leaves behind (WWF, 2013).

Feasibility and challenges/limitations. Africa's youth bulge offers a range of opportunities (Filmer and Fox, 2014). There are approximately one billion youth (15-24 years) representing 18 percent of the total population that live in the world today according to the United Nations (UN). In sub Saharan Africa, young people under 30 years are the major population segment, especially where about 80 percent of the youth live in rural areas where agriculture is the principal occupation. Each year between 2015 and 2035, there will be half a million more 15-year olds than the year before. Meanwhile, the population in the rest of the world is, or will soon be, aging (Filmer and Fox, 2014). The International Labour Organization (ILO) has had the issue of youth unemployment on its agenda since 1935, and the UN Millennium Development Goal 8 has as one of its targets to 'develop and implement strategies for decent and productive work for the youth' (White, 2012). But neither the ILO nor other developmental agencies or national governments have any idea how to generate 'decent and productive work for the youth' on the scale which is needed. Given the growing success CA in developing countries farming communities, and its confines within the Rio+20 Conference endorsed concept of Sustainable Development Goals, CA can provide a viable livelihood for young people.

Youth engagement in conservation agriculture in Zimbabwe

Zimbabwe's agricultural revolution. Zimbabwe is divided into five natural regions, also known as agro-ecological zones on which most cropping patterns and livestock keeping is based. The major crops are tobacco, maize, soyabeans, cotton, sugar cane, wheat, citrus fruits, tea, and coffee (Nyoni, 2012). The agriculture sector provides employment and income for 60-70 percent of the population, supplies 60 percent of the raw materials required by the industrial sector and contributes 40 percent of total export earnings. (Nyoni, 2012). Many agriculturalists contend that the overarching mission of farmers is to produce food and livestock for a growing population, many food activists and non-governmental organizations contend that the primary mission of agriculture is to end hunger (Eicher et al , 2006). Technological innovations in agriculture are a powerful tool for increasing agricultural production and improving incomes (Muchena, 2006). Under the present circumstances CA is appropriate for the vast majority of resource constrained farmers and farming systems (Chidziya, 2011). CA emphasizes that the soil is a living body, essential to sustain quality of life on the planet. In particular, it recognizes the importance of the upper 0-20 cm of soil as the most active zone, but also the zone most vulnerable to erosion and degradation (Dumanski et al, 2006). In a study on determinants of CA adoption by smallholder farmers in Zimbabwe, one of the recommendations was for initiatives to target younger farmers who have no ingrained traditional farming practices and easily take up new innovations. Sustainable development could be attained by boosting agricultural productivity through CA (Chidziya, 2011). CA consists of three simple principles: disturb the soil as little as possible, keep the soil covered, and mix and rotate crops (IIRR and ACT, 2005). Furthermore, CA is widely recognized as a pathway to sustainability because of its minimal impacts on the soil. This feature makes it attractive to Africa's young people to remedy unproductive soils of Africa.

Current understandings, opportunities and limitations. Promoting agriculture for development presents a serious challenge of managing multiple agendas and collective interests of formal and informal institutions (the state, the private sector and civil society), and their inter relationships, their obligations, processes, mechanisms and differences (Pretty et al, 2010). The government's possible and multiple objectives in the agriculture sector include growth, poverty reduction and improved national food security (Maxwell , 1998). Currently, youth engagement in Zimbabwe is designed within the political discourse of the day. Nevertheless, youths have been the fabric of the family in African culture going through rites and rituals to pass into the leadership of men hood and woman hood. Historically, before and during the long and bitter war for Independence, youths were trained as girl guides and boy scouts to serve the White colonial masters. The youths also forgo educational opportunities. Generally, youths are not a homogeneous group hence their development needs vary according to their age groupings, geographical location, religious or ethnic affiliation, educational and cultural backgrounds. The decision to grow a particular crop is a highly individualized decision (Muchena, 2006). Farmers have no fixed philosophical position but look for practical solutions that can improve their livelihoods (Manzungu, 2003). The decision may depend upon the farmers' assessment about the quality of soil, climatic conditions, availability of seeds, availability of marketing facilities, cost of cultivation, availability of credit for meeting the cost, the size of holding, net return from cultivation of a particular crop, and so on. Farmer perceptions about the above factors are likely to be more effective determinants of the decision (Muchena, 2006).

Conclusions

Young people in Africa are equally resourced to address sustainability problems which are: economic development, social inclusion, environmental sustainability and good governance. When youths are engaged, their energy and enthusiasm pushes the continent forward. The concept of youth engagement in CA and contribution towards sustainability in Zimbabwe will meet the standards of the world counterparts given the open-mind of the government to technological innovation – CA. Youths are not a homogenous group; however, intelligent efforts applied locally have the potential to transform the global landscape especially with CA. Africa-wide agricultural development goals have to be complemented by existing youth frameworks and initiatives, owned and driven by the youth themselves. Technological change is feasible with the accompanying political will. The urgent focus on youths and the drive towards a mindset change and human resources build up signifies that young Africans mirror the African Renaissance.

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Methodology to make Conservation Agriculture a practical reality for the small-scale farmer

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Key words: Pfumvudza, Foundations for Farming, Planting Station, Conservation Agriculture.

Introduction

In Africa 33% of small-scale farmers are undernourished (FAO/WFP. 2010), this is largely due to poor farming practices. Traditionally small-scale farmers in Zimbabwe have cultivated approximately 2 Ha of land to provide enough food for their families, this is because the national yield is cited at less than 0.5 MT/Ha (Farming for the Future, 2009). This means that many farmers are not able to sustain themselves from the land that they are utilising, even though they spend many hours tilling and working the land. Most of the seed and fertilizer utilised is managed so inefficiently that it does not produce a viable return (Thierfelder and Wall, 2009).

Many well meaning Non- Governmental Organizations (NGOs), who understand that conservation agriculture (CA) is a sustainable solution to this predicament have provided inputs in an attempt to persuade farmers that this is a better form of agriculture. However, this often fails once the "carrot" in the form of free inputs is removed, with the farmers quickly reverting to their conventional methods, accepting soil degradation and yield decline.

Foundations for Farming has been a regional leader in the area of conservation agriculture for many years, and has had much success through its training techniques in convincing farmers that CA is a more sustainable way of crop production and improves yields. Due to the fact that CA is initially more labour intensive, if the same area of land is cultivated, many farmers are discouraged from continuing to practice CA (Farming for the Future, 2009). The major problem however is the perception held by farmers that they need to cultivated the same area of land, as with conventional methods, to feed their families. The Pfumvudza concept has been developed to change this perception and help farmers to understand that a much smaller area, is all that is required. This smaller area leads to a radical reduction in labour when operations are carried out on time, to a high standard with the efficient use of inputs and minimal wastage of resources. This can be sustainably achieved by using an affordable comprehensive pack of inputs. The resultant improved yields, reduced labour and better profit margins will encourage permanent adoption

The primary objective of this Pfumvudza initiative is that a family should feed itself. It removes the burden of excessive labour in terms of field preparation and collection of mulch material. It provides all the inputs required to produce a crop, yet is so simple that once farmers are envisioned they are no longer reliant on the inputs to be successful.

Materials and Methods

This new way of approaching food security at farm level which is based on the principles and practices of CA is called “Pfumvudza”, and literally means “New Season”. The Pfumvudza concept has resulted in the development of a very precise set of essential inputs. These inputs have been divided into two easily transportable 23kg packs, which have all the ingredients necessary to meet the needs of the Pfumvudza plot. Each pack includes 6kg of Agricultural Lime, 8kg of basal fertilizer, 1kg of maize seed, 2 x 4kg of Top-dressing, the relevant fertilizer cups and instructions.

A rectangular block of land (Pfumvudza trial plot), 16m by 39m was demarcated using permanent pegs, early in the season. All plant material in the block was then cut down, using a hoe. The plants were severed at ground level, with minimal soil disturbance. All this plant material was then evenly spread over the entire area providing a thick mulch layer (at least 30% ground cover).

Eight cm deep planting stations were dug in a matrix of 60cm by 75cm across the entire area. The in row spacing across the slope was 60cm and the between row spacing down the slope 75cm (Fig 1). The plot of 16m by 39m resulted in a total of 1,456 planting stations. The holes should also be dug with the soil being deposited on the downward side of the station (Fig 2). The field was kept weed free at all times.

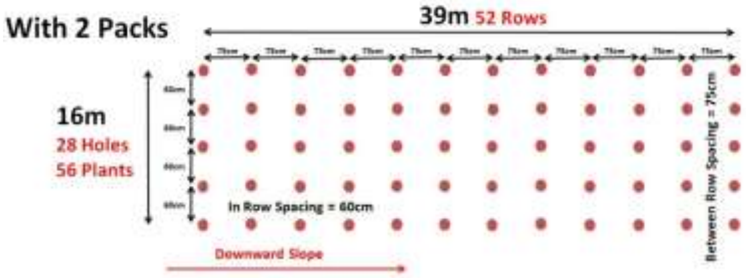

Figure 2. Planting Matrix

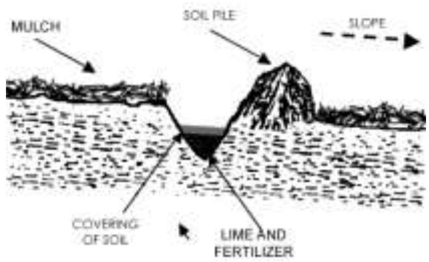

Figure 3. Cross Section of Planting Station

A 5ml cup of agricultural lime (from pack 1) was spread across the base of the planting station, then an 8ml cup of basal fertilizer (from pack 2) was added and carefully covered with a small amount of soil, maintaining a 5cm planting depth to ensure uniform emergence of the crop.

After the first effective rainfall (70mm after 15th November), (Oldreive, 2006) seeds were planted on 15th November. Three seeds were evenly placed within each of the planting stations, (from pack 3), at a depth of 5cm, then carefully covered with soil. The stations were levelled without depressions and covered with mulch.

Three weeks after emergence, when the soil was moist, thinning took place. The field was thinned to 2 plants per planting station, ensuring an optimal population of 44,000 plants/Ha. At the same time, the first of two split top-dressings was applied, (from pack 4), using a 5ml cup, 10cm from the plants on the upslope side. A second application was done once the crop began to tassel.

Results and Discussion

This plot was designed in such a way for a family to harvest a 20 litre bucket of maize from each row. This bucket of maize is adequate to feed a family of six for a week. There are 52 rows in the plot ensuring one bucket for each week of the year. To achieve this each of the 56 plants per 16m row must produce at least one cob weighing 250g. This has been proved possible on a small scale at our Resthaven Retreat demonstration plots, in Harare Zimbabwe. Table 1 below shows results from the only plot where measurements were made row by row. Verbal reports were made from 300 small-scale farmers, who were supplied the packs for the 2012/2013 season, and most claimed they were food secure for that year. During this 2013/2014 season a total of 12,000 of these packs have been planted and we eagerly await yield results, which can be compiled to support these claims.

Table 1. Average results from demo plot.

	No. of Cobs per row	Cob Weight per row (Kg)	Grain Weight per row (Kg)
Average	53.7	15.23	12.7

Pfumvudza is a concept, that was developed to feed a family for a year. It highlights the fact that by simply farming at a higher standard using CA, it is possible to feed a family from a very small area of land ($^1/_{16}$ Ha). However, it requires training, understanding and faithfulness to ensure success. With the confidence gained from the first year of successful production, farmers can expand gradually and become more profitable and sustainable. Most of the reasons why CA has a slow adoption in Africa can be eliminated using the Pfumvudza model. Increased labour is one of the main reasons for not adopting. In a hectare 22,000 planting stations are required, but a Pfumvudza plot only requires 1,456 stations. Women will no longer be over-burdened by a heavy work load. Ownership is another vital part of ensuring sustainability in any model. Thus to promote ownership farmers are encouraged to purchase these packs for themselves, reducing dependency. If compared to the costs usually incurred by a farmer to plant a hectare of maize the cost of 2 of these packs ($50) is very affordable. Mulch is often left out in CA practice simply because the task of gathering enough to cover a large area initially is too onerous. Due to the limited size of a Pfumvudza plot adequate mulch cover can be achieved, even if this means cutting and carrying it from an adjacent field. This small area can also easily be protected from animal grazing and fire. Rainfall also effects the standards of many farmers crops, either due to late start or dry spells during the season, which are alleviated by a good mulch cover. A dedicated farmer, who has taken ownership of his plot will even be able to apply enough water by hand if necessary, to a Pfumvudza plot. It is also a simple methodology, which can be achieved by following step by step instructions.

The design of the input pack by providing the convenience of all the inputs in one place, makes procurement and transport easy. Initially the pack helps in achieving success, but is not essential as farmers can use other available inputs (manure, compost etc). Pfumvudza is only a starting point into smallholder farmer food security where farmers are enlightened to the fact that to be food secure does not require large tracts of land, technology or machinery.

This concept is being applied to other crops, especially legumes which can be used in rotation as cash crops with maize, to improve soil fertility and reduce pest and disease challenges associated with mono-cropping.

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Impact of Conservation Agriculture on household food security and labour productivity in manual farming systems: Evidence from Southern Africa

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Key words: food security; impact; partial adoption; labour; innovations.

Introduction

Conservation Agriculture (CA), has been promoted as an agricultural technology capable of tackling a number of economic and agricultural challenges faced by smallholder farmers such as increasing food insecurity, and soil nutrient depletion in Southern Africa. Conservation agriculture is defined as "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment". It is based on three interlinked principles: a) minimum soil disturbance; b) surface crop residue retention and c) crop rotations (FAO, 2012). Although these technologies have been widely promoted in this region, empirical evidence have shown that adoption rates are low and often partial, the benefits for farmers remain highly debated and impacts seem to be context-specific (Baudron, et al, 2012; Arslan et al, 2013) Proponents of the technology argue that the whole system has to be adopted simultaneously for farmers to capture the synergies and full benefits [Gowing and Palmer 2008; Guto et al., 2011]. This implies that it is relatively unprofitable for farmers to adopt only one or part of the technology option. Anecdotal evidence, in southern Africa has shown that 75% of smallholders who practice CA rarely implement the CA systems comprehensively. Even where farmers implement all three CA principles, usually they do not follow the recommendations (e.g. sufficient ground cover and/or diversified crop rotations) as required to reap the full benefits. For example in Zambia and Zimbabwe, the few farmers that have adopted CA technologies tend to do it partially, either practicing some components or adopting CA on some plots but inconsistently (Umar, 2013; Mazvimavi and Twomlow, 2009). A limited number of studies have addressed the issue of partial adoption, its effects on maize production and labor use in manual farming systems [Van den Broeck, *et al* 2013]. Partial adoption of CA has been observed as a step toward full adoption in some cases , while in others it is an ongoing practice for farmers who mix and match diverse farming techniques as they see fit (Thierfelder, *et al.* 2013). Thus it is important to understand why farmers adopt some component of the CA system while they fail to adopt other aspects and evaluate the impacts of partial and full adoption on maize production and labour saving.

Materials and Methods

The survey that generated the data set used in this study was conducted in ten IFAD project communities practicing manual CA in the three Southern African countries – Malawi, Zambia and Zimbabwe were the International Maize and Wheat Improvement Center (CIMMYT) has on-farm trials to facilitate widespread adoption of CA technologies in maize-legume based farming systems. The manual CA seeding systems commonly practiced in southern Africa are dibble stick and planting basins. The data used in this study was collected in the 2011/12 cropping season using structured questionnaires from 469 randomly selected households and 1034 maize plots owned by these households.The endogenous switching regression framework was applied to evaluate the impact of adoption of these different components of CA on the expected food productivity. In addition, the control function approach and Heckman technique was used to estimate the impact of CA technology adoption on labour use and productivity.

Results and Discussion

The multinomial logit model results indicated that the probability of adopting different CA technology options was influenced by observable household, community and plot level characteristics. These included household head years of schooling, frequency of extension contact, private institutional extension support, credit access, number of years practicing CA and frequency of droughts. Increased access to education, credit and contact with extension personnel had positive and significant effect on the probability that farmers would adopt some CA technology. The results confirm other findings asserting that improved education, extension and credit access, private institution extension support and experience with the technology reduces uncertainty and risks associated with complex technologies whilst enhancing farmers' understanding and technical capacity of the technology (Mazvimavi and Twomlow, 2009; Taklewold *et al*, 2013). Number of years practicing CA, size of land operated and off-farm income positively influence partial adoption of CA technologies. These results imply that increased exposure of farmers to the technology can improve adaptation capacity and benefits derived from CA technologies. Thus investment in extension programs is of paramount importance in order to translate the underlying CA principles into practical advice (Taklewold *et al*, 2013). Proximity to input and output markets are important for enhancing adoption of different CA technology. These results confirm Umar's findings that smallholder farmers respond to economic incentives of agricultural innovations but market and institutional failure limit their responsiveness (Umar, 2013). Plot level characteristics such as soil type, fertility and slope helped to explain partial adoption of specific CA components. Farmers seem to prefer plots with high loam soil texture and slopes (>8%) for increased adoption of at least two CA components. These results support Wilkinson's findings that resource constrained farmers may use the comprehensive package in a particular niche on the farm to gain one particular benefit that maybe highly desired (Wilkinson, 1989).

The counterfactual analysis and treatment results showed that adoption of different CA technology components increases maize production per hectare. The results indicated that the impact of full adoption of CA technologies on household food production is greater for households that did not adopt (the counterfactual case had the adopted) relative to the actual adopters. The non-adopter would have increased their maize productivity by 43% had they adopted relative to the 31% of the actual adopters. The implication of these results is that the maize productivity and food security gains from the adoption of different CA technology components are higher for non-adopting households than for the adopters. Thus, these results suggest that the growing interest of donors and international organizations in promoting CA technologies particularly for the vulnerable households, those with the least capacity to produce food is in the right direction. Besides increasing maize production per hectare, adoption of different CA technologies also helps in smoothing consumption during periods of food deficit (hunger months January –March) and improves diets of these vulnerable households (Haggblade and Plerhoples, 2010). The labour saving effect of CA technology was significant with partial adoption of with at least two components. Reduced land preparation activities for those using dibble sticks and suppression of weeds by legume crops planted in rotations or associations might be a possible explanation of the labour saving effect (Rusinamhodzi, *et al.*, 2012). The labour saving effect of full adoption was not very significant probably because very few farmers adopted all the three principles consistently on their plots.

Figure & Tables

Table 1: Parameter Estimates of Maize Yield by Multinomial Endogenous Switching Regression Model (at plot level)

CA components/ Variables	**Minimum tillage only (N= 160)**	**Minimum Tillage & crop rotation/ associations (N= 180)**	**All 3 principles (N = 60)**
HHage	-0.015 (0.021)	-0.11 (0.015)	-0.006 (0.008)
HHedu	0.045 (0.009)**	0.138 (0.071)***	0.062(0.019)**
HHsex	0.126 (0.113)	-0.017 (0.006)	-0.023 (0.025)
Off-Income	-0.31* (0.47)	1.139** (0.583)	2.292*** (0.762)
extenconfreq	1.752*** (0.03)	2.345*** (0.011)	2.561*** (0.213)
Private institution extension support	1.624* (0.685)	2.316 (0.241)**	2.713 (1.40)***
Edu-other	0.85 (0.911)	1.03 (0.736)	1.59** (0.671)
Landope	0.39*** (0.26)	0.044* (0.01)	-0.145** (0.07)
Orgafli	0.489(0.217)	0.651 (0.340)	0.40 (0.081)
Inputmem	1.674 **(0.761)	2.891*** (0.391)	3.421*** (0.792)
Outputmem	1.342* (0.972)	2.751*** (0.87)	1.495** (1.021)
TLUs	-0.910(0.101)	0.851(0.661)	-0.375 (0.134)
Physical assets	1.091 (0.947)	-1.272 (0.839)	0.768 (0.817)
Credit	0.041(0.001)**	0.078** (0.061)	0.109*** (0.05)
Yrca	0.270 (0.48)**	0.39* (0.013)	0.337*** (0.028)
Maize variety Index	0.156 (0.113)	0.095 (0.155)	0.306(0.148)
Flood experience	-0.001(0.105)	0.744 (0.245)	0.218 (0.119)
Drought frequency	2.697***(0.820)	1.939(0.690)**	3.115 (1.153)**
outputdist	-0.086* (0.033)	-0.13* (0.018)	-0.017** (0.012)
inputdist	-0.24*** (0.015)	-0.079** (0.084)	-0.29***(0.032)
Medium soil Fertility	-0.071(0.023)	0.382* (0.016)	0.914** (0.417)
Low soil fertility	-0.514 (0.098)	0.749** (0.616)	0.409** (0.084)
Sandy loam	0.871* (0.645)	0.343 **(0.110)	0.919 **(0.667)
Clay loam	0.418*** (0.244)	0.141 (0.102)	0.877**(0.562)
High slope>8%	0.051 (0.023)	0.611*** (0.496)	0.728** (0.540)
Medium slope > 5%	0.103 (0.098)	0.314**(0.143)	0.446*(0.362)
Low slope < 5%	-0.487** (0.333)	0. 111(0.071)	0.217 (0.041)
constant	2.014 *(1.642)	2.674*** (1.225)	2.432* (1.061)
Wald $\chi2$ = 697.53; p > $\chi2$ = 0.0001			

Note: non-adoption is the reference category, standard errors in parentheses. Sample size: 1034 plots
* Statistical significance at 10% level, ** statistical significance at 5% level. *** statistical significance 1% level

Table 2: Average expected Maize yield per Hectare: Treatment and Heterogeneity Effects

Treatment sub-samples	Actual Maize Yield (kg/ha)	Counterfactual Maize Yield (kg/ha)	Treatment effect (Impact)
Non-adoption	1360 (245)[a]	2400 (150.5)	-1040 (166.3)***
Minimum tillage only	2680(385)[b]	1775(55.7)	902 (243.6)***
Minimum tillage and crop rotation/association	3100 (405) [c]	2150(165.3)	950 (80.9)***
All three principles	2870 (133.5)[c]	1950 (259.4)	920 (172.1)***
Adoption [12]	2980.33 (309.8)[d]	1958(183.6)	1022 (125.33)
Heterogeneity effects[13]	580**(25.7)	598 (60.87)*	-18 (30.9)*

Means followed by different letters a,b,c or d in a column indicate that the differs .Significantly at $p<0.05$ based on pairwise t test standard errors in parentheses. * Statistical significance at 10% level, ** statistical significance at 5% level. *** Statistical significance 1% level

Table 3: Impact of CA technology adoption on labour productivity and labour Use

Variables	Labour per unit of yield	Yield per unit of labour
Endogenous Variables		
Minimum tillage only	-0.006(0.001)	326 *(50.1)
Minimum tillage and crop rotation/association	-0.022 ***(0.01)	512.6 **(60.66)
All three components of CA	-0.019***(0.021)	491.34** (101.2)
Exogenous Variables		
Gender of the household head	- 0.22*(0.08)	17.3(0.021)
Household Head Education level	-0.039(0.005)	135.4 (22.8)
Log land operated	-0.023**(0.026)	-133.3(56.4)
Off- farm income (value)	-0.054 (0.037)	225.7 *(20.9)
Residual from adoption of 1 component of CA (=Residual #1)	-0.08 (0.006)	315 (113)
Residual from adoption of 2 components of CA (=Residual #2)	-0.13* (0.11)	- 420 (90.3)
Residual from adoption of all components of CA (=Residual #3	0.067 (0.034)	270.33 (110.4)
Interaction term (Residual #1*order #1)	-0.005	65 (22)
Interaction term (Residual #2*order #2)	-0.028 (0.009)	45.1(10.3)
Interaction term (Residual #3*order #3)	-0.001 (0.0017)	52.6(18.3)
Constant	0.053 *(0.027)	202*(42.5)

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[12] Adoption = 1 average for all households that adopted CA components

[13] Calculated as the difference between the actual yield for the households that adopted and the counterfactual for the non-adopters. Transitional heterogeneity is the difference between the effect of the treatment on the treated- adopter (TT) and the effect of the treatment on the untreated- Non-adopters (TU)

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Conservation Agriculture adoption by cotton farmers in Eastern Zambia

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Keywords: land preparation, smallholder, constraints, multinomial-logistic regression

Introduction

Typically smallholder farmers in Africa have very low yields, use few modern inputs and their land is being degraded through erosion and nutrient mining (Todaro and Smith, 2009; Crawford et al., 2003; Morris et al., 2007). Improved agricultural technologies have the potential to increase smallholders' productivity and dramatically improve their quality of life (Pretty et al., 2011; World Bank, 2007). Conservation agriculture (CA) has been promoted throughout Southern Africa as a means of increasing yields and reversing land degradation (Rockstrom et al., 2009). Uncertainty about the adoption potential of CA has led to a polarized debate about the merits of CA (Giller et al, 2009). CA advocates assert that there is no other means of sustainably managing the soil (Kassam et al., 2009; Hobbs, 2006;), while critics point out the inadequacy of a single solution for the complex problem of land degradation on smallholder farms (Baudron et al, 2012; Wall, 2007).

This study adds empirical evidence to this debate by analyzing the factors driving farmer decision making about land preparation methods. The statistical relationships among economic and agronomic variables are supplemented by farmers' explanations about why they choose to use minimum tillage on some plots but not others, why they have disadopted or have never tried it. Assuming farmers are making rational decisions about CA use given their individual objectives and constraints, the hypotheses being tested are that labor, wealth, experience, soil characteristics, input availability and promotion may all constrain the use of CA. The goal is to determine the limitations of the CA technologies in order to focus innovation and adaptation. The focus of the study is on smallholder cotton farmers in Eastern

Province, Zambia, where adoption levels are relatively high. The results not only provide guidance on how to overcome constraints to CA adoption but also have implications for sustainable intensification efforts in general.

Materials and Methods

This research used a combination of qualitative and quantitative methods with smallholder farmers to obtain an in-depth understanding of the factors affecting their use of CA. In-depth interviews were completed with 50 farmers in 10 communities. The results of these interviews were used to develop a survey that was carried out with 326 farmers in 21 communities across Eastern Province. A complex survey design (including clustering and two levels of stratification) made possible the efficient collection of adequate data from a wide range of adoption levels. Thematic analysis was used to analyze the qualitative data. Plot-level econometric analysis was used with the quantitative data from the 775 maize and cotton plots of the farmers in the survey to ascertain the partial effects of a marginal change in each variable while holding the other variables constant. In this study the dependent variable is a categorical choice of land preparation (plowing, ripping, hoeing or basins) at the plot level. Plots were defined as contiguous areas with a single land preparation method and a single primary crop. A multinomial logistic regression was used to estimate how plot, household and community-level variables affect the probability that a plot will be prepared using any one of these four methods.

Results and Discussion

Drivers of CA use. Most farmers in this study who use conservation agriculture land preparation methods said that they changed to CA in order to address their concerns with inadequate and unreliable rainfall and because of the need for improved soil fertility, especially for maize plots. In the interviews many ripper farmers emphasized how ripping enabled them to plant early and it channeled the water into the rip lines thereby increasing the moisture available to the crops. Smallholder cotton farmers in general believe that basins and ox-ripping result in higher yields, better soil fertility, better crop performance during drought years and reduced erosion. Interestingly most also think that conventional tillage does better in wet years. There is less agreement about how the amount of work and weeds differ between minimum tillage and conventional tillage.

Adoption levels. Despite these benefits and generally favorable opinions about CA, adoption levels remain relatively low. Though over 50% of the farmers have tried some form of CA, only about 12% of cotton area and 20% of maize area were prepared using minimum tillage methods. Furthermore, 85% of ripped plots were banked (tilled mid season to control weeds) and less than 50% of basin plots had been under minimum tillage the previous year. This suggests that many of the long-term benefits of minimizing soil disturbance are not being realized.

Constraints to basin use. Farmers' opinions and the statistical analysis both suggest that labour limitations constrain the use of hand-hoe basins even relative to conventional hoe tillage. Basin plots are smaller on average than all other plots and are most likely to be planted to local maize. Basins also tend to be used on lower quality plots that are more likely to have white sand (poor quality) soils and to be ranked lower than other plots. Over one third of basin plots have manure added to them. Land constrained and labour-abundant farmers tend use basins as an intensive way of using their labour and manure to produce more maize on land that is not prone to erosion.

Constraints to ripper use. Ripping tends to be used by well-trained and better-off farmers in combination with herbicides. These farmers have the ability to invest in the new equipment and take the risk of trying a new technology. Plots are more likely to be ripped if the farmer has been trained, has more cotton experience or has received a more adequate demonstration of CA from the lead farmer in the community. Ripping rental markets are lower than expected, probably due to the need to conserve the strength of oxen during the dry season. Oxen must be vigorous enough to be able to rip through the dry season and overcoming this challenge would require improving animal health and meeting the dry-season nutritional needs of large oxen.

General constraints. Most farmers are of the opinion that crops under CA will perform sub-par in a high rainfall season or after high rainfall events. For this reason alone many farmers may choose to use a variety of land preparation methods on their land in order to mitigate the chance of complete failure in any given year. If they have to plant late, farmers prefer conventional tillage in order to eradicate the weeds that have grown with the first rains. Farmers may plant a plot late due to labour constraints, illness or for early maturing or highly drought-tolerant crops.

Conclusion

These constraints to CA use, combined with the diversity of smallholder cotton farmers and their livelihood strategies make it unlikely that CA adoption will take off exponentially. Nevertheless, providing effective farmer training on CA practices and making ripping equipment more available may help to increase CA adoption. Efforts to improve smallholder productivity should use participatory approaches to ensure that promoted technologies match farmers' resources and constraints. Providing farmers with a wide range of improved production practices will make it more likely that all types of farmers will find something that matches their resource endowments and allows them to be more productive.

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Figures and Tables

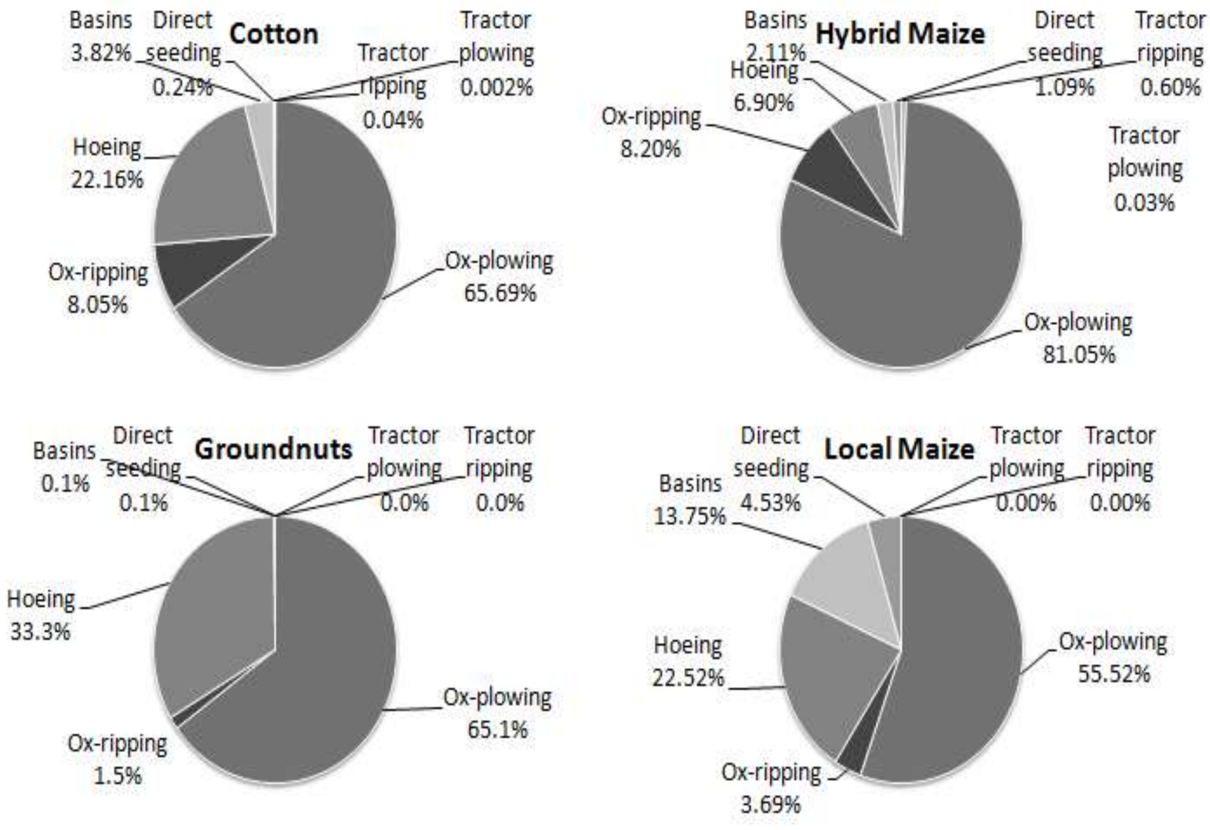

Figure 1: Percent of area under each land preparation method for the four largest crops

Table 1: Abbreviated list of factors affecting land preparation method decisions of cotton farmers[1]

Explanatory Variables	Plow vs. Hoe			Ripping vs. Plow			Basins vs. Hoe		
Plot Level	**β**	**Std. Error**		**β**	**Std. Error**		**β**	**Std. Error**	
Plot area (ha)	0.39		(0.54)[2]	-0.11		(0.24)	-2.34	*	(1.32)
Flat (Y/N)	-0.07		(0.46)	0.42		(0.42)	2.33	***	(0.77)
Rank Ratio	0.58		(0.96)	0.87		(0.92)	3.18	***	(1.19)
Tenure Secure (Y/N)	-0.15		(0.93)	0.54		(0.70)	-2.24	**	(0.98)
Household Level									
Trained in CA (Y/N)	1.96	***	(0.55)	3.89	***	(1.33)	2.16	**	(1.00)
Workers per hectare	1.02	**	(0.39)	-1.07		(0.81)	1.03		(0.71)
Wealth index	5.27	***	(0.78)	0.98	*	(0.54)	1.67		(1.19)
Cotton experience (Yrs)	0.04		(0.05)	0.13	***	(0.05)	0.13	**	(0.05)
Community Level									
Years CA promoted	-0.50	**	(0.22)	-0.15		(0.25)	-0.56	**	(0.25)
Buyer CA practice	0.61		(0.42)	0.91	***	(0.32)	0.36		(0.50)
Herbicides avail. (Y/N)	5.56	**	(2.19)	-0.31		(2.99)	-1.15		(1.73)
Pop. density (1000/km^2)	-1.84		(7.45)	15.7		(11.63)	-25.4	***	(8.47)

Observations	775	Wald Chi^2 (93) =	759.36	Pseudo R^2 =	0.6857
		Prob > chi^2 =	0.0000	Log pseudolikelihood =	-89,187

Source: survey of NWK and Cargill farmers, 2013

[1]The coefficients can be interpreted as follows: for a *m* vs. *n* comparison, a unit change in the explanatory variable is associated with a e^β change in the odds of a plot being prepared using *m*.

[2]* is for p < 0.1, ** for p < 0.05, and *** for p < 0.01, standard errors are in parentheses.

Pearl millet's root lengths and yields under conventional and conservation tillage methods in Ogongo, Namibia

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Keywords: Conventional tillage, conservation tillage, root length, yields, Namibia

Introduction

More than 70% of Namibia's two million people depend on agriculture for their livelihood. (Tjaronda, 2009). Pearl millet (*Pennisetum glaucum*) is the crop that is widely grown by small holder farmers in Northern Namibia and it is also their staple food. The yields of pearl millet on smallholder farms are extremely low, at about 400 kg/ha (Davis & Lenhardt, 2009; Mahangu and Sorghum Task Team (MSTT), 2009). All crop residues (stover) are removed, either by livestock or for domestic use, in addition there is a lot of mono-cropping of pearl millet leading to deterioration of the farm's ecology and declining yields (Contill 2009).

Conventional tillage and the preparation of a fine seedbed are still considered characteristics of good farming practice in Namibia (Mudamburi & Namalambo, 2010). The objective of this study was to compare the effects of 4 tillage methods (two for Conventional Tillage (CV) and two for Conservation tillage (CT) used by farmers in Omusati conditions of Namibia on root development and yield of pearl millet. The tillage methods are tractor drawn disc harrow, tractor drawn ripper furrow, animal drawn mouldboard plough and animal drawn ripper furrow.

Materials and Methods

The experiment was carried out at Ogongo Campus in the North of Namibia during 2010/2011 and 2011/2012 cropping seasons. The station lies in a semi-arid region and receives a mean annual rainfall between 300 and 500 mm (Kuvare et al., 2008). The soils at the site are predominantly sandy.

An animal drawn mouldboard plough and a tractor disc plough were used to conventionally till the land whilst an animal drawn ripper furrower and a tractor ripper furrower were used in the conservation tillage. Planting was done by dropping and covering seeds into ripped and ploughed plots. The research was set up in a split plot design i.e. five treatments, and two mulch rates (no mulch and mulch) with 4 replications totalling 40 plots. The treatments are: (1) animal drawn mouldboard plough (AMP), (2) Animal drawn ripper furrow (ARF), (3) tractor disc harrow (TDH), (4) tractor ripper furrower (TRF), and (5) Control- No tillage No crop (NTNC). The plots were 10 x 10m, with 5m borders between blocks and 2m between plots to allow proper turning and movement of tractors and animals. Trained operators and animals were used initially in test runs and then in the experimental plots. Well designed harnesses were also used for the animals.

Plant population of 80 000/ha of pearl millet were used with seed rates of Okashana 1 at 3 to 4 kg per hectare. One meter inter-row spacing and in-row spacing of 25 cm were used. The crops for the first year trial were planted in January 2011 and second year in January 2012. Fertiliser was applied at 150kg per ha of Mono ammonium phosphate for all treatments. In order to establish fertility, goat manure at 5t per ha was applied at planting stations. The roots of five random samples from the two middle rows of each plot were measured with a ruler in centimetres. The yields of five random samples in kg per plot were also measured after harvesting using a scale. All random samples were taken from the two middle rows. Whole plot yields were also measured at the end to compare since there was bird damage in some plots. The Genstat statistical package was used to analyse the data. Analysis of variance was used to test for any significant differences among the root length and yield means of all tillage technologies at a confidence level of 95% ($p=0.05$).

Results and Discussion

Figure 1 shows mean pearl millet root length in centimetres. There were no significant differences in mean root length among the tillage methods in 2011 season ($p=0.120$) but they were significantly different in 2012 ($p<0.005$). There were no significant differences in mean root lengths between mulched and un-mulched plots. This is most likely attributable to the abundance of rain in the two years of experimentation thereby resulting in adequate soil moisture even with un-mulched plots. Figure 2 shows the mean pearl millet yield per ha. There were no significant differences ($p = 0.410$ in 2011 and 0.078 in 2012) in mean yield among the tillage methods. There were also no significant differences ($p = 0.758$ in 2011 & 0.348 in 2012) between the mean yields of the mulched and un-mulched plots. Yields from the trials for 2011 ranged from 980 to 2 056kg per ha in TRF, 1 163.8 – 1 811.3 per ha in ARF, 1 163.6 to 1 706.3 per ha in AMP and 1 435 to 1 723.8 kg/ha in TDH irrespective of mulch. Max yields from the trials in 2012 were 5362 kg per ha in TRF, 4 981 per ha in ARF, 4434.3per ha in AMP and 4587 kg/ha in TDH irrespective of mulch. In both 2011 and 2012, TRF achieved the highest mean root length and high yields overall.

Results from the study show a vast improvement in the yields in all the tillage methods particularly in the second year. This shows that other factors contributed to the increase in yield. Rusinamhodzi (2013) concluded in his studies that crop productivity under conservation agriculture depends on the ability of farmers to achieve correct fertiliser application, timely weeding, and the availability of crop residues for mulching and systematic crop rotations which are currently lacking in Southern Africa. One reason for high yields could be the plant population of 80 000 plants per ha as compared to 40 000 that extension normally recommends to farmers. Increase in yields could also be attributed to putting manure and fertiliser at more or less the same place in the furrows. However this will only work if there is enough manure and fertiliser. The increases in yields in the second year is in line with the studies from Zimbabwe that showed that nutrients like nitrogen from manure become more available to crops in the second season (Nyamangara et al., 2003). The study showed that yield and root length were not significantly influenced by CT. In good rainfall years, there may be no noticeable differences in CT and CV in an arid area like Namibia. The increase in yields on TRF can greatly improve the Namibian farmers' pearl millet yields through the use of Conservation Agriculture (CA) practices.

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Figures

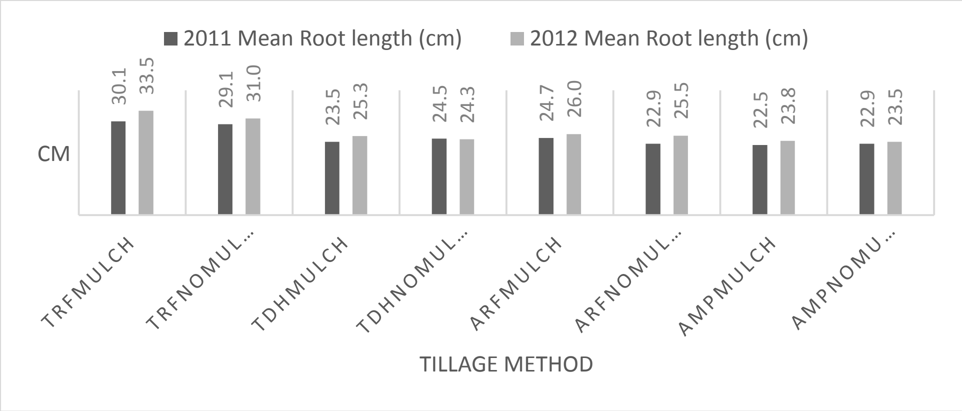

Figure 1: Pearl Millet mean root length in cm

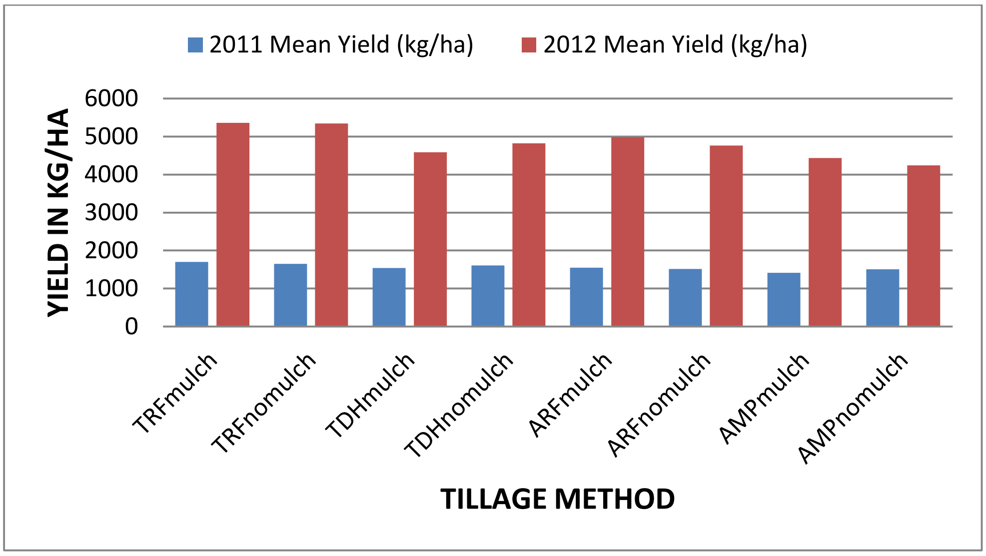

Figure 2: Pearl millet yield in kg/ha

Sub-Theme 5: Effective research, inclusive of socio-economic challenges, and targeting strategies for enhanced CA adoption

Conceptual typology of Conservation Agriculture systems for semi-arid and sub-humid areas in West and Central Africa

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Key words: agroecology, smallholders, diversity, farming practices, West and Central Africa

Introduction

West and Central Africa (WCA) is considered as part of the areas where the potential benefits of conservation agriculture (CA) are believed to be the highest (Lal, 2007). CA is increasingly promoted as an option that could enable smallholders of semi-arid and sub-humid areas of WCA to meet the rampant food, economic and environmental challenges (Djamen *et al.*, 2013). CA is a generic concept that refers to a family of cropping systems in which three fundamental principles are implemented simultaneously at farm level based (FAO, 2008): no or minimum mechanical soil disturbance, maintenance of permanent soil cover, and diversification through of crop rotations and/or associations. In WCA, the successful operationalization of the CA concept requires the consideration of the wide diversity of socio-economic and biophysical conditions (Jalloh *et al.*, 2012). Hence, there is a need to develop a range of CA system to meet the variability of the context. In this article we define a CA system (CA-S) as a particular combination of implementation modalities of each of the three CA principles, the modalities being chosen according to their suitability with the biophysical and socioeconomic characteristics of the environment and farms where they are applied. This article presents a conceptual typology of CA systems designed to support the ongoing efforts for the promotion of CA in WCA.

Materials and Methods

This research was conducted in the framework of the Smallholders Conservation Agriculture Promotion in Western and Central Africa (SCAP) whose study sites were scattered in Burkina Faso, Guinea and Niger. The objective of SCAP was to contribute to the identification of the potential and implementation modalities of CA in WCA. The typology presented in this article is an outcome of SCAP project. The methodology used for the elaboration of locally adapted CA-based cropping systems consisted first of the diagnosis of existing farming practices, biophysical and socio-economic characteristics of the study site so as to identify potential entry points for the development of locally adapted CA practices. Based on the results of the diagnosis options for the implementation of CA principles were identified and discussed with farmers. The following criteria were considered to have key in influencing the modalities of application of the three CA principles: rainfall, socio-economic conditions (land pressure, food security, cattle rearing, access to market etc.). Existing farming practices prior to the introduction of CA were also considered and added to the above criteria to build a matrix matching characteristics of the site and options for the implementation of CA.

Results and Discussion

Four types of CA systems were identified for WCA smallholder farming (Table 1):

- CA-S1: CA featuring agroforestry, direct seeding under mulch from tree/shrub pruning, cereal in association with leguminous food crop.

- CA-S2: CA featuring crop residue retention; direct seeding under mulch of crop straws, cereal in association preferably with leguminous food crop.
- CA-S3: CA featuring cover crops, direct seeding under biomass of cover crops, cereal grown in association or rotation with fodder crops.
- CA-S4: CA featuring cover crops, direct seeding under mulch of cover crops, cereal grown in rotation with fodder crops or improved fallow.

CA-S1 is formulated for area with a very low rainfall (<500 mm year^{-1}) and high population density (>70 inhabitants km^{-2}). Population density is very high and food insecurity is frequent, hence the cover crops selected by farmers are leguminous food crops and mainly cowpea and groundnuts. Crop varieties to be used in association with the cereal should have a short cycle, and if possible be resistant to drought and pests, and less demanding regarding water and nutrients. Direct seeding, generally without application of herbicide, is already well practised taking advantage of the shallow nature of soils, but also to meet the challenges of lack of equipment and the poor and unpredictable rainfall. The achievement of soil cover is a major issue because of the low rainfall and the high pressure of livestock. However, the minimum of 30% soil cover recommended by FAO to fulfil the principle of soil cover can be reached by mobilizing millet straw and mostly biomass from prunings from native shrubs such as *Piliostigma reticulatum* and *Guiera senegalensis*. This CA system is already part of the traditional cropping systems in many villages of the WCA Sudano- Sahelian zone where farmers managed trees/shrubs as coppiced stumps. CA-S1 is a concrete example of the emerging concept of 'evergreen agriculture' which is defined as the integration of particular tree species into annual food-crop systems (Garrity *et al*., 2010).

Table 1. Potential CA-based cropping systems for WCA smallholder (Djamen *et al.*, 2013)

	CA-S1	CA-S2	CA-S3	CA-S4
Soil tillage	Direct seeding/ripping	Direct seeding/ripping	Direct seeding + herbicide	Direct seeding + herbicide
Material for organic soil cover	Biomass of shrubs (*Piliostigma reticulatum*, *Guiera senegalensis*, *Hyphaene thebaïca* etc.) + cereal straw	Mulch of cereal eventually complemented with biomass of shrubs or grass	Biomass of cover crops + straws of cereal	Biomass or cover crops + grasses
Main crop	Millet/sorghum	Sorghum/millet	Maize, sorghum, cotton	Rice/maize
Cover crops /associated crops	Cowpea/groundnuts	Cowpea/groundnuts	Fodder crops (brachiaria, mucuna, dolichos etc.) / leguminous food crops	Fodder crops (brachiaria, pigeon pea, *Stylosanthes* sp., mucuna, *dolichos* etc.)
Crop association / rotation	Association	Association	Association/rotation	Rotation
Average accessible soil cover rate (%)	30–50	50–70	80–100	100

CA-S2 is designed for the semi-arid areas, but with slightly better rainfall (600–800 mm year^{-1}) than in zones for CA-CS 1. Thanks to the relatively good rainfall, the main food crop grown here is sorghum or even maize in some cases. Cover crops including *Mucuna* sp. and

Brachiaria sp. among others can be grown, but farmers tend to prefer a food leguminous crop because of the rampant food insecurity and the land scarcity. Cereal straws are the main materials used for soil cover; these residues can be eventually complemented with shrub biomass, grasses or crop residues collected on other plots or in the bush. It is possible to achieve a soil coverage of 50 to 70%. As in CA-S 1, crop diversification is achieved mainly through crop associations because of high pressure on land.

CA-S3 is tailored for areas with an average rainfall of about 800–1200 mm year^{-1}; this rainfall is enough for the production of a wide variety of cover crops that can also be used for human or animal feeding. A rate of 100% soil coverage is possible as the rainfall enables production of biomass. The pressure on land is not very high because of a medium population density (20–70 inhabitants km^{-2}). The third principle of CA can be achieved either through crop associations or crop rotations. In fact farmers prefer to practise crop association with leguminous food crops (cowpea, groundnuts) and use crop rotations with fodder crops like *Mucuna* sp. or *Brachiaria* sp., which they consider difficult to manage when cultivated in association with cereal on the same field. In this sub-humid areas, it is necessary to grow cover crops to produce complementary biomass for soil cover as biomass of the main crops (maize, cotton) does not always last throughout the dry season or is easily decomposed by termites as compared to sorghum or millet straws. Soil tillage is practised by a majority of farmers to control weeds that grow rapidly ahead of the sowing of the crop. Hence, a transformation of existing farming practices into CA will require the use of herbicides for weed control at least at the beginning of the process.

CA-S4 has almost the same characteristics as CA-S3, except that it is more appropriate for areas with high rainfall (>1400 mm year^{-1}) and a low population density (<20 inhabitants km^{-2}). The high rainfall is favourable for the cultivation of a wide variety of cover crops. In some cases, the rainfall pattern might be bimodal, allowing two cropping seasons per year. Furthermore, it is possible to produce a large volume of crop biomass to ensure 100% soil cover. The low population density enables the implementation of the practice of fallow, which can be improved by the introduction of cover crops including shrubs that can bolster nutrient supply through nitrogen fixation and nutrient cycling. Potential cover crops that could be used in this area include *Brachiaria* sp., *Mucuna* sp., *Stylosanthes* sp., *Crotalaria* sp., *Dolichos lablab* and *Cajanus cajan* amongst others. The cultivation of fodder crops could be an entry point for the development of CA. Herbicide is used to control weeds.

Boundaries of areas of the different CA systems are not rigid. Depending on the socio-economic and agronomic conditions, more than one type of CA system can be practised in the same area (Figure 1).

Conclusion

Sub-humid areas with better rainfall and low population density offer more favourable conditions for the production and conservation of biomass. However, the implementation of CA in these areas seems more costly because of the high dependence on external farm inputs including mainly herbicides for weeding, seed of cover crops and fertilizers. It appears from the characteristics of different types of CA-S that when markets for farm inputs and products are well developed, areas with high rainfall and low population density are the most favourable for the full implementation of CA principles. However, despite some agroecological and socio-economic challenges, it is observed that there is room for CA in semi-arid zones with even some innovations that can contribute to enriching the implementation of the concept of CA. Further research operations are still needed to provide comprehensive knowledge on the evidence and performance of all the four types of CA systems. The diversity of CA-systems highlights that the full benefits of CA might differ according to the context. If the maximum benefits are most likely observed in less populated humid and sub-humid areas, it appears that CA can also generate some specific benefits in semi-arid zones, hence contributing somehow in the improvement of the performance of farms of those areas. The typology proposed in this article could be further refined through the integration of irrigated agriculture and also the role of livestock which is increasingly becoming a key pillar for the resilience of WCA smallholder farming systems.

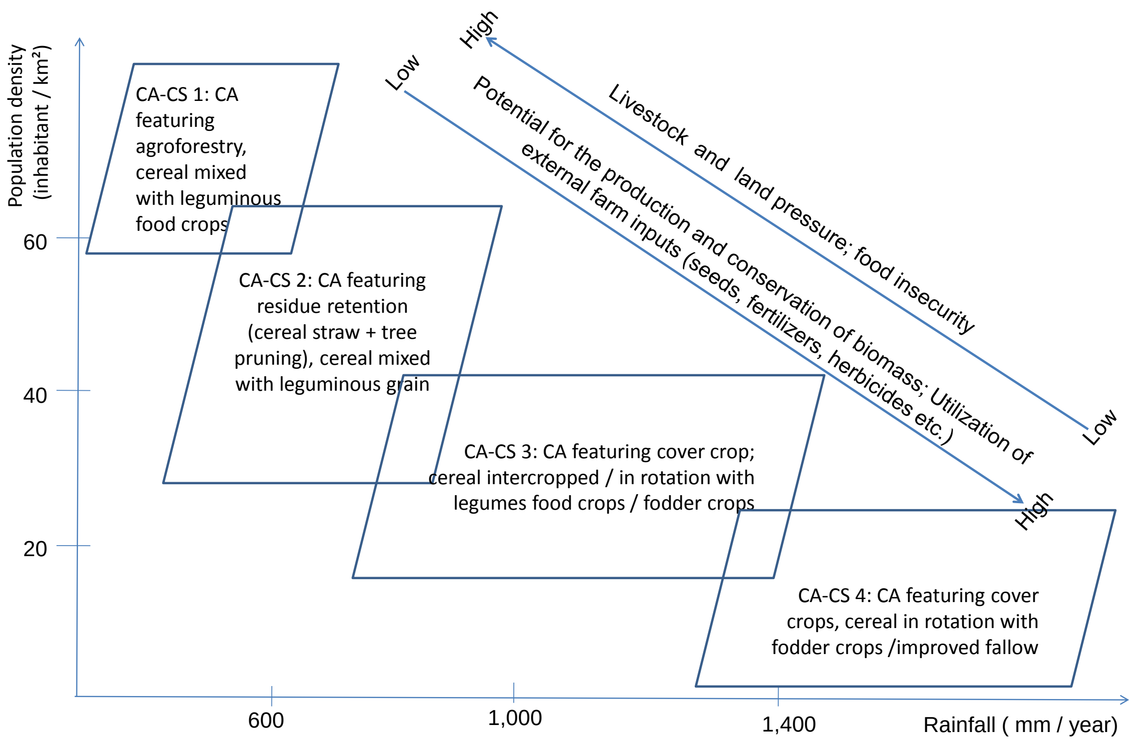

Figure 1. Conceptual distribution of different types of CA systems in WCA according to rainfall and population density (Djamen *et al.*, 2013)

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Increasing Conservation Agriculture options for smallholder farmers in different agro-ecological regions of Zimbabwe

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Keywords: Basins; conservation agriculture; direct seeding; net benefits; ripline seeding

Introduction

Conservation agriculture (CA) has the potential of increasing and stabilizing crop yields, and improving profitability of smallholder cropping systems (Ngwira et al., 2012; Wall et al., 2013). The three CA principles, when implemented together, result in improved soil health, increased soil water conservation and higher crop productivity compared with conventional agriculture (Thierfelder et al., 2014). With CA crops can withstand dry spells experienced during cropping periods because soil water conservation improves over time (Wall et al., 2013; Thierfelder et al., 2014). Economic returns and profitability of cropping enterprises are higher using CA systems compared with conventional agriculture (Ngwira et al., 2012). Various CA systems targeting households of different resource endowment have been introduced in southern Africa over the past decade (Thierfelder et al., 2014). In Zimbabwe the basin CA system was widely promoted for households with no access to draft animal power (Mazvimavi and Twomlow, 2009). However, these excluded farming households with draft animals from practicing CA. Animal traction CA systems such as tine ripping and direct seeding have shown great potential for sustainably increasing crop productivity. However, information on maize and legume yields and economic benefits of conventional practice, planting basins, tine ripping and direct seeding under smallholder farming conditions in different agro-ecologies of Zimbabwe is still limited. The objectives of the study were to determine (a) the effect of conventional tillage, planting basins, animal drawn tine ripping and direct seeding on maize, cowpea and soybean yields, and (b) the economic benefits of planting basin, tine ripping and direct seeding systems compared with conventional tillage in different agro-ecological regions of Zimbabwe.

Materials and Methods

On-farm studies were conducted in Kariba district which is located in Natural Region (NR) 3 and, Gokwe and Zaka districts which lie in NR 4 of Zimbabwe (Vincent and Thomas, 1961). Annual rainfall varies from 500 to 800 mm in NR 3 and, 450 to 650 mm in NR 4 (Vincent and Thomas, 1961). Major soil texture in both NRs is sand with patches of clay soil occurring in some parts of the districts. Trials consisting of four cropping systems were established at 10 farms in each district and the sites were maintained over the study period. Tillage systems tested were (a) conventional mouldboard ploughing (b) planting basins, measuring 15cm x 15cm x 15cm and spaced at 90cm x 50cm (c) animal drawn ripline seeding and (d) animal drawn direct seeding. Maize, soybean and cowpea crops received equal basal fertilizer (165 $kgha^{-1}$) ($7N,14P_2O_5,7K_2O$) at seeding and nitrogen (34.5%N) (200 $kgha^{-1}$ ammonium nitrate) topdressing for maize in the four cropping systems tested. Initial weed control in CA systems was done using glyphosate (2.5 l ha^{-1}) (1.025 l ha^{-1} a.i) and subsequent weeding in all four cropping systems was done manually with hand hoes. Crop yield and socio-economic data were collected at each trial site each year and analyzed using ANOVA in Statistix 9.0 (Statistix, 2008).

Results and Discussion

Crop yields from different cropping systems

In NR 3 animal drawn ripping and DS systems gave higher maize and soybean yields compared with conventional and basin systems (Fig.1). Direct seeding had better yields than the other CA systems, an observation attributed to better crop stand and growth in the DS treatment. In NR 4 maize yields were higher in basin system compared with other tillage treatments (Fig. 2) in a year which had the lowest seasonal rainfall, emphasizing the rainwater harvesting advantage of basins in semi-arid environments. Ripper and DS systems had higher cowpea yields (Fig. 2), a reflection of better crop stands that were observed in these two treatments compared with conventional and basin systems. Animal traction CA options offer an opportunity for increased crop productivity in different NRs of Zimbabwe.

Economic benefits of different cropping systems

In both NRs the DS CA system gave the highest net benefits to the farmer compared with the conventional practice and basin CA system (Table 1) and this can be attributed to reduced labour requirement (e.g. land preparation, fertilizer application, seeding) of the system and the higher crop yields achieved in this treatment. In most instances basin CA system gave the lowest benefits and this can be attributed to higher labour costs compared with conventional, ripper and DS cropping systems. Animal traction direct seeding option increases farm income in different NRs compared with ripline, basin and conventional systems.

Figures

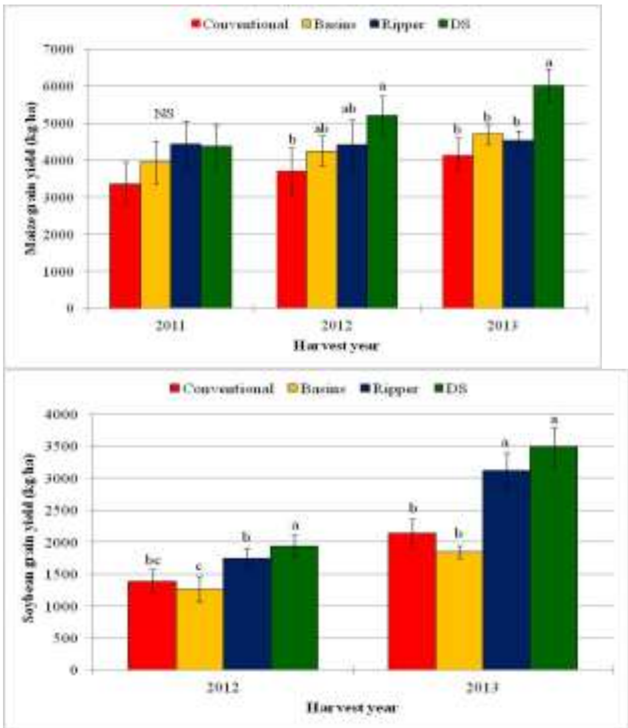

Figure 1. Maize and soybean grain yields achieved in the 4 cropping systems tested on farmers' fields in NR 3.

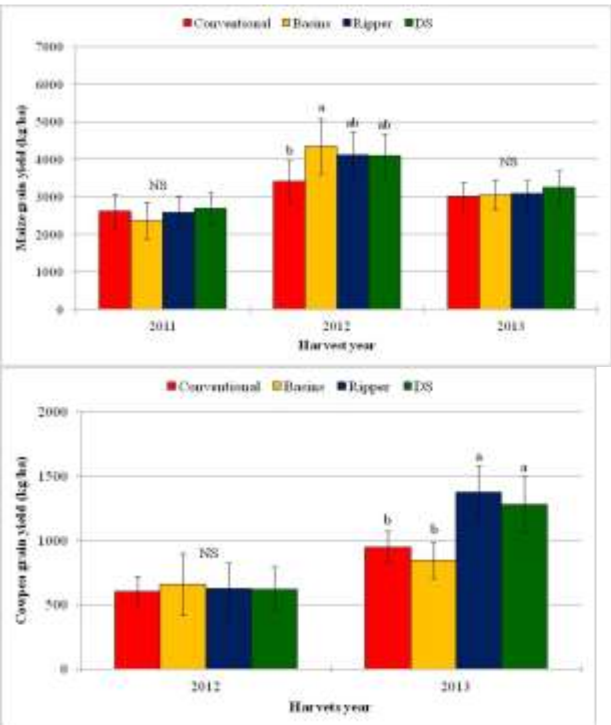

Figure 2. Maize and cowpea grain yields achieved in the 4 cropping systems tested on farmers' fields in NR 4.

Table 1. Economic benefits derived from using the 4 cropping systems tested on the farmers' fields

Natural Region	Harvest year	Cropping system	Crop grown	Net benefits (US$/ha)

3	2012	Conventional	Maize	58.68
		Basins	Maize	51.07
		Ripline seeding	Maize	96.11
		Direct seeding	Maize	202.77
3	2013	Conventional	Maize	1019.00
		Basins	Maize	908.00
		Ripline seeding	Maize	824.00
		Direct seeding	Maize	1308.00
3	2013	Conventional	Soybean	589.00
		Basins	Soybean	575.00
		Ripline seeding	Soybean	1213.00
		Direct seeding	Soybean	1441.00
4	2013	Conventional	Maize	750.00
		Basins	Maize	721.50
		Ripline seeding	Maize	769.00
		Direct seeding	Maize	1005.00
4	2013	Conventional	Cowpea	686.00
		Basins	Cowpea	528.50
		Ripline seeding	Cowpea	1083.50
		Direct seeding	Cowpea	1121.00

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Options for adaptation of Conservation Agriculture practices on nutrient-depleted soils by smallholder farmers in Southern Africa

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Key words: ABACO, innovation platforms, Learning Centres, resource-constrained, soil fertility

Introduction

There has been accelerated research on conservation agriculture (CA) in Africa over the past decade. Although the research has often generated impassioned scientific debate and controversy, the bottom-line has been an emerging vision towards transformation of the predominantly smallholder farming systems into more efficient, productive and resilient systems (Jat *et al*., 2013). A key area of scientific contention in the discourses on CA relates to the applicability of the three main principles (rotations, mulching and minimum soil disturbance) under smallholder farming systems (Giller *et al*., 2009; Sumberg and Thompson, 2012). However, with evidence that global demands for food will require agricultural production to increase by at least 70% by 2050 to feed a growing population (FAO, 2010), concerns remain about capabilities of current farming systems in Africa for sustainable intensification in the face of a depleting natural resource base, land degradation and climate change and variability. There is therefore a telling knowledge gap on agricultural technical packages integrating options for increased productivity, agro-biodiversity and resource conservation. This paper describes how farmer participation in the context of innovation platforms (IPs) can add value to the CA discourse, and roles they can play in adapting and integrating the principles/practices of CA with other approaches. A CA research agenda is proposed for Africa, drawing from experiences and lessons of farmers participating in a CA-based ABACO project (Tittonell *et al*., 2012) implemented in Zimbabwe by Soil Fertility Consortium for Southern Africa (SOFECSA)

Materials and Methods

The study was conducted in Wedza district in eastern Zimbabwe, which receives 500-750 mm yr^{-1}, with evidence of deteriorating seasonal distribution over the past three decades. SOFECSA introduced the concept of IPs into district agricultural stakeholders and services providers leading to the establishment of a District Innovation Platform (DIP) convened and facilitated by the district agricultural extension officer. Local-level committees were established jointly with communities to form Ward-IPs (WIPs), which in turn mobilized farmers into learning alliances that interacted closely with agro-service providers including CA equipment manufacturers and seed and fertilizer producers. In partnership with the research team and members of the DIP, the WIP facilitated establishment of CA-based Learning Centres. The Learning Centres enabled participatory evaluation of combinations of different tillage and soil fertility management treatments on the performance of maize and grain legumes crops grown in rotations and/or intercrops. Tillage treatments included basins, ripping and conventional ploughing, while soil fertility treatments comprised mineral fertilizer at 14 vs. 26 kg P ha^{-1} and 46 vs. 90 kg N ha^{-1}) and organic fertilizer at 7 t ha^{-1}under each tillage treatment. Farmers also experimented with variants of these treatments in their own fields. Soils from all sites were characterized for fertility status. Crop yields were jointly assessed with farmers, while participatory action research (PAR) techniques were used to examine major lessons and experiences by farmers on the benefits, limitations and potential options for adaptation of CA practices on their farms.

Results and Discussion

Both tillage and soil fertility management options had a significant effect on maize yields. Yield benefits under basins were more pronounced under low rates of nutrient inputs than under high rates (Figure 1). Similarly, on relatively infertile soils, basins performed well regardless of rate of nutrient input. These results suggest that the yield benefits associated with basins, as also corroborated by farmers, are most likely due to the concentration of nutrients in the basins. This further indicates that soil fertility is the major limiting factor, which should be overcome before the other benefits of CA are discernible. Addressing this factor comprehensively through use of appropriate organic and mineral fertilizer inputs is likely to change farmer perceptions about the principles of CA and its classical long term benefits such as yield stabilization.

Farmers in Wedza defined CA primarily as ‘basins’, most likely due to the large-scale promotion of these basins by non-governmental organization across the country prior to the intervention period for this study (Andersson and D’Souza, 2013). However, it was evident from the study that farmers were concerned about the high labour demands associated with both the digging of basins and the mulching exercises under CA (Table 1). Farmer suggested options such as winter-ploughing of fields before the digging of basins, and the alternating of ploughing and basins (Table 1), suggest the need for research towards revision/broadening of three principles CA currently underpinning the CA framework. Farmers also indicated the benefits of CA associated with earliness of planting operations confirming findings by Marongwe *et al*. (2011), and also showed their preference for ripping as a less laborious tillage operation enabling cropping of larger land areas.

The study findings suggest a critical need to shift from the current debate on the ‘uniquely’ defined principles of CA, and whether CA works or not, to a focus on the quest to meet the unique needs of farmers in ways that still address broader concerns of food security, systems resilience and sustainability.

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Figures and Tables

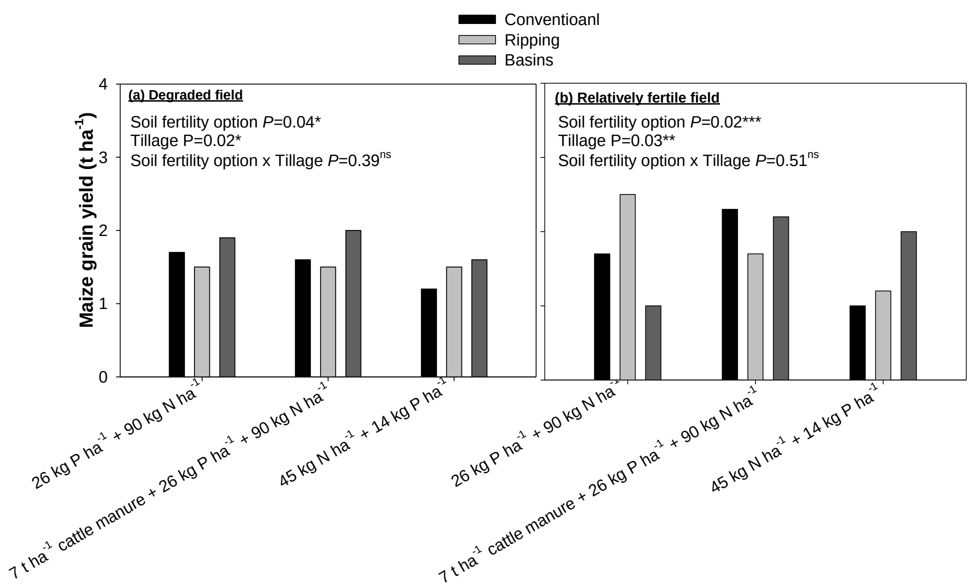

Figure 1. Effect of tillage and soil fertilty management on maize grain yields at Goto Learning Centre in in Wedza, Zimbabwe during the 2012-13 season (*denotes significance P <0.05, ** = P<0.01, ***= P<0.001, ns = not significant)

Table 1 Characterization of conservation agriculture and its perceived benefits by two farming communities in Wedza District in Zimbabwe

Community	Farmers' CA definition	What farmer like most	What farmer do not like	Farmer Prioritized options for CA
Goto	• Making basins using a hand-hoe	• Pooling labour • Planting with first rains • Use of locally available organics	• labour on basins • labour on mulching • More weeds • Cattle destroying basins • Mulching with maize stover	• Winter-ploughing then basins • Ripping • Weeding in winter then basins • Alternating basins and ploughing • Use of machinery in CA
Ushe	• Making basins • Ripping	• Use of locally available nutrient resources • Conserving nutrient/water • High crop yields • Reduced soil/water loss	• High labour on basins • High labour on mulching • Cannot crop large areas • Residual nutrients in basins not used • Use of maize stover for mulch	• Winter-ploughing then basins • Ripping • Training on herbicide use

Déterminants de l'adoption de la fumure organique dans la région semi-aride de Kibwezi (Kenya). *Abou. S[1].; Folefack, D.P[1].; Obwoyere Obati.O[2].; Nakhone. L[2].; Wirnkar. L.F[1].*

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Mots clés: Adoption, fumure organique, semi-aride, Kibwezi

Introduction

La dégradation des terres engendrée ou accentuée par les changements climatiques constitue une menace pour la survie et les moyens de subsistance de millions de personnes en Afrique sub-saharienne (MOA 2009). La fertilité des sols est en baisse dans de nombreuses régions de l'Afrique sub-saharienne parce que les fortes pluies, le ruissellement et les vents intenses emportent les terres fertiles alors que les fortes températures oxydent la matière organique et durcissent les sols, les rendant moins perméables. Afin de s'adapter à ces effets et d'assurer leur survie, les agriculteurs de la région de Kibwezi, qui sont essentiellement des agroéleveurs, ont adopté plusieurs stratégies d'adaptation dont certaines semble très efficaces et à leur portée. L'objectif de cette étude est d'identifier les variables socio-économiques qui influencent l'adoption de la fumure organique par les agriculteurs face à la baisse de la fertilité des sols de la région.

Matériels et Méthodes

L'étude a été réalisée dans le district de Kibwezi, situé au sud-est du Kenya. Une première descente sur le terrain nous a permis de réaliser des focus-groups dans trois villages sur les effets du changement climatique sur les ressources naturelles agricoles et les stratégies d'adaptation, et de faire des observations de terrain. Par la suite, un questionnaire structuré a été administré à 186 chefs de ménages choisis au hasard suivant un transect matérialisé par les principales routes reliant les différents villages. Des entretiens semi-dirigés ont également été conduits auprès des responsables des structures publiques et privées (Ministères en charge de l'Agriculture, de l'Elevage, de l'Eau, Croix Rouge, USAID), les données ont permis d'étoffer les résultats des enquêtes

Les outils des logiciels SPSS et Excel ont servi à analyser ces données. L'objectif de notre étude était d'identifier les facteurs qui influencent l'adoption des stratégies d'adaptation utilisées par les agriculteurs sous la forme d'une probabilité. Le modèle Logit simple a été utilisé, et les variables explicatives testées sont l'âge, le sexe, le statut matrimonial, le niveau d'éducation, la main d'œuvre, les connaissances techniques, accès au crédit, aux ressources, au marché et aux informations, les relations sociales dans le village, et les enfants allant à l'école.

Résultats et Discussions

Effets du changement climatique sur les sols

Tous les effets perçus ici par les agriculteurs sont liés entre eux, conduisent tous à la baisse de la fertilité des sols, et sont directement ou indirectement liés au changement climatique. En dehors de la baisse de la fertilité et de l'induration des sols qui sont des phénomènes plus facilement perceptibles par la majorité des agriculteurs, surtout lors des périodes des semis (induration des sols) et des récoltes (baisse de la fertilité), tous les autres effets sont perçus seulement par une petite minorité. Cette situation s'explique selon le GIEC (2007) par la différence de certaines caractéristiques socioéconomiques entre les populations.

Stratégies d'adaptation des agriculteurs face à la baisse de la fertilité des sols

Les paysans ont développé plusieurs stratégies d'adaptation, parmi lesquelles celles relatives aux pratiques agricoles comme la gestion de la fertilité des sols (terrasses, fumure organique, engrais chimiques, plantation d'arbres), aux techniques de gestion de l'eau (terrasses, irrigation), et à la diversification des cultures etc. (tableau 1). L'utilisation massive des terrasses dans cette région (87%) pourrait s'expliquer par le fait que dans cette région, l'érosion hydrique est très accélérée (relief pentu), et fait perdre d'énormes quantités de matières fertilisantes. L'usage de la fumure organique brute (39%) sous forme de déjections animales, ou de fumier, vient en seconde position après les terrasses. Son usage pourrait s'expliquer par une prise de conscience de certains agriculteurs suite aux multiples efforts de vulgarisation du KARI dans la zone (Kenya Agricultural Research Institute) par rapport au lien qui existe entre tous les autres effets sur les sols et la baisse de la fertilité.

Déterminants de l'adoption de la fumure organique : Modèle logit

De toutes les stratégies d'adaptation utilisées par les agriculteurs de la région, l'usage de la fumure organique est celle qui à la fois est facilement à la portée des paysans, présente des avantages indéniables en matière d'amélioration de la fertilité des sols, et qui est déjà utilisée et bien maîtrisée par au moins le tiers des paysans. Ceci dit, la variable expliquée est représentée par l'utilisation de la fumure organique pour s'adapter à la baisse de la fertilité des sols, engendrée ou accélérée par le changement climatique dans la région semi-aride de Kibwezi. Les résultats du modèle Logit simple mettent en évidence une corrélation entre les facteurs socio-économiques et l'utilisation de la stratégie (tableau 2). Les variables telles que le statut matrimonial, les connaissances techniques locales, l'accès aux ressources, et les relations sociales dans le village ont une influence significative sur la probabilité d'utilisation de la fumure organique au seuil de 5%. Parmi ces variables certaines ont des effets positifs sur la probabilité d'utilisation, notamment, le statut matrimonial et les relations sociales dans le village, tandis que les autres affectent négativement le choix de la stratégie, notamment, les connaissances techniques et l'accès aux ressources.

Conclusions et Recommandations

Le statut matrimonial et les relations sociales dans le village sont parmi les principaux facteurs qui influencent significativement et positivement l'adoption de la fumure organique. Afin d'augmenter davantage la probabilité d'adoption de la fumure organique, il serait intéressant que les pouvoirs publics à travers la recherche agricole incitent et appuient les paysans à militer dans des groupements associatifs (GIC, tontines). Ils doivent également améliorer leur accès aux structures d'encadrement agricole. Le problème foncier doit également être résolu en allouant des portions de terre aux nouveaux immigrants venus des collines Kyullu afin de faciliter les investissements dans les parcelles agricoles. L'usage du compost parles paysans conjointement avec la fumure dont la disponibilité est limité à cause de l'abandon progressif de l'élevage bovin, doit aussi être vulgarisé. .

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Tableaux

Tableau 1: Stratégies d'adaptation des agriculteurs

Stratégies d'adaptation adoptées	Fréquence	Pourcentage (%)
Terrasses	97	87,4
Fumure organique	43	38,7
Plantation d'arbres	6	5,4
Irrigation des sols	5	4,5
Usage des engrais	4	3,5
Usage de la charrue pour casser les sols indurés	1	0,9

Tableau 2 : Variables utilisées dans le modèle

Variable	Description des variables et de leurs valeurs	Moyenne	Ecart type	Min	Max
USMARASO	Utilisation de la fumure organique (1 s'il utilise et sinon)	1,61	0,489	0	1
AGE	Age de l'enquêté (années)	45,42	12,77	25	90
GENDER	Sexe de l'enquêté (1=homme et 0=femme)	1,49	0,502	0	1
MARSTAT	Situation matrimoniale (1=marié et 0=autres)	1,16	0,564	0	1
LEVEDUC	Niveau d'éducation (1=primaire et 0=autres)	1,67	1,02	0	1

NYCROPF	Nombre d'années dans l'agriculture	17,80	9,87	2	47
LABOAVAI	Disponibilité de main d'œuvre (1=oui, 0=non)	1,69	0,463	0	1
TECHSKIL	Connaissances techniques locales (1=oui, 0=non)	1,73	0,441	0	1
ACCESCRE	Accès aux crédits (1=oui, 0=non)	1,67	0,470	0	1
ACCESRES	Accès aux ressources (1=oui, 0=non)	1,07	0,259	0	1
LOCLINKS	Relations sociales dans le village (1=oui, 0=non)	1,29	0,459	0	1
ACCMARKT	Accès aux marchés (1=oui, 0=non)	1,24	0,430	0	1
ACCNEWS	Accès aux informations (1=oui, 0=non)	1,090	0,287	0	1
CHILSCHO	Enfants allant à l'école (1=oui, 0=non)	1,49	0,502	0	1

Nombres d'observations = 1

Lessons from long-term Conservation Agriculture research in Southern Africa: Examples from Malawi and Zimbabwe

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Keywords: CA adoption, direct seeding, soil quality improvements, yield benefits, climate adaptation

Introduction

Conservation agriculture (CA) has been promoted in southern Africa since the late 1990s with the aim of reversing the effects of declining soil fertility and productivity on current farming systems as well as adapting to projected increase in climate variability and change (Thierfelder et al., 2014). Conservation agriculture (CA) aims at taking away the unsustainable parts of current conventional tillage-based systems by replacing excessive soil movement with minimum soil disturbance; exchanging monocropping with diversified crop rotations and finally protecting the soil with living or dead plant material instead of burning or removing it (Wall et al., 2013). Research evidence from the region shows that CA maintains high levels of water infiltration thereby increasing the available soil moisture (Thierfelder and Wall, 2009). CA also improves different soil quality parameters such as soil fauna, aggregate stability, soil carbon amongst others which all lead to increased productivity in the medium to long-term (Thierfelder and Wall, 2010). However, the adoption of CA is often constrained by numerous factors as a result of the diversified and complex farming systems and the socio-economic circumstances of smallholder farmers in southern Africa.

These constraints are mainly the access to critical inputs (fertilizer, herbicides and specialized machinery) and markets, competition for crop residues in mixed crop-livestock systems, weed control if no herbicides are used and finally the mindset of farmers that agriculture is only possible and adequate if the soil is tilled (Thierfelder et al., 2014). The performance of different CA systems was analyzed from 2004-2013 in two on-farm communities of Malawi and Zimbabwe to explore the feasibility of CA under different agriculture and socio-economic environments and to find out what might be the keys to success for widespread experimentation and adoption of this crop management systems.

Material and Methods

The study was carried out with the assistance of the regional NGO Total LandCare at Zidyana in Nkhotakota District, Malawi (13.11 S, 34.15 E), from 2004-2013 on fertile *Luvisols* and average annual rainfalls of 1344mm, and at Zimuto Communal Area in southern Zimbabwe (19.85 S; 30.88 E) from 2005-2013 on very sandy soils (*Arenosols*) with annual rainfall of 655mm with the help of AGRITEX. At both sites a cluster of at least six replicated demonstration plots with two CA and one conventional control treatment was established. At Zidyana, the treatments were a) conventional ridge and furrow system (CRF) and hand seeding of sole maize into the ridges, b) conservation agriculture seeded with a dibble stick with sole maize (CAM), and c) conservation agriculture seeded with a dibble stick with maize-cowpea intercropping (CAML). Treatments were seeded at recommended plant populations (53,000 pl ha^{-1}), fertilized with recommended rates (69 kg ha^{-1} N:21 kg ha^{-1} P_2O_5:4 kg ha^{-1} S) and weeds were controlled with pre-emergence (glyphosate) and residual (Harness® or Bullet®) herbicides. At Zimuto the treatments were a) conventionally ploughed control treatment, seeded with maize (CP); b) rip-line seeded maize treatment (RI) and c) animal traction direct seeded maize treatment (DS). All treatments were routinely intercropped with cowpeas. The recommended plant population was 36,000 plants ha^{-1}, the crop was fertilized with 80 kg ha^{-1} N:23 kg ha^{-1} P_2O_5:12 kg ha^{-1} K_2O and weeding was done with hand hoes.

Both research sites were sampled for soil carbon and water infiltration using a proxy measurement called "time to pond". Maize grain yield was measured at the end of each cropping season. Besides biophysical measurements, both sites were surveyed through intensive focus group discussion to identify constraints to adoption in areas where CA has been extended since 2005. Adopting farmers were recorded from registers of both implementing partner organizations.

Results and Discussion

Results from the high potential area, Zidyana in Malawi, showed that hand-seeded CA treatments outyielded conventional systems (Figure 1) and showed improved soil quality indicators (e.g. increased water infiltration) over time. This has been previously reported by Ngwira et al. (2012) and supports the conclusion that CA systems are more productive than conventional ridge and furrow systems. The socio-economic assessment in the target area showed that it was conducive to adopt CA. Central Malawi is characterized by low crop-livestock interaction and receives strong private and governmental extension support. Farmers use and have access to critical inputs such as fertilizers and herbicides, and, in some cases can make use of credit for input purchase and markets for produce. Adoption has therefore increased in the target area from 12 farmers in 2005 to more than 15,000 farmers in 2013, as has been reported by Corbeels et al. (2013), highlighting which socio-economic circumstances may be conducive for farmers to embrace the full concept of CA. The reduced risk of crop failure in Zidyana has also encouraged farmers to move away from widespread maize monocropping and successful maize-groundnut rotations under CA have started to thrive. This will not only increase the level of food security but also the financial income and nutrition for farm families in the longer term.

At Zimuto, the lower potential area on sandy soil with low soil carbon levels, CA treatments seeded with an animal traction direct seeder and ripper outyielded conventional ploughed system after the third cropping season onwards (Figure 2). Soil quality indicators equally improved over time as has been previously reported by Thierfelder and Wall (2012). However, the number of farmers adopting CA was not expanding due to an unfavourable socio-economic environment and stayed at a number of less than 100 farmers in the target area. Farmers mainly live of remittances, lack the capacity and opportunity to purchase critical inputs and are guided by weak extension services. Additionally the economic meltdown in Zimbabwe and periodic droughts since the 2000s have made farmers more and more dependent on food aid. Despite the huge potential of CA to adapt to climate variability and change, the perceived risk of crop failure in this area is a serious constraint for farmers to move into different forms of agriculture.

The study proved that CA is a viable and adaptable system in contrasting environments due to its biophysical benefits. However, the adoption is guided by socio-economic conditions and farmers' perceptions towards improved cropping systems. Governmental support should focus on providing access to critical inputs and viable extension services as they proved to trigger large scale experimentation and adoption. In areas where CA is not suitable it may also be too marginal for general crop production. These areas should therefore be converted into rangeland or other uses.

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Figures

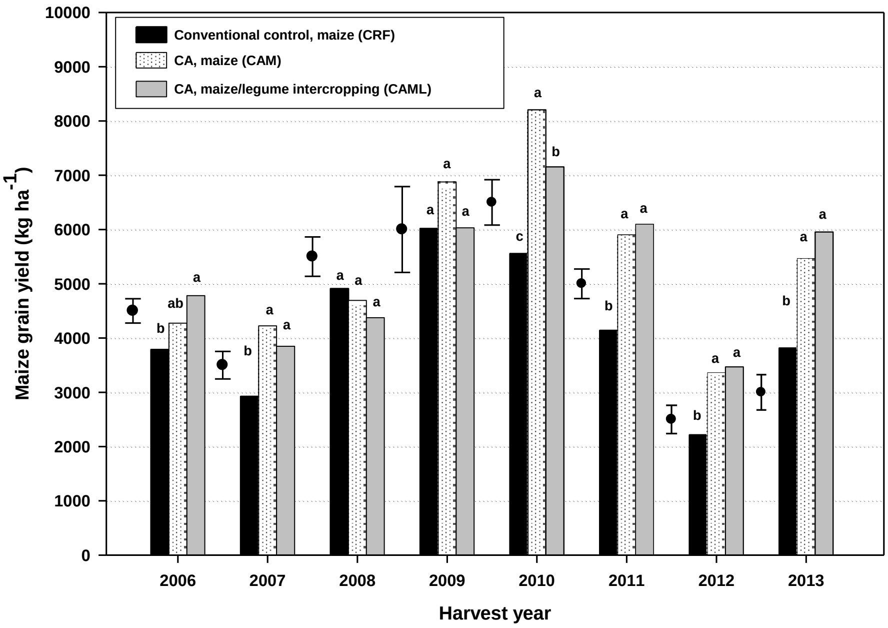

Figure 1. Long-term effects of a conventional and two CA treatments on maize grain yield (kg ha^{-1}) in Zidyana, Nkhotakota District, Malawi, 2006-2013

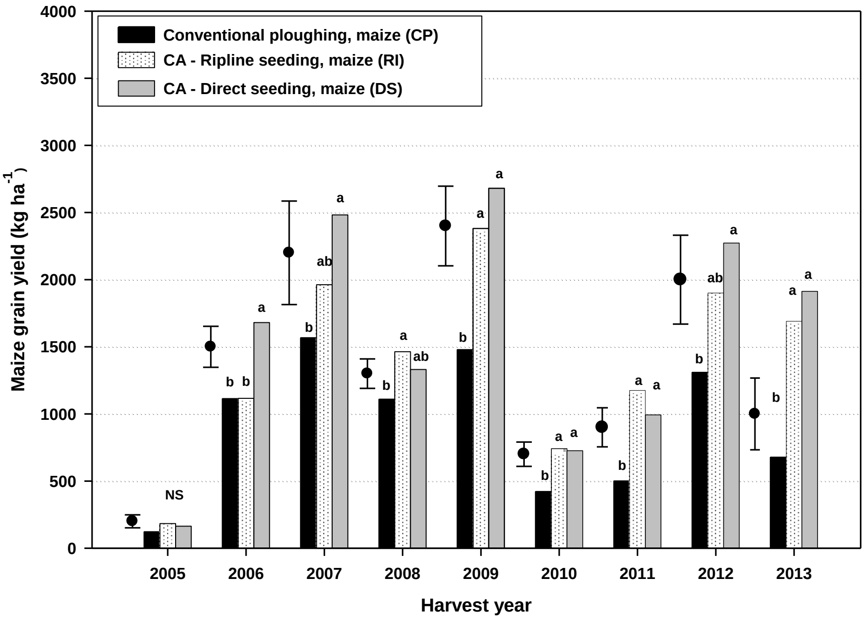

Figure 2. Long-term effects of a conventional and two CA treatments on maize grain yield (kg ha^{-1}) in Zimuto Communal Area, Masvingo Province, Zimbabwe, 2004-2013

Effects of Conservation Agriculture on soil microbial community dynamics

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Keywords: Biolog EcoPlates™, enzymatic activity, soil health

Introduction

Increasing demand exists to quantify the impact of agricultural management practices on physical, chemical and biological soil properties to ensure recommended practices sustain soil health / fertility and maximise farmers' profitability. While agricultural practices are known to have significant effects on soil physico-chemical properties, less is known of the associated changes on soil biological properties. Microbial biodiversity is an integral part of soil quality and crucial to maintain ecosystem function. Monitoring the effect of management practices on soil microbial communities' functional diversity and activities will enable researchers to develop biological indicators for sustainable crop production. The main objective of this study was to quantify the effects of various tillage practices and cropping sequences on soil microbial diversity and activity as potential soil quality indicators.

Materials and Methods

Soil samples were collected during pre-planting (October), mid-season (January) en pre-harvest (June) from selected treatments at the Zeekoegat Conservation Agriculture Trial, Roodeplaat, South Africa, between October 2008 and June 2013. The influence of reduced tillage (RT) and conventional tillage (CT), and different planting systems, i.e. maize monoculture (MM), maize/soybean rotation (MS), and maize/legume intercrop (ML) on soil microbial community functional diversity and enzymatic activity was determined. A portion of the soil samples were inoculated into Biolog EcoPlates™ (Biolog® Inc.) to determine the functional diversity of soil microbial communities. The other portion of soil was utilised to determine soil microbial enzymatic activity, viz microbial activity through the soil microbial community's ability to convert soil carbon, phosphorus and nitrogen into readily available forms for plants (Deng & Tabatabai, 1997). This ability was assayed by measuring ß-glucosidase, phosphatase (alkaline and acid), and urease activities in the soil (Dick *et al*., 1996). Data was statistically analysed using STATISTICA 6 (StatSoft, Inc ©) by cluster analyses, one-way ANOVA, and homogenous grouping with Fisher's Least Significant Difference (LSD).

Results and Discussion

Soil Microbial Functional Diversity. The mechanism of colour development in Biolog EcoPlates™ is related to differences in carbon source utilisation which, in turn, appears to relate to the number of microorganisms able to utilise the substrates within the wells of the EcoPlate as a sole carbon source. The produced patterns represent microbial metabolic response useful in the characterisation of soil microbial communities (Garland & Mills, 1991). The influence of cropping systems and/or tillage practices implemented in this conservation agriculture trial on soil microbial functional diversity is shown in dendograms (Figure 1). Cluster analysis was performed to assign treatments into groups, so that treatments in the same cluster are more similar to each other than to treatments in other clusters. This is clearly illustrated in Figure 1, by the two separate main clusters caused by reduced tillage (RT) and conventional tillage (CT). The influence of the different cropping systems is illustrated in the separate sub-clusters within each of the main clusters. PCA analysis (results not shown) also revealed a clear shift in functional diversity as a result of the agricultural practices used in the previous season and their influence on root exudates composition, and their availability to soil microbial communities. The composition of root exudates is greatly influenced by the crop present. The difference in root exudate composition between crops thus contributes to the difference in physiological profiles of soil microbial populations. The released root exudates attract microbial populations that are especially well adapted to utilise the specific compounds very rapidly.

Soil microbial enzymatic activity. Enzyme assays are process-level indicators and a culture-independent method. The activity of any soil enzyme assayed is the sum of active and potentially active enzymes from all the different sources. Results are presented as a means of determining the potential of soil microbial communities to degrade or convert substrates. Soil enzymatic activities, thus, microbial activity, have been used to evaluate the fertility of the soil and the functioning of the ecosystem. The influence of different cropping systems and tillage practices on the activities of four enzymes, i.e., ß-glucosidase (Table 1), alkaline phosphatase, acid phosphatase and urease (results not shown), were analysed for this trial as a measure of soil microbial activity. Comparative results indicate an overall increase in soil microbial activity from the first year up to the third year, irrespective of agricultural practice. Results indicate higher ß-glucosidase alkaline phosphatase activity under reduced tillage (RT) practices, compared to conventional tillage (CT). Over a 3-year period, cropping systems also influenced enzymatic activity, with maize monoculture (MM) treatments demonstrating the highest ß-glucosidase activity, maize/soybean rotation (MS) the lowest activity, and maize/cowpea (ML) intercropping systems an intermediate enzyme activity in the third year (Table 1).

Agricultural practices influence sensitive soil biological properties as indicators of soil health/fertility (Batisda *et al.*, 2012). During the course of this trial, reduced tillage practice had a seemingly favourable effect on soil microbial diversity and enzymatic activity. Stimulation of soil microbial populations with the correct agricultural systems could promote availability of carbon sources for microbial utilisation (Zak *et al*., 1994). This influences enzymatic activity and soil microbial diversity; ultimately resulting in increased mineralisation rates and faster nutrient recycling. In due course, these factors could eventually result in increased soil quality and fertility, resulting in a significantly beneficial effect on the sustainability of agricultural management practices.

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Figures and Tables

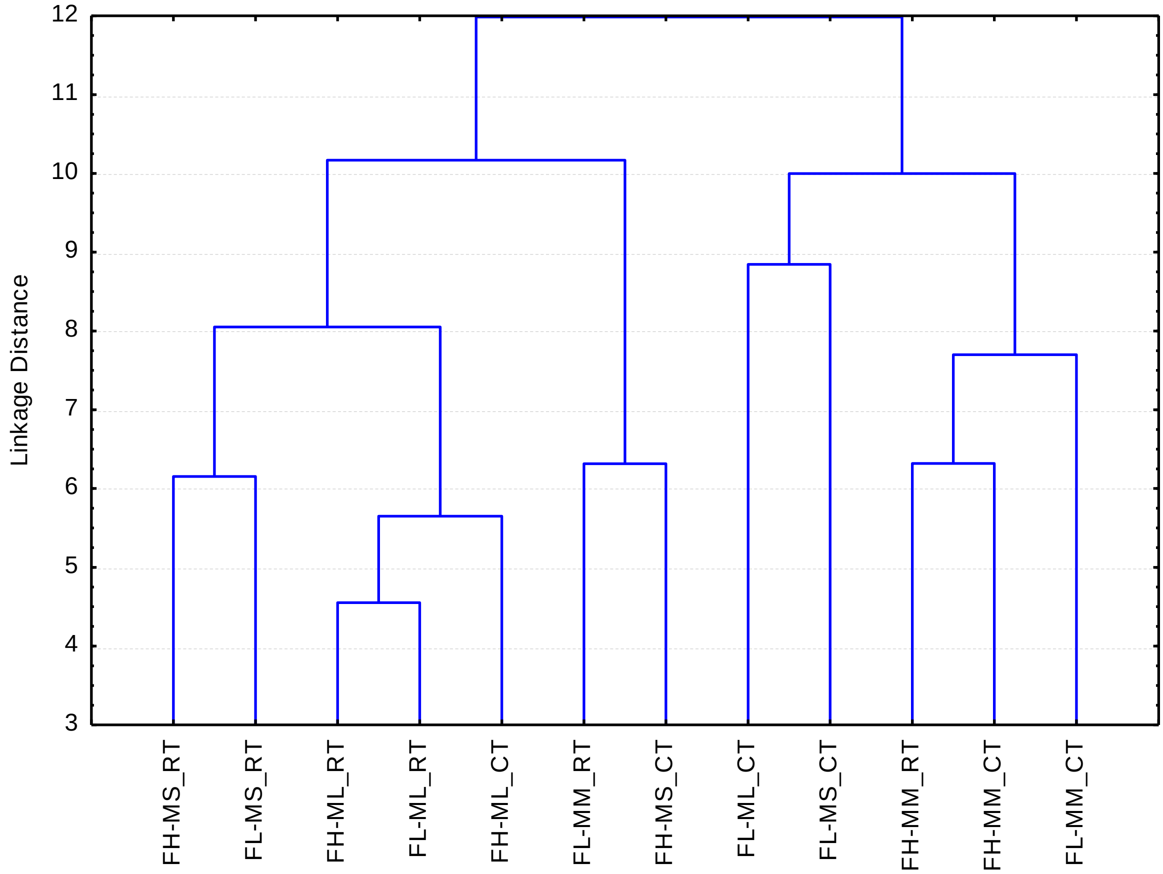

Figure 1: Cluster analyses illustrating the influence of cropping systems (MM = maize monoculture, MS = maize/soybean rotation, ML = maize/legume intercrop) and tillage (RT = reduced tillage, CT = conventional tillage) on soil microbial functional diversity.

Table 1: The influence of cropping systems (MM, MS, ML) and tillage (RT, CT) on ß-glucosidase activity over a period of 3 consecutive years

Treatment	ß-glucosidase activity (*p*-nitrophenol µg/g/h)		
	2009	2010	2011
MM_RT	591.35	1100.44	2647.30
MS_RT	591.86	1184.62	2309.70
ML_RT	n/a *	1085.87	2432.72
MM_CT	544.78	933.39	1452.20
MS_CT	603.66	762.00	1274.54
ML_CT	n/a *	1012.59	1413.65

* n/a = data not available

What explains minimal usage of minimum tillage practices in Zambia? Evidence from District-representative data

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Key words: Conservation farming, agriculture, minimum tillage, planting basins, ripping, double hurdle model, rainfall variability, Zambia

Introduction

Conservation agriculture or conservation farming (CF) as it is often called in Zambia, is widely believed to have potential for promoting sustainable agricultural productivity growth (Haggblade and Tembo, 2003; Baudron *et al*., 2007; Arslan *et al.*, 2013). CF technologies practiced in Zambia involve dry-season land preparation using minimum tillage methods (zero tillage, ripping and/or planting basins); retention of crop residue from prior harvest; planting and input application in fixed planting stations and crop rotations. Although CF has been promoted for more than two decades in Zambia, there is a dearth of reliable nationally-representative evidence on the extent to which CF practices have been adopted by farmers. Available evidence is based on case studies, small samples, and one-season snap-shots in selected regions, leading to widely differing impressions about the extent to which farmers are taking up CF practices as a means to raise their productivity and as a response to climate change (e.g., Haggblade and Tembo, 2003; Baudron *et al*., 2007; Nyanga 2012).

This study was designed to fill this gap by providing nationally-representative evidence on trends in two of the most important CF practices (planting basins and ripping) over a 5-year period. The study objectives were fourfold: i) To examine trends and spatial patterns in the use of planting basins and ripping from 2008 to 2012; ii) to determine factors influencing farmers' decisions to use planting basins and ripping; iii) to determine the influence of lagged rainfall shocks on farmers' decision to use planting basins and ripping; and, iv) to identify the factors affecting how much land farmers cultivate using minimum tillage practices.

Materials and Methods

The study used pooled cross-sectional data from Crop Forecast Surveys (CFS), collected annually by the Central Statistical Office (CSO) and the Ministry of Agriculture and Livestock (MAL) for the period 2008 to 2012. CFS data are collected annually from about 13,600 farm households across the country, giving a total sample of roughly 63,000 households over the 5 year period in the current analysis. These farmers are exposed to CF promotion programs for varying durations depending on their specific locations. We also used rainfall data for the corresponding agricultural seasons obtained from the Zambia Meteorological Department (ZMD). We report trends in minimum tillage use (defined here as using either planting basins or ripping as the main form of land preparation on any field by a farm household). Instrumented bivariate probit and double hurdle econometric models were used to determine factors influencing farmers' decisions to use minimum tillage and the amount of land allocated to particular minimum tillage practices, while controlling for potential endogeneity resulting from "program placements effects" of CF promotion activities. Because such programs only operate in selected areas, there are likely to be non-random unobserved characteristics that may influence CF adoption. We therefore use an Instrumental Variables approach to address the potential endogeneity problem. The IV used was a bivariate variable identifying districts where the Dunavant Company operated its programs in Zambia.

Results and discussions

Descriptive results and discussions

National trends in use of ripping and/or planting basins among smallholder crop farmers from 2008-2012

Results show an estimated 51,000 farmers or only 3.9% of Zambia's smallholder farmer population, practiced minimum tillage in 2012. However, there has been an upward trend in CF use since 2008, when only 1.8% of farmers practiced minimum tillage (Figure 1). Planting basins is the more common form of minimum tillage, being used by 39,000 (3.0%) of farmers nationwide in 2012, compared to only 12,000 (1.0%) for ripping. Use of planting basins has more than doubled over the 2008-2012 period, while use of ripping only increased marginally. However, use rates for both planting basins and ripping were highly variable between 2010 and 2012. Moreover, and perhaps surprisingly, the percentage of farmers using either form of minimum tillage was less than 10% even in the four provinces where CF has been most actively promoted in Zambia. Given the apparently huge benefits associated with the use of minimum tillage and conservation farming in general (e.g., Haggblade and Tembo, 2003) and the fact that the technology has been promoted for over two decades, the stubbornly low use rates observed in the districts where CF has been most actively promoted for over two decades raises questions about the constraints that farmers face in utilizing these practices.

What explains low and variable use of minimum tillage in Zambia?

Results from focus group discussions (FGDs) held in Chama, Choma and Petauke districts highlighted two main reasons for low use of minimum tillage in Zambia: i) high labor requirements of some practices like basins at times when labor is engaged in other activities; ii) high cash costs associated with purchase of requisite implements (Chaka hoes for basins and ox-drawn implements for ripping) and inputs like herbicides, hybrid seed and mineral fertilizers. Other reasons for low CF uptake drawn from literature on sub-Saharan Africa include competing uses for crop residues, farmers' inability to leave mulch on land used for communal grazing, difficulties with implementing cereal-legume rotations proposed by CF because most farmers do not grow cereals and legumes on the same scale owing to market access problems for legumes grown in excess of household consumption requirements (Andersson and Giller, 2012).

Econometrics results and discussion

Factors influencing use of planting basins and ripping by smallholder farmers between 2008 and 2012 in Zambia

Empirical results presented in Table 1 indicate that male-headed households were more likely to use ripping than female-headed households and would cultivate larger parcels of land using minimum tillage in general. Additionally, results suggest that increasing landholding size is associated with higher probabilities that farmers would use minimum tillage and cultivate larger parcels of land. For each one hectare increase in landholding size, the vast majority of non-CF farmers would not increase their use of CF at all, but farmers already practicing CF would increase land cultivated under basins and ripping by 0.49 and 1.12 hectares, respectively. Our results also indicate synergies between CF and climate variability. We find that farmers are more likely to use minimum tillage practices in the season following a drought, and less likely to use these practices in the season following a flood, indicating farmers' perceptions that planting basins and ripping are appropriate for conserving moisture during drought stress, but inappropriate when rainfall is excessive. Moreover, the area under CF cultivation increases among users of minimum tillage after a year of low rainfall, and declines after years of excessive rainfall. We also find that farmers in districts where conservation farming programs have been operating are significantly more likely to use ripping and minimum tillage in general. Cattle disease is found to significantly reduce the use of ripping, which is expected as ripping requires oxen for it use.

Conclusions and implications

In summary, the main conclusions from this study are:

Despite having been actively promoted for over two decades, minimum tillage use by smallholder farmers in Zambia is less than 5% at national level and less than 10% in the top 10 districts with the highest use rates over the study period of 2008 – 2012.

There is need to revolutionize development facilitation in the area of conservation farming and design extension programs that provide farmers with economic incentives (such as phased cost share agreements for the purchase of CA equipment) to overcome constraints on the sustainable use of conservation farming practices.

More support should be given to institutions gathering and disseminating weather information in order to guide farmers' decisions regarding tillage methods, as prospects of low rainfall raise farmers' incentives to use ripping and planting basins, while the prospects of excessive rainfall make these practices less appropriate.

There is need to support programs addressing animal disease outbreaks and those linking farmers to use of tractor drawn rippers and zero tillage planters as alternative ways to implement minimum tillage.

There is need to initiate a more detailed nation-wide panel survey of farmers capable of better identifying the factors associated with adoption and dis-adoption of CA in Zambia.

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Figures and Tables

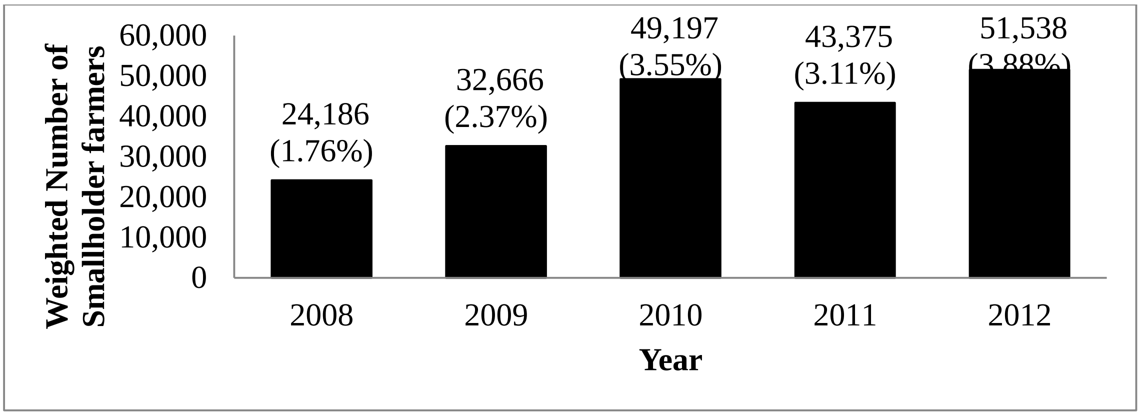

Figure 4: Trends in the total weighted numbers of smallholder farmers using ripping and/or planting basins by year from 2008-2012 in Zambia: Source: CFS 2008-2012

Table 2: Determinants of use of planting basins, ripping and minimum tillage from the Bivariate Probit model

	(1)	(2)	(3)
Variables	**Planting basins**	**Ripping**	**Minimum Tillage**
Male headed household (=1)	-0.0027*	0.0038***	0.0083**
	(0.0015)	(0.0015)	(0.0034)
Age of the household head (years)	0.0001*	0.0000	0.0001**
	(0.0000)	(0.0000)	(0.0000)
Land holding size (ha)	0.0018**	0.0060***	0.0065***
	(0.0008)	(0.0009)	(0.0010)
Rainfall stress(# of 20 day periods with less than 40mm of rain	-0.0002	-0.0004	-0.0001
	(0.0006)	(0.0006)	(0.0007)
Positive rain deviation (mm)	-0.0268***	-0.0341***	-0.0474***
	(0.0069)	(0.0082)	(0.0078)
Negative rain deviation (mm)	0.0110	0.0412**	0.0276
	(0.0131)	(0.0171)	(0.0187)
CFU has operations	0.0010	0.0328**	0.0788***
	(0.0048)	(0.0139)	(0.0279)
Agro ecological zone 2a * negative rain deviation (1, mm)	0.0500***	0.0033	0.0454**
	(0.0183)	(0.0138)	(0.0223)
Cattle disease (=1)	-	-0.0108***	-0.0187***
	-	(0.0030)	(0.0025)
Joint provincial dummy	187.77***	77.51***	205.70***
Joint year dummy	168.72***	194.07***	171.75***
Number of observations	62,708	62,708	62,708
Log Likelihood	-27,045.6	-23,738.1	-28,906.7
Bootstrap replications	400	400	400

Notes: Average partial effects with bootstrap standard errors in parenthesis; ***, **, * Significant at 1%, 5% and 10% respectively; Base ag. Zone is 1 (<800mm): Base year: 2008

The effect of planting basin size as a form of reduced tillage on crop yield in the smallholder farming systems of Zimbabwe

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Keywords: planting basin size, soil fertility status, maize yield

Introduction

Hand-hoe planting basin based conservation agriculture (CA) has been widely promoted in the smallholder areas of southern Africa, targeting resource constrained farmers with limited or no access to draught power. The technology was pioneered at Hinton Estates in Zimbabwe where high yields and effective soil erosion control were achieved (Twomlow *et al*., 2008). At Hinton estates small planting basins (SMALL) made from one hoe stroke, just enough to apply fertilizer and seed and therefore minimizing soil disturbance, were used. However other tillage methods have since been developed and promoted: the dibble stick (DIBBLE STICK) method made by punching the soil using a sharpened broom sized stick to the desired planting depth and therefore minimizing soil disturbance; medium size planting basins (MEDIUM) which measure 15 cm in length width and depth and are partially covered after planting in order to harvest runoff water; and the large planting basins (LARGE) which are 18-20cm deep in order to break the plough pan in addition to harvesting runoff water after planting (Haggblade and Tembo, 2003; Mazvimavi *et al*., 2008). However, these four tillage methods were developed in different agro-ecological conditions and their effectiveness under similar conditions are largely not known. This information will enable extension officers to appropriately recommend tillage methods to farmers as currently various promoters of CA tend to promote a particular tillage method across all agro-ecological regions. The aim of this study was to compare the four conservation tillage methods across different agro-ecological conditions and soil types. It was hypothesized that smaller basin sizes are more suitable in high rainfall areas whereas larger basins are more suitable in semi arid areas where they also harvesting runoff water.

Materials and Methods

The study was conducted both on-station and on-farm in the sub-humid and semi-arid zones of Zimbabwe. On-station experiments were conducted at Mlezu College (sandy soils) and Kaguvi College (clay soil) located in NR III (650-800 mm per annum) and at Matopos Research Station (both sand and clay soil) in NR IV (450-650 mm per annum rainfall).The trials were conducted for two seasons (sandy soil) and three seasons (clay soil) at Matopos Research Station, and for two seasons Mlezu and Kaguvi colleges. The trials tested five tillage types; Dibble stick, Pot-holing (PH), planting basin (PB), Zambian planting basin and the plough. On-farm trials (both sandy and clay soils) where conducted in Bindura and Murehwa districts (NR II, 800-1000 mm per annum), Gokwe South District (NR III, 650-800 mm per annum) and Hwange District (NR IV, 450-650 mm per annum) for one season, and only the SMALL and MEDIUM size basin tillage treatments were tested. In each district, four to seven farmers were purposively selected by ward based agricultural extension workers. A basal fertilizer rate of 200 kg ha^{-1} (7% N: 6% P: 6% K) was applied on all treatments. Maize was used as a test crop at varying N fertilizer rates (7-90 kg N ha) to represent different farmer resource endowment groups found in smallholder areas of Zimbabwe. Both grain (12.5% moisture content) and stover yields are reported.

Results and Discussion

On-station grain yield results at the clay soil site at Matopos Research Station showed that yields were generally variable and treatment differences across the tillage treatments were not significant. In the first season grain yield was highest under the Small basin (PH) tillage treatment, in the second season the yields where highest in the MEDIUM size basin tillage treatment, and in the third season yield were similar across the tillage treatments. Yields were depressed due to excessive mid-season dry spell in the third season. Fertilizer rates had no effect of grain yield, this might have been the result of limited nutrient assimilation due to moisture stress as the rains stopped soon after application of top dressing fertilizer. Similar grain yield treatments were also observed at the sandy soil site.

At Mlezu College, grain yields in the second season were significantly ($P<0.05$) higher in the MEDIUM size basin tillage compared with other tillage treatments in only under the manure plus N fertilizer treatment. In other tillage treatments, there were not significant effects. Generally yields were higher under the manure and/or fertilizer treatments compared with the control. Similar yield trends were observed at Kaguvi College. The grain and stover yields are presented in figures 1-4.

In on-farm trials only SMALL and MEDIUM size basin tillage treatments were compared. Although grain yields were higher in the medium size basin treatment, except in Murehwa District, the yield differences were not significant (Table 1). Yields were higher in sub-humid areas compared to semi-arid areas Therefore the hypothesis that smaller basin sizes are more suitable in high rainfall areas whereas larger basins are more suitable in semi arid areas where they also harvest runoff water was not confirmed.

The study, though based on 1-3 season data showed that there was no advantage in choosing a particular tillage method ahead of another across all the three agro-ecological zones which covered sub-humid to semi-arid conditions. Therefore other considerations, such as labour, ease of manure application, should be considered where recommending a suitable tillage method to farmers. However, longer term studies covering more seasons, especially on-farm, are required in order to come up with conclusive recommendations. There is also need to conduct studies to determine moisture storage and loss dynamics under the tillage methods in order to develop innovations that optimize water storage and minimize losses.

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TABLE1: MAIZE GRAIN YIELDS (KG HA^{-1}) FOR SECOND SEASON (2010/11) ON MEDIUM SIZE BASIN AND DIBBLE STICK TILLAGE TREATMENTS ACROSS FIVE DISTRICTS IN DIFFERENT AGRO-ECOLOGICAL REGIONS IN ZIMBABWE

Natural region	**District (n)**	**Medium basin**	**Dibble stick**	**SED***
II	Bindura (4)	2616	2597	732.0
II	Murewa (5)	1909	2019	849.5
IV	Gokwe South (4)	1714	1521	88.3
V	Hwange (5)	984	744	160.1

*SED – standard error of the difference of the means, n – number of trial sites

Figures

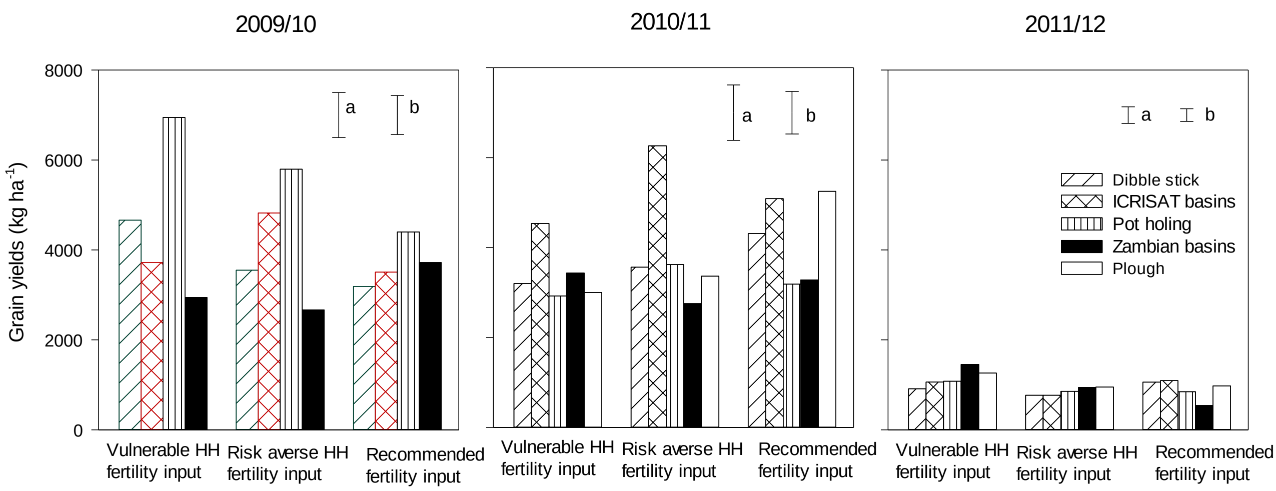

Figure 5:Grain yields of different tillage and fertility treatments on a clay-loam (West-acre-AER IV) in the 2011/12 season. Bars represent LSD at 5 % for a – tillage and b – N input

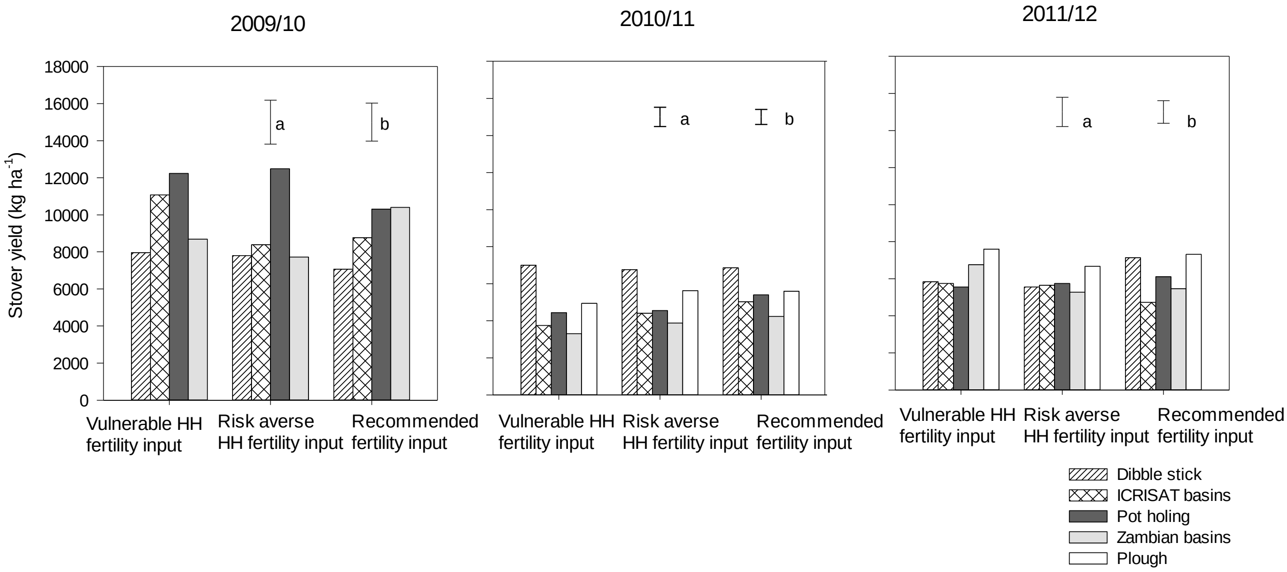

Figure 6: STOVER YIELDS OF DIFFERENT TILLAGE AND FERTILITY TREATMENTS ON A CLAY-LOAM (WESTACRE) IN THE 2011/12 SEASON. BARS REPRESENT LSD AT 5 % FOR A – TILLAGE AND B – N INPUT

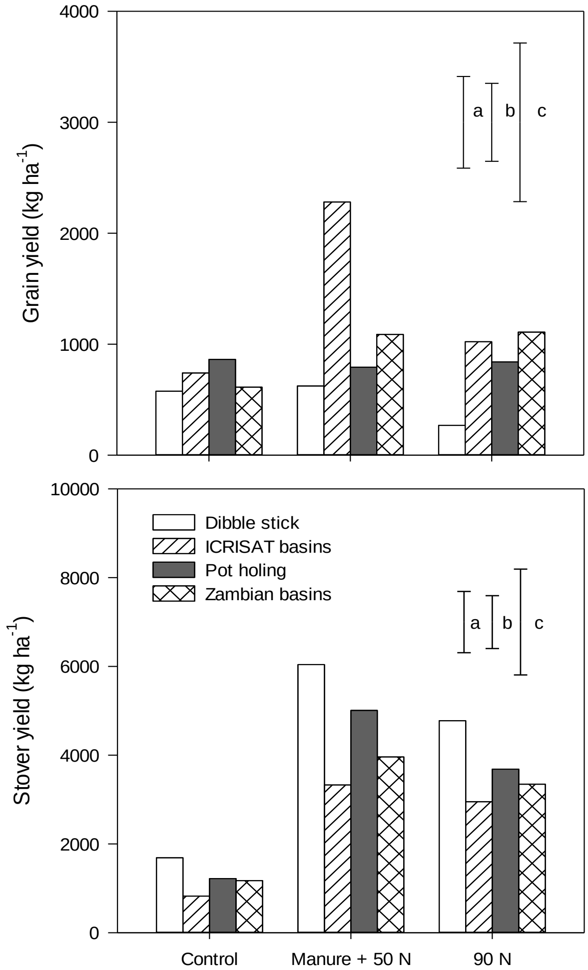

Figure 7: GRAIN AND STOVER YIELDS OF DIFFERENT TILLAGE AND FERTILITY AMENDMENTS ON A SANDY SOIL (MLEZU AGRICULTURAL COLLEGE-AER III) IN THE 2011/12 SEASON. BARS REPRESENT LSDS AT 5% FOR A – TILLAGE, B – FERTILITY AMENDMENT AND C – TILLAGE AND FERTILITY INTERACTION

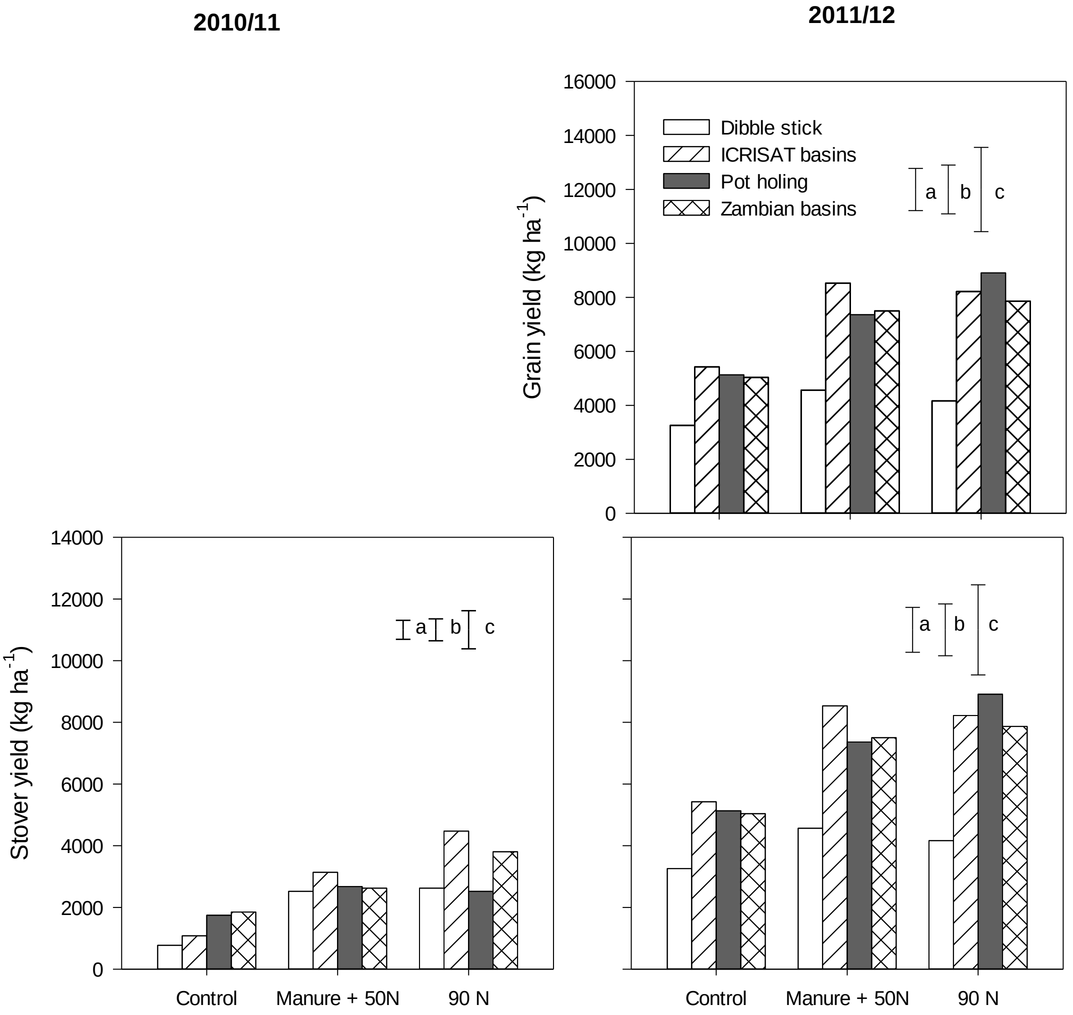

Figure 8: GRAIN AND STOVER YIELDS OF DIFFERENT TILLAGE AND FERTILITY AMENDMENTS ON A RED CLAY SOIL (KAGUVI VOCATIONAL COLLEGE-AER III) IN THE 2010/11 and 2011/12 SEASON. BARS REPRESENT LSDS AT 5% FOR A – TILLAGE, B – FERTILITY AMENDMENT AND C – TILLAGE AND FERTILITY InteRACTIONS

Spot applied lime combined with manure for effective soil acidity management and increased crop yield

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Keywords: compost, conservation agriculture, flocculation, Zambia.

Introduction

Yields on smallholder farms have remained low in Zambia, averaging around 1.5 - 2 t ha^{-1}. Among other factors, poor land husbandry practices and high cost of inputs are cited as contributing to the low production and productivity. Use of animal manure is a viable alternative to supplement inorganic fertilizers. However, there has been no scientifically tested spot application method of lime in combination with manure as practised in Conservation Agriculture (CA) systems in Zambia today. Smallholher farmers mix lime and manure in the planting basins to address both the constraints of soil acidity and low nutrient reserves.We hypothesised that (a) placing OM over lime would ease movement of lime to address subsoil acidity; (b) Mixing of lime and OM would restrict movement of lime because of interaction between the two resources. The main objective of this study was to identify an effective spot-placement method of manure and lime in combination for effective translocation of lime.

Materials and Methods

The soil used was Misamfu Yellow Soil Series collected from Region III. Compost employed in the study had been composted for five months. The soil was ground and sieved to pass through a 2 mm sieve. One metre plastic columns with 13.75 kg soil added to a height of 80 cm were used. Treatments were added to the top 20 cm of the columns. Limed treatments received 30 g lime while 60 g was given to composts treatments. Five grams Compound D fertilizer (10:20:10; NPK + 6% S) was added as a blanket at planting. The columns were watered twice a day with up to 500 ml of deionized water for a total of twelve weeks. The plants were cut, chopped and placed in tussel bags and fresh sample weights taken. These were dried in an oven at 70^0C for 72 hrs. Dry sample weights were taken. The soil column was devided into 0-10, 10-20, 20-40, 40-60 and 60-80 portions.

The test soil had a marginal pH (5.4 in H_2O), low in Calcium (100 ppmCa), potassium (25 ppmK) and Organic Carbon (0.89%OC) while had adequate levels of Magnesium (140 ppmMg) and Phosphorus (23ppmP). The compost manure had 390 and 240 ppm Ca and Mg respectively. Lime used is dolomitic with a neutralizing value (NV) of 100 % and 47.7% $CaCO_3$ and 40.1% $MgCO_3$equivalents.

Results and Discussion

Table 2 shows yield attributes following application of different placement treatments of lime and compost manure, including average plant heights, shoot and root yield. Placement of lime overlying compost (CB+LT) treatment gave 35% more shoot biomass yield than the other placement treatments, contrary to what was expected.

Placement of lime overlying compost (CB+LT) recorded the largest increase in pH at subsurface soil level, 60-80 cm column depth (**Fig. 1**) with 1.35 pH units rise attributable to lime. This probably explains the high dry matter yield reported above as the root system was able to explore a larger soil volume. Conversely, placement of compost overlying lime and mixture treatments had highest pH at 0-20 cm and less so beyond, suggesting negative influence of the lime on the mobility of the alkalinity from the compost as it percolates through the limed portion of the column. This suggests that direct contact of lime with OM, either solid or in solution through the labile organic colloids has no direct positive influence on the movement of the lime. This could be attributable to flocculation of the colloidal particles on the lime surface (Sparks, 1995). The liquid phase of OM has been demonstrated to be more effective in ameliorating soil acidity than the solid phase, (Butterly *et al.* 2013; Sakala *et al.*, 2004; 2008). The soil being a variable charge, however, charge will also increase following the increase in pH (Nkhalamba, *et al., 2003*). Lime being less soluble, will form an active surface for ready flocculation of the available ions in the solubilised OM. It would be logical to argue that a Zambian smallholder farmer would get a maize grain yield increase of up to 35% by separating lime and manure in spot application, with the organic resource placed below the lime, compared to mixing the two resources as is the practice now.

Conclusions

Flocculation was identified as the main mechanism attributable to the reduced translocation of lime to the subsurface column layers.

Placement of lime overlying compost (CB+LT) has been found to be the best spot placement method for surface applied lime for effective translocation of the lime by compost to correct subsoil acidity.

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Table 1. Lime (L)/Compost (C) treatments

Treatment description	Treatment category	Trt Code
Lime bottom and compost Top	Placement treatment	LB+CT
Compost Bottom and Lime Top	Placement treatment	CB+LT
Lime, Compost and soil mixture	Placement treatment	LCSMix
Compost and soil mixture – Compost Check	Check - Compost	CSMix
Lime and soil mixture – Lime Check	Check - Lime	LSMix
0 Lime and 0 Compost - Control	Control	0L0C

Table 2. Yield attributes following application of different placement treatments

Treatment description	Code	Average Plant height (cm)	Fresh biomass yield (g/plant)	Dry Matter Yield (g/plant)	Root Yield (g/plant)	Yield Ratio (Root shoot)
Lime bottom and compost Top	LB+CT	89	156	25	11	2.3
Compost Bottom and Lime Top	CB+LT	101	151	39	14	2.8
Lime, Compost and soil mixture	LCSMix	83	133	25	11	2.3
Compost and soil mixture – Compost Check	CSMix	105	141	28	8	3.5
Lime and soil mixture – Lime Check	LSMix	45	63	5	10	0.5
0 Lime and 0 Compost - Control	0L0C	64	50	10	5	2.0
$Lsd_{0.05}$		14.9	33.5	7.7	1.0	
Cv (%)		10.3	16.3	19.6	6.8	

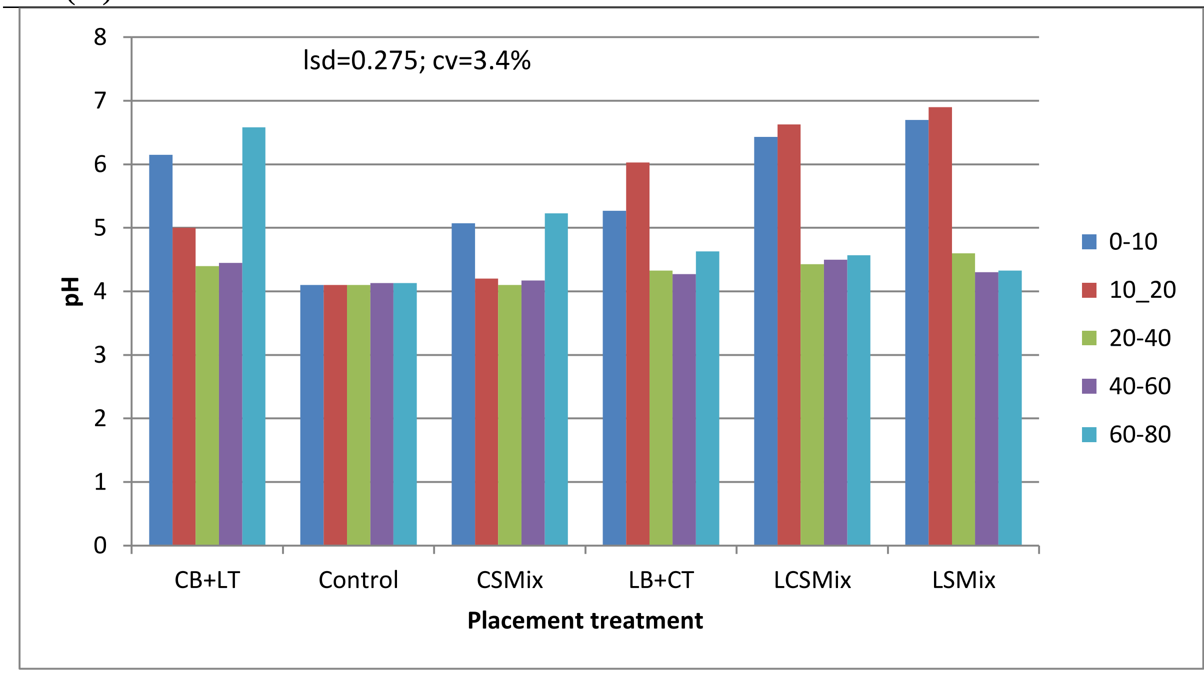

Figure 1. Interaction between placement treatment and depth on pH response

Baseline physiochemical properties of soil in selected Conservation Agriculture sites of the Lake Chilwa Basin in Malawi

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Keywords: land degradation, soil fertility, bulk density, organic matter

Introduction

The question of providing enough food and better nutrition to the world's poorest people is a big challenge especially when viewed against the very meagre crop yields and ever-increasing cost of labour and inputs (Mongi and Huxley, 1979). Malawi is no exemption because a better part of Malawi's population lives in rural areas and make out a living based on unimproved traditional agricultural production systems in marginal areas. Due to increasing population pressure, many of these fragile ecosystems have suffered rapid degradation; soil fertility loss and productivity has dropped significantly (FAO, 2008). As a result, food supplies are dwindling, and hunger and malnutrition are rampant. In Malawi, one of the areas that have been adversely dealt by land degradation is the Lake Chilwa basin (Mwafongo, 1998). Limiting nitrogen availability and soil erosion among other problems have affected productivity of soils in the Lake Chilwa basin. Climate change and variability effects have exacerbated the situation.

Conservation agriculture (CA) in the basin is seen as the most promising sustainable land use system to arrest land degradation. It offers a continuing supply of food to the affected people in the face of climate change and variability (FAO, 2008). In some cases, CA is poised to reclaim degraded areas. However, before CA intervention is undertaken, an evaluation of soil physical and chemical properties is important in order to establish the soil fertility status of an area and track any resulting changes in future.

Materials and Methods

The Lake Chilwa basin is located in the southern part of Malawi. It was formed as a result of tectonic forces and variability in terms of parent material and soils is high. The basin has been filled with sand, silt and various debris through denudation processes of the down-warped Shire Highlands Miocene peneplain. The eastern side of the lake and the river mouths of some rivers are made up of sandy soils (Mwafongo, 1998).

Soil samples were collected from Kasongo, Mpinda, Naminjiwa, Ngwelero, Nsanama and Nanyumbu extension planning areas (EPAs). These sites are located in the designated basin hotspots which are prone to drought, with variable mean annual rainfall range between 800 – 1,200 mm. In these areas poor soil quality is one of the main causes of pitiable crop performance at farm level and the areas are generally said to be of low productivity.

Three composite samples were collected from each field at a depth of 0 - 10cm, 11- 20cm and 21-30cm. Soil samples were collected from 176 fields that were to be used as CA demonstration fields and analyzed for physical and chemical properties using standard analysis procedures (Anderson and Ingram, 1989). Mechanical analysis to determine texture classes and bulk density was done using hydrometer method where Sodium carbonate and Sodium hexametaphosphate were used to disperse the soil. Soil pH was analysed using pH meter in Calcium chloride (0.01mol). Soil organic matter was analysed using Walkley-Black method in Potassium dichromate and Sulphuric acid reaction. Soil carbon was derived from the same Walkley-Black method with further calculations done based on weight of soil sample used(Anderson and Ingram, 1989).

Results and Discussion

Soil physical properties. In the Lake Chilwa basin, seven specific textural classes were observed, namely clay, clay loam, loam, loamy sand, sand, sandy clay loam and sandy loam soils. It was generally observed that Lake Chilwa basin is dominated by loam sand soils (39.7%) followed by sandy soils (27.0%). Clay (0.8%) and loam (0.3%) are the least prevalent texture classes in the basin.

Bulk density did not vary with depth in all EPAs observed under this study. The overall average bulk density was 1.50gcm^{-3}, and it ranged from 1.10gcm^{-3} to 1.60gcm^{-3}. However, Nanyumbu had the highest overall mean bulk density (1.60gcm^{-3}) while Ngwelero EPA had least mean bulk density (1.45gcm^{-3}). Statistical analysis of the results show that the mean soil bulk density (%) did not vary significantly with soil depth (P=0.05). However, the results showed that they varied significantly (P=0.05) across the EPAs.

Soil chemical properties. Results show that the soils in the study area ranged from slightly acidic to slightly alkaline with pH ranging from 4.5 – 7.2 (mean pH ranged from 5.5 to 6.0). Nsanama EPA recorded highest mean pH (6.0) whilst Ngwelero had the lowest mean pH (5.5). Generally, the soils under observation fell within the acceptable soil pH range but did not show any significant difference (P=0.05) as we dig from 0 to 30cm. However, the results showed significant differences (P=0.05) across EPAs.

Soil organic matter (SOM) content in the study area fell within the normal range of agro-ecozones of Malawi (between 2 to 6%), except for Ngwelero EPA which recorded 1.2%. It was observed that Naminjiwa EPA had the highest mean SOM content (3.32%) while the lowest mean SOM was recorded in Ngwelero EPA (1.2%). Although SOM concentration varied with depth (Figure 1), there was no clear pattern of variation. Distribution from 0 to 30cm depth along the profile varied but there was no significant variation at (P=0.05) yet the results varied significantly across the EPA (P=0.05).

Soil Carbon is the main constituent of SOM. Results show that Naminjiwa EPA had the highest mean carbon percentage as compared to other sites (1.92%). This augurs well with the recorded high mean SOM of which Carbon is an ingredient. It was also noted that carbon content variation with depth was negligible and did not show clear pattern. Statistical analysis showed that there was no significant difference (P=0.05) as we move from 0 to 30 cm in the profile but the results showed significant differences (P=0.05) across the EPAs. Normally, carbon is supposed to be more concentrated in the 0 – 10cm range because it is within this layer where there are more organic material and more microbial activities taking place (Brady and Weil, 2002).

It is expected that a review of soil status after some years of CA practice will reveal improvements in the above observed physical and chemical soil properties. CA improves soil surface aggregates, reduced compaction through promotion of biological tillage, increased SOM and soil carbon content with reductions in greenhouse gas emissions (FAO, 2008). In this context, CA offers locally adapted external inputs that are beneficial to the most vulnerable farming communities. It increases the input of fresh organic matter, controlling of soil organic material losses through soil erosion, and reducing the rate of soil organic material mineralization. CA would also allow farmers to make more use of nutrients from vegetation and agroforestry for soil amelioration. This means fields can be cultivated for a longer period of time with a sustained stable productivity, thus potentially reducing the need for land conversion. In this way, CA is considered a powerful mechanism to adapt to climate change as it increases farmers' resilience to drought and increases soil water- use efficiency (FAO, 2008).

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Figure

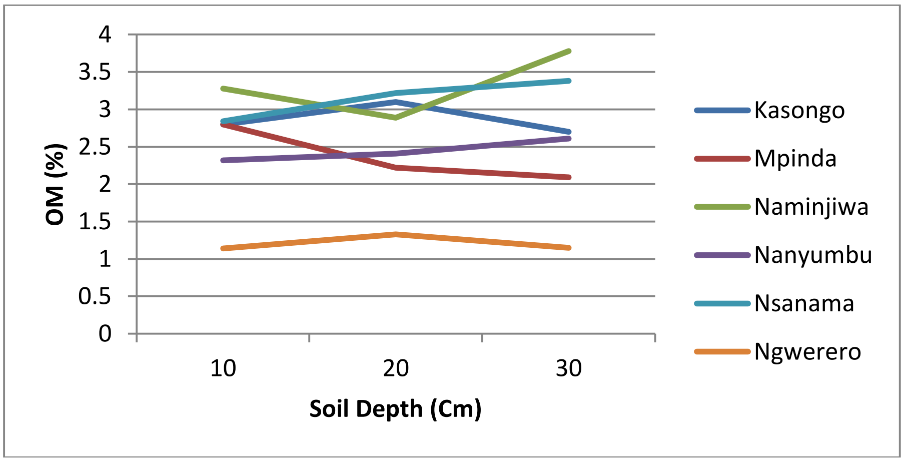

Figure 1: Soil Organic Matter Distribution by Depth in EPAs

Soil fertility restoration: An underlying pre-condition for establishing Conservation Agriculture systems on degraded fields

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Keywords: Degraded fields, Soil rehabilitation, P fertilization, soil productivity, Zimbabwe

Introduction

Anchored on three principles of (i) minimum mechanical soil disturbance, (ii) permanent organic soil cover and (iii) diversified crop rotations and intercrops, conservation agriculture (CA) has been widely promoted in smallholder farming communities of sub-Saharan Africa (SSA) as a technology to increase and stabilize crop yields and lower production costs (Hobbs, 2007). However, most of the croplands in smallholder farming systems in SSA are degraded, as evidenced by severe nutrient deficiencies and critically low SOM levels (Mapfumo et al., 2005), such that the anticipated crop yield benefits of CA are likely to be minimal in the short-term. The lack of immediate crop yield benefits to attract farmers' commitment has often been highlighted as a major bottleneck to adoption of CA in SSA (Giller et al., 2009). In order to realize the CA crop yield benefits, soil fertility management options that restore soil biochemical properties and increase responsiveness to mineral fertilizers are therefore key to 'kick-starting' productivity on these degraded croplands. As suggested by Vanlauwe et al (2010), rehabilitation of degraded soils may require a stepwise addition of combinations of different organic and inorganic nutrient sources to maximize the agronomic efficiencies of the applied nutrients and increase crop yields. This paper presents on how sequences of integrated soil fertility management (ISFM) options were used as entry points for rehabilitating degraded sandy soils on smallholder farms in eastern and southern Zimbabwe.

Materials and Methods

On-farm researcher-managed experiments were conducted, over 3 years, in Hwedza (18° 41´S; 31° 42´ E) and Makoni (18 ° 13´S; 32 ° 22´E) smallholder farming areas in eastern Zimbabwe. Hwedza and Makoni receive an average annual rainfall of over 750 mm and 650-750 mm, respectively, between November and March (Vincent and Thomas, 1961). Both areas are characterized by granitic sandy soils broadly classified as Lixisols (World Reference Base, 2006). An additional on-station experiment was established at Makoholi Research Station (19 ° 47'S; 30 ° 45'E) in the southern part of the country where soils are also granitic sands (Arenosols). For the on-farm trails (**Experiment 1**), farmer participatory research methods were first employed to investigate farmers' knowledge of soil degradation. Local indicators were identified and farmers defined a common criteria for what were perceived to be degraded soils. These indicators were then used for participatory identification of a field for experimentation in each area. Soil samples were collected from the 0-20 cm depth and analyzed using standard laboratory procedures (Anderson and Ingram, 1993). In the first year, the field sites were tilled using an ox-drawn plough followed by demarcation of plots measuring 72 m^2. The treatments allocated to the respective plots are shown in Table 2. The treatments for the first year included indigenous legume fallows (indifallows) and sunnhemp (*Crotalaria juncea* L.), with natural fallows and continuous maize as controls. The experiments were laid out in a completely randomized block design (CRBD), with 3 replicates per treatment. Cattle manure (7 t ha^{-1}) was added in the second year, followed by a maize test crop in the third year. Phosphorus was applied at 26 kg ha^{-1}. In the first year, data on biomass productivity of the different fallow systems were collected using the quadrat method. In the third year, the influence of the different ISFM options on maize grain yield response to mineral N fertilizer was assessed. The second experiment (**Experiment 2**) was conducted at Makoholi Research Station to determine the single and interactive effects of tillage (conventional, ripping and basins) and soil fertility management options on maize grain yields. The treatments were: (i) 26 kg P ha^{-1} + 120 kg N ha^{-1}, (ii) 14 kg P ha^{-1} + 35 kg N ha^{-1}, (iii) 26 kg P ha^{-1} + 90 kg N ha^{-1} and continuous unfertilized maize. The experiment was set up as a CRBD with tillage as the main plot and the soil fertility treatments randomly assigned under each tillage option. In both experiments, data were analyzed through analysis of variance (ANOVA) and treatment means separated at $P < 0.05$.

Results and discussion

Initial soil physico-chemical properties: Initial characterization showed that the soils had an average clay content of 9 % across the sites (Table 1). Plant available soil P averaged 4 mg kg^{-1}, while organic C ranged between 0.3 and 0.4 %. Cation exchange capacity (CEC) was 2.6, 2.8 and 3.1 for Makoholi, Hwedza and Makoni, respectively. Most of the soil chemical and physical properties on these fields were lower than values reported under better-managed sandy soils in Zimbabwe (e.g. Zingore et al., 2006).

Initial biomass productivity on degraded soils: Indifallow yielded > 10 t ha^{-1} above-ground biomass compared with < 3 t ha^{-1} under natural fallow. Indigenous legumes contributed > 80% of the biomass produced under indifallow. The high legume biomass under indifallow was as a result of increased plant population due to deliberate seeding confirming earlier findings in Zimbabwe (Mapfumo et al., 2005). These results suggest that herbaceous N_2-fixing legumes such as naturally-adapted indigenous legumes offer prospects for generating high initial biomass on degraded soils.

Maize yield response under herbaceous legume-based ISFM sequences: Indigenous legumes- and sunnhemp-based sequences gave the highest maize grain yield of 2.5 t ha^{-1}, with responses to mineral N fertilizer greatest at 90 kg N ha^{-1} (Figure 1). Continuous fertilized maize gave a maximum yield of 1.1 t ha^{-1} while continuous unfertilized maize yielded < 0.4 t ha^{-1}. The better mineral N fertilizer use efficiency under the legume-based sequences could have been as a result of reduced N leaching and increased water capture through addition of the predominantly legume biomass generated in the first year and cattle manure applied in the second year.

Effects of tillage and soil fertility management on maize performance on degraded soils: Although all treatments yielded < 1 t ha^{-1} of maize grain, conventional tillage gave significantly higher yields than the minimum tillage options (Figure 2). These results could be explained by better water capture under conventional tillage given that mulch was added at low rates (Baudron et al., 2012). Tillage could also have stimulated mineralization of soil organic matter leading to enhanced N availability under conventional tillage compared with minimum tillage options.

These preliminary results imply that prospects for realising crop yield benefits under CA depends on the initial soil productivity level. For degraded fields, high quality organic resources such as adapted N_2-fixing legumes are a pre-requisite to rehabilitate the soil before CA systems can be established.

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Figures and Tables

Table 1. Physical and chemical characteristics of soils at experimental sites.

	Site		
Parameter	Hwedza	Makoni	Makoholi
Clay (%)	8(0.2)	9 (0.1)	8 (0.3)
Sand (%)	81 (2)	77 (3)	81 (0.5)
Organic C (%)	0.3(0.05)	0.4 (0.03)	0.4 (0.02)
Total N (%)	0.02 (0.007)	0.03(0.005)	0.03 (0.005)
Available P (ppm)	4 (2)	4 (1)	3 (0.5)
pH (0.01M $CaCl_2$)	4.1 (0.11)	4.5(0.13)	4.6 (0.13)
Mineral N (mg kg^{-1})	17 (1)	21(4)	16 (0.5)
Exc. Ca (cmol $_{(c)}$ kg^{-1})	0.4 (0.02)	0.4(0.02)	0.3 (0.02)
Exc. Mg (cmol $_{(c)}$ kg^{-1})	0.3 (0.01)	0.2(0.01)	0.3 (0.01)
Exc. K (cmol $_{(c)}$ kg^{-1})	0.2 (0.001)	0.2(0.001)	0.1 (0.004)
CEC (cmol $_{(c)}$ kg^{-1})	2.8 (0.03)	3.1 (0.08)	2.6 (0.04)
Bulk density (kg m^{-3})	1700 (56.6)	1750 (65.8)	1700 (38.9)

Figures in parentheses denote standard error of mean.

Table 2. Sequencing framework of ISFM options on degraded sandy soils on smallholder farms in Zimbabwe

Sequencing option	Year 1	Year 2	Year 3
'Indifallow-start '	Indifallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
'Sunnhemp-start'	Sunnhemp fallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
'Natural fallow-start'	Natural fallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
Fertilized maize	Fertilized maize	Fertilized maize	Fertilized maize
Unfertilized maize	Unfertilized maize	Unfertilized maize	Unfertilized maize

Figure 1. Maize grain yields (t ha^{-1}) and responses to mineral N fertilizer different ISFM sequences on degraded soils in (a) Makoni and (b) Hwedza farming communities in Zimbabwe. Vertical bars represent standard error of the difference of means (SEDs)

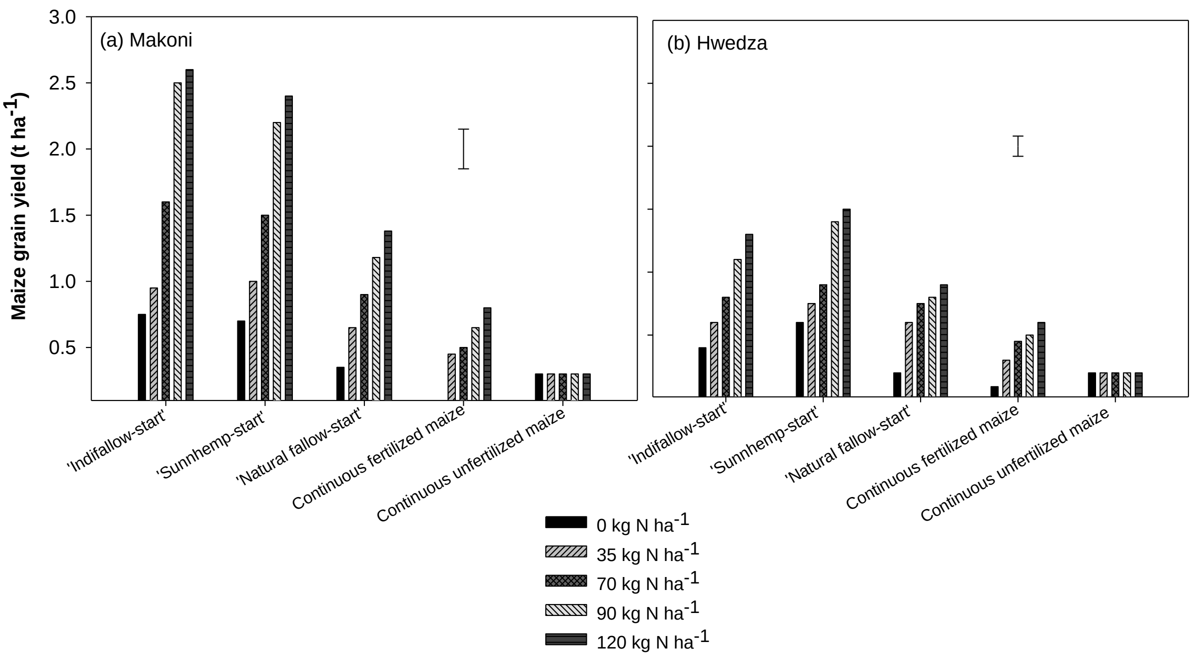
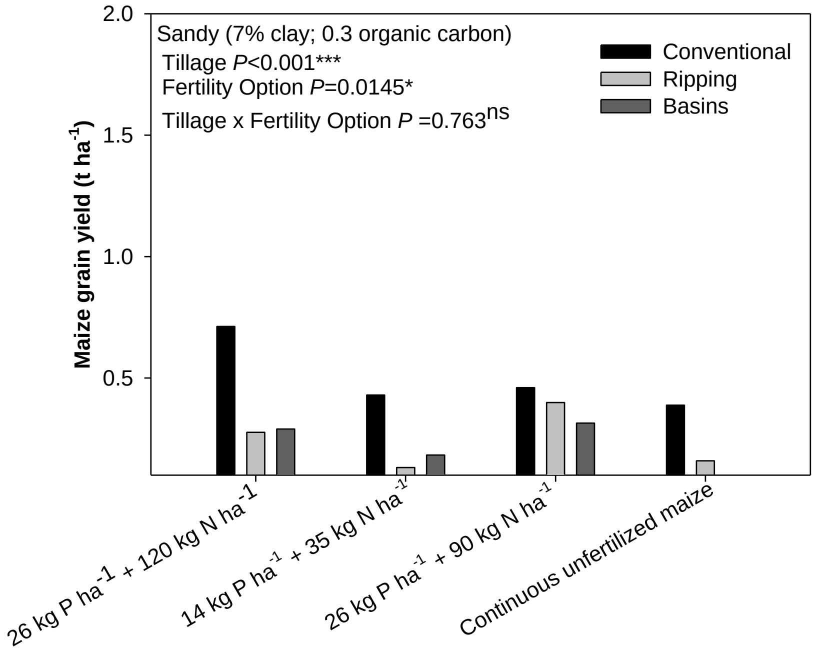


Figure 2. Maize grain yields (t ha^{-1}) under different tillage and soil fertility management options at Makoholi, Zimbabwe. *P* values refer to the following levels of significance: *<0.05, **<0.01, ***<0.001, and ns not significant.



The role research and development in the "foundations for farming system" of conservation agriculture (*a review paper*)

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Keywords: Foundations for farming, Research and Development, Centres of Excellence.

Introduction

Brian Oldreive is considered by most to be one of the pioneers of conservation agriculture in Zimbabwe, and indeed in Africa. Brian was managing a large-scale commercial farm in Muteptepa (Bindura) in Zimbabwe in the '70s. Methods for conservation agriculture for large scale commercial farming were readily available from the USA and Europe. What were not readily available were methods for small scale farmers. Out of this quest, Foundations for Farming was born with a specific mandate to give low-income small-scale farmers a system to enable them to produce enough food to feed their families and make a profit on sustainable basis.

Through demonstration plots, trial and error, and constant improvements, the method for farming now known as the "Foundation for Farming System" was developed. Foundations for Farming (FfF) moved its headquarters from Bindura to Westgate in Harare in 2004. With that move, the concept of creating "Centres of Excellence" was born. These centres are designed for improved demonstration, research, with the ability to disseminate information through well attended field days, annual reports and adoption of findings in the day to day training of the organisation[1].

This centre attracted funding, primarily from the donor community, throughout the hyper-inflation years in Zimbabwe and beyond (2006 – 2012) . During this period there was a shift away from non-replicated demonstration plots to replicated trials, with 3 off-station trials in 2011-2012. The funding to Zimbabwe was greatly reduced in 2012, and the research grant to Foundations for Farming stopped.

This paper will describe the Foundation for Farming System in detail, as it is taught today. It will describe key findings from the Research and Development (R&D work), which have come about through combination of demonstration plots, replicated trails and general observations made over many seasons. It will also examine the leads that the research team is currently pursuing.

An important aspect is how the Research and Development unit in 2013 has managed to raise money to fund its research and how this may be improved upon in future.

Material and Methods

This paper is based on the key aspects of the FfF system as given in training[2], and attempts to improve the current system. The three components of CA as outlined in the FAO definition of CA[3] are as follows:

- **Minimal soil disturbance** - Digging of planting holes for maize on a 75 cm x 60 cm grid in rainfall areas above 700 mm and 75 cm x 75 cm (in rainfall areas from 500 – 700 mm. Planting holes are small (15 cm x 15 cm x 8 cm), and the primary method of improving soil moisture status is mulch. Furrows are used for small grains and legumes in the same position as the maize rows.
- **Mulch** - is derived from the previous crop residues. Great emphasis is placed on protecting crop residues for future crops. Emphasis is placed on mulch as the mechanism for improving soil moisture and not on large planting holes or basins.
- **Crop rotation** in the traditional sense is practiced. Tight rotations with legumes are encouraged. A maize – soya – maize rotation at Westgate has been so successful that yields of 7 t/ha in maize after soya, with no fertilizer have been achieved consistently. Soya rows are super-imposed on the maize lines at 75 cm apart. Narrower spacing is used for smaller legumes like groundnuts and beans. .

The Foundation for Farming System places a lot of emphasis on management. This aspect will not be cover in the paper, but good management is considered vital in enabling farmers to adopt this new technology.

Potential areas of improvement of the system

1. Reduced costs of nutrients. Composting has become an important component of the system as a means of reducing use and the cost of inorganic fertilizers. Compost as a basal fertility treatment coupled with chicken manure top-dressings (as nitrogen source) has shown promise as a way of growing maize without any inorganic fertilizer.

2. Improving soybean growth on sandy soils with a clay content of < 10%. If soybean yields of 2 t/ha or more could be achieved on these soils, then maize yields could also be increased with a maize-soya-maize rotation. One trial has shown that when Rhizobium inoculum on soybean is of the correct strength under the right conditions of moisture and organic matter, the soya can be grown on sandy soils.
3. Research on fertility on sandy soils poses the following challenges:
   a) In-situ, sandy soils are never uniform. They have anthills which pose a real challenge to doing replicated fertility trials on farmers' lands.
   b) In a research trial there can be numerous combinations of lime, basal fertilizer, compost manure etc.

   This has led to the establishment of a screening unit made of 200 x 200 l drums. The drums are filled with sand of 8% clay content. This screening unit allows for screening of promising treatments quickly, at a relatively low cost. This system is designed to handle 50 treatments x 4 replicates. A very high level of management is needed for such a trial, but if this achieved, it allows for a quick method for screening excellent treatments from mediocre ones.
4. Research on adoption and implementation and developing integrated farm models, which include livestock and cash crops. A start has been made on this type of work, but much more needs to be done.

Results and Discussion

Early results from demo trials have shown the following trends:

1. High levels of manure could give equal yields to inorganic fertilizer.
2. 200 kg/ha of compound fertilizer plus 200 kg/ha AN was adequate for good yield on maize, in a maize-soya-maize rotation, on the soil at Westgate (40% clay).
3. No fertilizer on maize could produce a yield of 7 t/ha, if the maize is rotated in a maize-soya-maize rotation.
4. There was a trend for manure to perform better than compost in early demonstration trials, however emphasis is placed on compost because it uses 25% manure, and therefore a farmer can spread his manure on four times the area if he turns his manure into compost.
5. Where imported mulch is used (e.g. thatch grass that has been cut from the bush), early mulch performed better than late mulch and no mulch at all.
6. Levels of mulch of 4 t/ha have been shown to be optimal. Visually this represents 25 – 50% ground cover.
7. In one trial, a yield of 4 t/ha was achieved with *Rhizobium* applied to the seed and drenched onto the mulch in the furrow. This was with a very wet season. *Rhizobium* production in Zimbabwe is onto peat moss, and batches can be variable. Results show that under the right conditions with Rhizobium of good quality, yield of soybean on sandy soils can be increased. This work will be the primary focus of all new fertility trials in future. *Rhizobium* inoculum is relatively cheap, and the improved yields in soya can have an impact on maize yields as well. User –friendly formulations of inoculum which do not require chilling are a must for widespread adoption by small-scale farmers.
8. The first trial with cabbages in the Fertility Screening unit showed that the system produced reliable and useful results, despite being from pots and not the field trials.
9. *Mucuna puriens* when grown commercially on a large block as a uniformity crop grew vigorously, gave a yield of 2 t/ha and a biomass of 4 t/ha. This crop which has

been adopted in Brazil and other Latin American countries could play an important role in the system in future. It is a cheap way of establishing a good mulch cover when starting a field on the FfF system.

Cost of Research

Research is expensive per unit area and 2013, the R&D section introduced a concept whereby local Seed Houses paid a per plot fee to demonstrate their varieties. The maize varieties are along the road frontage on the main road from Harare to Chirundu. Eye catching signage will be used to highlight this "variety shop-window". Most of the varieties grown in Zimbabwe are on display in this "shop-window" for any farmer to see. This concept has proved very popular with the seed houses, and it has enabled FfF to raise enough money to fund the R&D department for 6 months.

Other ways of raising an income are at discussion stage and will be published when implemented. In future, more work will be done in "giant pots" because many treatment can be screened simultaneously and with the power of modern computing results can be analysed, producing valuable information.

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Understanding (non-)adoption of CA: contributions from Social Psychology

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Keywords: Minimum tillage, reasons for adoption, attitude, social norms, perceived control

Introduction

Conservation Agriculture (CA) has been promoted in sub-Saharan Africa in recent years to improve food security and adapt to climate change, in particular erratic rainfall and more frequent droughts (Tittonell *et al.* 2012). In order to achieve such an impact, CA has to be tailored to the agro-ecological and socio-economic context of smallholder farmers. However, even with a perfect fit, the choice to adopt CA or something else has to be made by the smallholder. While respecting this freedom, it is imperative to understand the reasons why farmers do the agricultural activities that they do in order to achieve food security in a sustainable manner. The current study takes a socio-psychological approach to understand (non-)adoption of CA practices by using the Theory of Reasoned Action (TRA) (Fishbein and Ajzen 2010). This contrasts with approaches that try to explain (non-)adoption with demographical characteristics (e.g. education level), production factors (e.g. access to market), attitudinal constructs (e.g. perception of land degradation) or personality traits (e.g. innovativeness).

Within the theory of reasoned action (see Figure 1) it is assumed that social behaviour ultimately follows from the information or beliefs that people hold about the behaviour under consideration. The intention to implement CA practices, i.e. the 'action', is mediated by 1) the attitude towards the action; 2) the social norms with respect to the action; 3) the perceived behavioural control over the action. The social norms consist of both an injunctive norm, which is the perception of what others think they should do, i.e. peer pressure, and a descriptive norm, which is the perception of what others actually do. Together these three factors will determine whether someone has the intention or not to engage in a specific action. Besides the intention, the importance of abilities and environmental factors is included as actual control (Fishbein and Ajzen 2010).

Materials and Methods

The study was undertaken in Laikipia East District of Laikipia County in the Rift Valley Province of Kenya. Laikipia East is part of the cool highlands which are characterised by the semi-humid to semi-arid agro-ecolocial zones north-west of Mount Kenya. Mean annual rainfall varies between 400mm and 700mm per year and maize, beans and potatoes are the main staple crops (Min.ofAgr 2013). Four Farmer Field Schools (FFS) were selected to represent the agro-ecological variety of Laikipia East, from which a sample of 33 respondents was selected. Another sample, consisting of non-FFS farmers (n=62) was selected with the criterion that they came from the immediate vicinity of the FFS farmers from the first sample. The gender ratios were kept proportional with the district averages. Four specific agricultural practices have been identified that are relevant to understand the adoption of minimum tillage, using the Theory of Reasoned Action: *ploughing*, *direct planting* (planting without ploughing first), *spraying herbicides* and *shallow weeding* (scraping the weeds from the soil surface without turning it). The survey was developed on the basis of focus group discussions; questions about intentions and perceptions were based on a Likert scale (1-5) to indicate likelihood or influence.

Results and Discussion

Attitudes and mindset change. The results (Figure 2) show significant differences between FFS farmers and non-FFS farmers. For ploughing, non-FFS farmers show positive attitudes while FFS farmers show negative attitudes towards ploughing. If it is assumed that the attitudes of all farmers were similar before group formation, it can be stated that the FFS has induced a "mindset change". There are some farmers who hold relatively positive attitudes towards both ploughing and direct planting, which they practice on different parts of their land. This suggests that abandoning ploughing on the whole land is more related to a negative attitude towards ploughing than to a positive attitude towards direct planting. When it comes to the effectiveness of shallow weeding, beliefs of FFS farmers and non-FFS farmers are almost the opposite, but perceived control is high for both groups. Shallow weeding is seen as a traditional practice which makes it a familiar technique, but also gives it a backward connotation to the non-FFS farmers. To improve the adoption of shallow weeding, as an alternative for deep weeding or herbicides, the focus should be on influencing the negative attitude. FFS farmers indicated that their change in attitude was generally triggered by 'seeing' how it works on the demonstration plots and by 'experimenting' on their own farm. Moreover, trainings and extension contributed to the basic knowledge and exposure to information and new ideas. Many farmers however indicated that it is difficult to change. Farmers who have heard and seen the same things, may ultimately draw different conclusions.

Social Norms. The social norms are rather neutral for all actions, and few significant differences are found between FFS and non-FFS farmers. Most farmers indicated that although they will consider the opinion of other people, they make their decisions independently. This social independence was proudly expressed by many farmers, and is partly due to the fact that most farmers are relatively new settlers in the area. Injunctive norms are significantly different, presumably because FFS membership reflects (pre-existing) social networks and thus social pressure. For the descriptive norm the values remain rather neutral because neighbouring farmers practice a mix of conventional and CA farming.

Perceived control. For all three CA practices considered, the perceived control is significantly higher for FFS farmers than for non-FFS farmers, indicating that the FFS influenced the perceived control over CA. In the case of direct planting and spraying herbicides, the attitude of non-FFS farmers is neutral (not negative), but their perceived control over these actions is limited. From what farmers explained about their perceived control, two aspects can be distinguished: access to the different kinds of inputs, and the knowledge and capacity to use them. So besides capacity building it is necessary to achieve a higher actual control that will positively influence the perceived control and therefore the intention to engage in spraying herbicides and direct planting which are crucial components of CA in Laikipia, Kenya.

In conclusion it can be noted that there is a dual function for information and training, as it influences both attitude and perceived control. Farmers will not necessarily conform to the opinion of extension officers; trainers should appeal to this independent attitude of farmers, and facilitate their making of an informed decision together with other relevant actors. The involvement of actors from the financial sector and local manufacturers would be imperative to establish positive change in the farmers' actual and perceived control over CA practices by improving accessibility to inputs and equipment.

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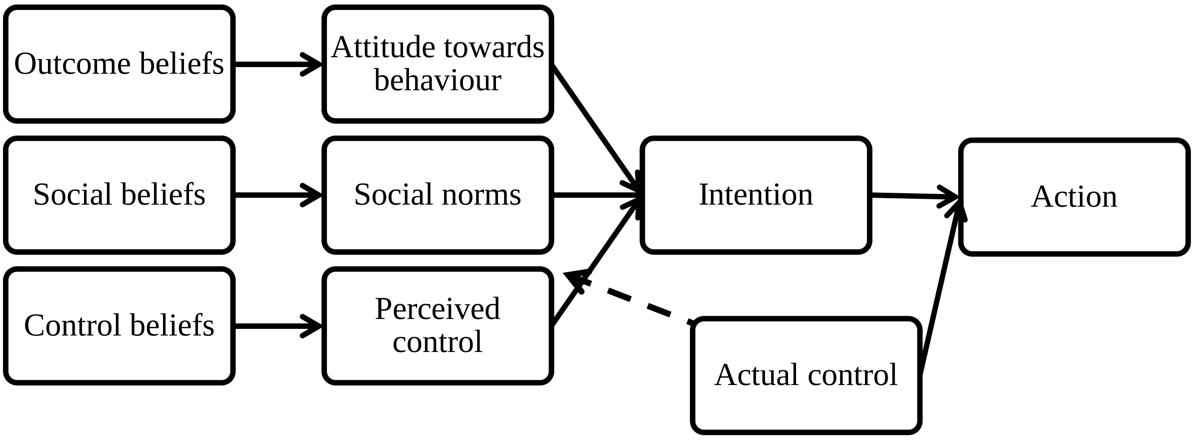
Figure 9 Simplified model representing the Theory of Reasoned Action, (Fishbein & Ajzen 2010)



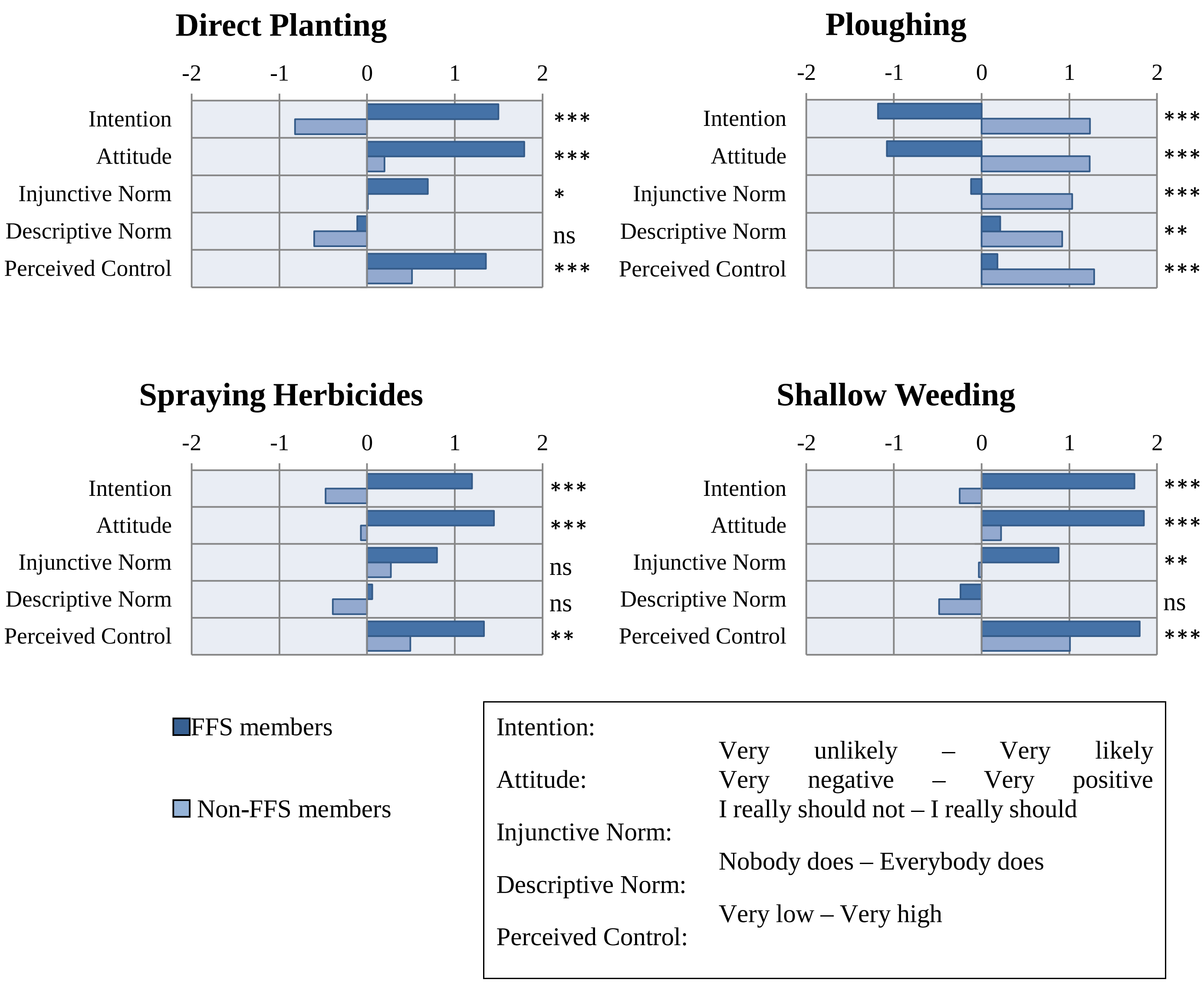


Figure 10 TRA results for four agricultural practices related to minimum tillage in Laikipia County, Kenya. Statistical significance of difference between FFS and non-FFS farmers: *** = p<0.001, ** = p<0.01, * = p<0.5; ns = not significant.

Sub-Theme 6: Harnessing the power of collaboration – networking, partnerships and communities of practice

(Papers merged with those of sub-theme 7)

Sub-Theme 7: Increasing CA adoption - how innovative technology, approaches, infrastructure support and policies can drive greater adoption of conservation agricultural systems in Africa

An evaluation of communication strategies for scaling up conservation farming techniques, Case study: Chibombo District, Central Province in Zambia.

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Introduction

The major problem behind low farmer adoption rate of conservation farming technology in Chibombo District and many other development policies in Zambia is the low knowledge intake due to inadequate information flow among farming communities. This is because a lot of farmers live far from information centres and the cultural phenomenon of resisting change is low due to low intensity. Some farmers have no interest in new ideas and do not understand the social benefit of conservation farming.

The Government policy of subsidizing chemical fertilizer under the Fertilizer Input Support Programme (FISP) has also contribute to destroying the good will of conservation farming; instead of promoting Conservation farming in its totality the policy makers are busy directing the provisions of subsidized giving out chemical fertilizer for crop production.

The genesis of conservation farming/ conservation agriculture in Zambia started in the 1980's this was due to majority of small-holder farmers experiencing hardships due to decreasing land productivity. According to (Mwale 2002) the decrease in land productivity was attributed to soil degradation due to poor farming systems, assorted with Government Policy of subsidizing chemical fertilizers for maize production. This resulted in low fertile and fragile soils due to organic matter and carbon depletion leading to increased land desertification, stagnant crop yields, poverty and food insecurity and malnutrition. Soils were acidified due to depletion of organic matter and compacted soils hampered by plough pans following excessive ploughing that impedes both plant root and soil water penetration.

In response to the mentioned factors, the development of conservation farming/agriculture emerged, where by conservation /farming (CF) implies cropping using minimum tillage or conservation tillage (CT), incorporating legumes in rotation and diversifying crops resulting in reduced soil erosion and better rain water infiltration .(Aagaard, 2007) It involves dry season minimum land tillage using hand-hoe or ox drawn rip lines laid out in a precise grid of 15, 850 basin per hectare; no burning but rather retention of crop residues from the previous harvest; to where maximum soil cover planting and input application in fixed planting stations and rotating with nitrogen-fixing crops for fertility restitution to soils. In Zambia conservation tillage practices under CF have been developed for various categories of farmers.

This paper looks at the reasons behind the low rate of farmer adoption towards conservation farming technology despite the massive success stories that Zambia continues to record in grain yields from as low as 1.2 mt/ha to 3.6 mt/ha.. The topic under study was done in Chibombo District, central province.

Location: Chibombo District is one of the six (6) Districts in Central Province and about 90 Km from Lusaka it has great potential in agricultural production. Agriculture is the main economic activity and ninety per cent (90%) of the District inhabitants depend on Agriculture for their livelihood.

The climate condition of the district is typically of agro ecological region II. The district receives rainfall averaging 800 mm to 1000 mm, however the climatic pattern varies from season to season. The climatic conditions are suitable for production of most crops such as maize, cotton, sunflower, cowpeas, beans, groundnuts, paprika, soya beans, and tobacco and so on; including several horticultural and vegetable crops as well as agro forestry tree plants such as Jatropher and Moringa.

Chibombo District has about 41,849 small holder- scale farmers, 5,153 medium scale farmers and 256 commercial farmers mainly concentrated around Chisamba area. Over seventy-five (75%) of crop production in the District is done by small scale farmers.

Methodology

To ensure that much data as possible was collected in the study; both quantitative and qualitative survey was used. Due to the triangulation nature of the study the following some of the data collection approaches used included, questionnaires, in-depth interviews, focus group discussions, use of secondary data, attending local meetings, field days and physical observations.

Findings and Discussion

Communication tools and approaches

The concept of communication on the context of development strategy can be stated as the use of communication process, techniques and media to raise people's awareness of their own situation and options they have at their disposal for activities involving change, as well as helping to resolve social conflicts and working together to reach a consensus (Ibondo 2000). In addition communication should assist people in planning activities involving change and sustainable development so that they are aware of the knowledge and qualifications needed to improve their living conditions.

A communication tools are strategies that are used to share on idea and provide feedback. Some of the communication tools include print and electronic media and publications such as poster, flyers, and handouts. A visit to District Agriculture Coordinators Officer (DACO) reviewed that main communication tools, which were through the use of extension officers who organise farmers and information conveyed by verbal, face to face and use of Focus Group Discussion (FGD). At times literature on specific topic is given to the farmers after a lesson, use of agricultural shows, seed fairs, field days, demonstration plots and any formal gathering to create awareness and information dissemination.

Kennedy Sinyangwe, the District Agricultural Information Officer (DAIO) in Chibombo district reviewed that dissemination of conservation farming messages is done through electronic and print media. Asked how this was done in a rural area, he mentioned that information from subject matter specialist on a specific topic like conservation farming that is audio recorded and information packaged and sent to the National Broadcasting Station (Zambia National Broadcasting Cooperation) for transmission.

The agriculture Information office also uses Radio Farm Forum groups. This is a special radio listening group formed in all agricultural productive area of Zambia. The group consist of up to fifteen (15) farmers. They elect their own Chairman, Secretary and Treasurer. Radio Farm forum programmes come on specific days and time on the national radio, on the day of the broadcast farmers gather at their meeting place with their radio (most forums are supplied with radio by Government). The Extension Officer/Agricultural Information Officers sits with the farmers when the programme is on, the farmers listen to the subject being discussed e.g. "conservation farming". After the programme they discuss the content and agree on the action to take-hence their motto 'Listen – Discuss – Act'. In Chibombo District, radio creates awareness and reaches a wider audience, more for the people away from the information centres and those that lack of adequate road-way and social media communication. It is not uncommon in rural areas to see men walking along listening to a portable radio.

To obtain information from print publications is a challenge because most farmers in Chibombo District have low education levels where over fifty-four (54%) per cent cannot read and write.

It was also reviewed that conservation farming manual booklets prepared by Zambia National Farmer Union (ZNFU) comes in a language that may seem too technical for farmers and almost all is in English.

For television as a source of information, only those farmers along the line of rail watch agricultural television programmes on a programme called **"LIMA TIME"** meaning *Time to Farm* which is transmitted every Sunday on Zambia National Broadcasting Corporation Television (ZNBC) at 18:00 hours. The survey also reviewed that more and more people are watching television using car batteries.

An evaluation of findings

The adoption experiences with farmers was done using farmer categories groups,

- Adaptors
- Disadaptors
- Non-adaptors.

In Chibombo District almost 75 percent of farmers who adopt conservation farming do not apply the technology in totality to their plots/fields. About one and half of the plot size is applied for conservation farming basins while the rest is ploughed under conventional farming.

Adaptors: Farmers interviewed under this category reviewed that awareness of the technology was through awareness meeting held by the local extension officers, field and practical demonstrations trials, knowledge from fellow farmers (peer to peer communication) and own farmer observations.

Asked on what persuaded them to start implementing the technology. They indicated that they had seen the good field crop and harvest of farmers that had ploughed using CF; to begin the technology most farmers indicated that they tested the technology on small portions of four to six lines of maize (Corn) and the rest of the field was left under conventional farming, then compared the yields. After the harvest they were convinced that under conservation farming the yields were better than conventional farming, this was convincing evidence to adopt CF.

Disadaptors: Evidence from a village headman in Chibombo District, Headman Chipembele reviewed that he had stopped practicing CF; he said "I now have animals and use machines to cultivate". He explained that conservation farming was for people who had little resource and now that he had increased his income under conservation farming practice he decided to graduate; bought animals and implements to help plough his field; and also he was able to afford chemical fertilizers and now plough on bigger field.

Non-adaptors: Some of the reasons for farmers not adopting the conservation farming technology was because it was laborious especially weed control management and needed large families that could manage to dig basins for water conservation and moisture retention.

Conclusion and Recommendations

Chibombo District has low education levels making it difficult for farmers to grasp the technology, some farmers were not real farmers but opportunists looking for hand out from Government and NGOs.

In all, standard conservation farming manual by Zambia National farmers Union (ZNFU) be translated into local dialect and more copies distributed to enable more farmers acquire knowledge, adopt and increase food production despite changes in the weather pattern.

Based on the results under study the following recommendations were made:-

In the short-term, farmers need continuous encouragement on the benefits of conservation farming in relation to its importance in this time of climate changes and weather patterns that have continued being experienced year in year out. More donors and promoters of CF should increase funding to CF under knowledge Management so that more farmers are aware of the technology and adopt.

In the medium-term, a deliberate policy to screen real farmers from none farmers be introduced**.** This would reduce on having seasonal/opportunist farmers that come for incentives. Access to rural communities be improved so that remote farmers are accessed and encouraged to adopt CF.

In the long-term, Conservation farming promoters, policy makers in partnership with stakeholders (NGOs) needs to work with the Ministry of Education to improve the education levels of farmers so that they are able to read and understand innovations. This would also assist women to start contributing to national development programmes as majority of women have lower education levels. In Zambia over 80 percent of the small-holder farming is done by women.

Conservation farming promoters need to utilise more hands on methods to convince farmers to adopt conservation farmers e.g. use of field demonstrations; as they say goes, " seeing is believing".

Develop more communication centres and engage more extension workers to assist in awareness creation; adoption process and explain benefits of CF as an insurance against drought and famine. This would encourage more youths to take up farming and reduce on unemployment.

To open a community radio station that will be able to broadcast agriculture and related community issues. More that the National broadcast station can hardly be picked in the area and few people own television sets.

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Fig. 1. Smallholder farmers in Kapiri-Mopshi District, Zambia.

Extending Conservation Agriculture benefits at landscape through Agricultural Innovation Platforms

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Key words: smallholders, trade-offs, coordinated action, institutions

Introduction

Natural resource management (NRM) initiatives in smallholder contexts are increasingly difficult to organise, or sustain especially due to target landscape changes. Landscape changes are necessary for wider or long term benefits such as increased biodiversity and communal harmony. Natural Resources Management is perceived as bringing limited short term benefits, not commensurate to efforts, or expensive. Natural Resources Management, especially through conservation agriculture (CA) can however benefit smallholders making a living through intensive cultivation on slopes. CA has potential for both short term farm-level, and long term communal benefits. The scope for communal NRM at landscape is dwindling. Many initiatives involve actors who operate alone or in multi-stakeholder platforms that are loosely organised to target long term benefits. To realise landscape results, multiple incentives are required, especially in the short term. Farmers residing up-the-hill and down-the-hill need to work in a structured manner, for instance to practice CA so both farm-scale and landscape benefits are realised. A local entity is first needed to ensure residents synchronise their actions by having a common vision (Makini *et al*., 2013; Nederlof and Pyburn 2012). Second, to represent, and act on behalf of residents to engage with non-farmer institutions to form Innovation Platforms.

Agricultural Innovation Platforms (AIP) here refer to alliances of stakeholder interactive diagnoses of constraints, exploring of opportunities, analyses of solutions along maize value chain to generate and facilitate technology applications for sustainable impact (see also Adekunle and Fatunbi, 2012). These structured alliances are critical to conjoin complementary processes, projects, capitals and actors to create multiple benefits, including immediate ones, and at landscape scale.

In spite of the potential of contemporary research practices especially CA, the focus to promote them at farm-level or among households cannot ensure the range of benefits and adoption possibilities. Conservation Agriculture requires systematic approaches, especially through multifunctional AIP formed along critical value chains.

The goal of this paper is therefore to analyse how CA benefits can be harnessed at landscape level, through AIP approach.

Methodology

With information from secondary knowledge and illustrations from a case study, we explain how AIP can work to generate multiple benefits at scale among smallholders. The Bungoma South Farming Innovation Platform - SIMLESA (BUSOFIPs) in western Kenya is supporting the adoption of CA. It was purposively selected for an ethnographic study; illustrative, retrospective and sequential evaluation. This AIP has significance for many African smallholder contexts. Field visits and participant observation, focus group discussions with AIP actors, and institutional mapping and analyses of local Maize Value Chain were undertaken.

Findings and Discussions

Targeting sustainability at landscape

Why is it an issue in African smallholder contexts?

Africa has the twin problem of natural resources management (NRM) and farm productivity. These two issues are linked. For instance, the more land is cultivated especially on slopes, the more land is degraded. In Bungoma, like elsewhere agriculture often happens at the expense of NRM. Smallholders share few resources; they farm on individual plots and prioritise few landscape activities. These two issues can, however, be tackled simultaneously to the advantage of both. Through AIP the many agricultural development initiatives in Africa that yield shorter term benefits can be conjoined with NRM programmes that target elusive longer term results. Conservation

Agriculture is a development approach that is being used as an entry point to conjoin many initiatives, including businesses and subsidy. These are being innovatively combined to create many incentives for short term and long term benefits in rural Bungoma.

Agricultural Innovation Platforms, CA and Natural Resources Management

We focus on AIP, including through illustrations from BUSOFIPs with regards to the complex process of managing soils, especially to sustainably improve land productivity. Initiatives that target NRM have often been stand-alone, with narrow focus and take long to generate benefits. Most rural Bungoma has limited communal owned yet shared resources such as water and land, yet individual farmers need to farm sustainably so necessary landscape benefits are realised.

Like most NRM initiatives CA is difficult to recommend among Bungoma smallholders, who see few short term incentives. However, AIP can support smallholders living on slopes to adopt CA and generate immediate and landscape benefits. Institutions involved in CA and related development have formed BUSOFIPs, a structured framework that brings together complementary (efforts to plan, execute and manage) initiatives that are interrelated. Through the Sustainable Intensification of Maize-Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) Project, a wide diversity of actors including research, seed sector, equipment dealers, fertiliser sector, water initiatives, climate change risk management, trees and livestock are partnering in Bungoma and several other sites in Africa. They're synchronising complementary initiatives into structured multi-stakeholder processes with multiple benefits. The combined actions create many more immediate benefits, and assist residents to sustain CA practices necessary to build longer term benefits for natural resources management. By networking several initiatives, a large pool of practices and results are occurring under SIMLESA, and landscape changes are increasingly possible.

Targeting landscape through complementarity of actors and actions

Conservation Agriculture innovations are usually developed to improve the sustainable use of soils for agriculture. For CA to result in broader benefits including at landscape there is need for AIP structures that support multifunctional action (Misiko et al., 2013).

Improving crop and livestock yield while at the same time conserving soils, water, ecosystems is delicate process. These need structured approaches to plan, act, and spread benefits. For instance, residents living on rocky sloping farmlands will minimise landslides, gullies or nutrient wash-away when both up-the-hill and down-the-hill cultivators collaborate beyond mere efforts to adopt CA. In many SIMLESA sites where CA is being promoted, other initiatives on different but complementary components such as livestock are being implemented. Residents in these sites have multiple, yet related problems. For instance, Bungoma smallholders have grazing problems, and still seek more farmland. BUSOFIPs is providing a framework for them to partner, and to engage outside institutions to strengthen local innovation. Smallholder representative CBO is critical as the focal point for AIP engagements. Complementarity in BUSOFIPS is found when CBOs, private companies, input dealers, livestock initiatives, among others (Figure. 1) work collaboratively.

The core activities need not involve all actors at once. In reality, each activity in BUSOFIPs only engages core actors at a time. Business models are being explored among actors for mutual relationships.

Linking CA benefits across scales

An AIP ensures benefits do not simply add up, or are only generated, but rather create new ones quickly to ensure longer term ones are realised. For instance, besides targeting improved yield on individual plots, CA can reduce conflicts resulting from degradation, etc. In the immediate term, farmers save production costs, labour, produce commercially for markets, save money that would be spend on fodder, save land from animal degradation, and so on. Different actors must realign to generate such quick benefits (see also World Bank 2012). Entry points may not necessarily be land management, but rather in business models that bring farmers reduced costs, saved money or improved yields. These are critical for sustained CA implementation to realise landscape benefits.

Trade-offs

For landscape results to be realised, there are trade-offs involved. For instance, residents on slopes need collective, coordinated approach that sees the land protected through changed use or abandoned activities. Farmers need to plant more cover crops, protect their soils through less tillage, reduce or eliminate grazing livestock on slopes, etc. With shorter term benefits, farmers can widely practice CA up-the-hill and down-the-hill, then benefits are realised at landscape and at farm level. Those up-the-hill avoid losing their crops or homes to erosion. Those down-the-hill avoid loses resulting from mud-floods, etc. When their actions are synchronised, and when AIP improve actor complementarity, then CA benefits are manifested in the short term (such as reduced drudgery and fertiliser costs) and at landscape (such as reduced landslides).

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Figures

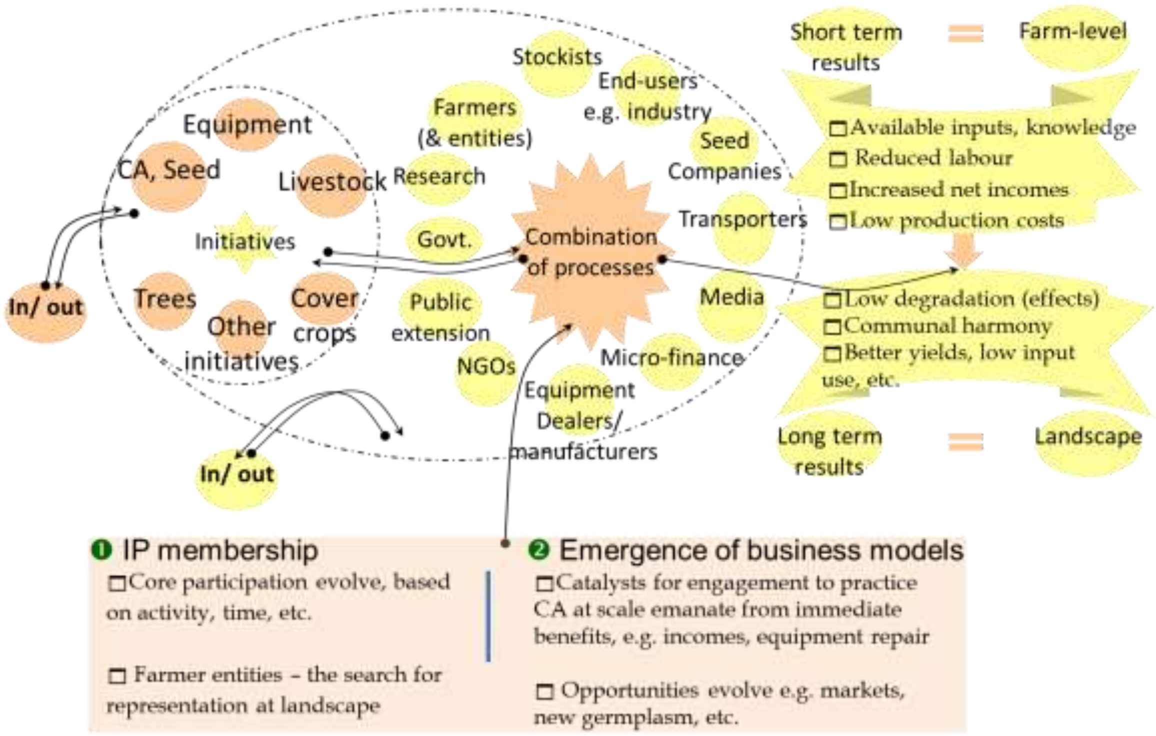

Fig. 1 Innovation platforms for Conservation Agriculture in SIMLESA (simlesa.cimmyt.org)

A reflection on the role of innovation platforms for Conservation Agriculture in Africa

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Keywords: innovation platforms, conservation agriculture

Introduction

Conservation agriculture (CA) is heralded by many as a means to achieve sustainable agricultural intensification, increase farmers' resilience to climatic variability and address soil degradation in sub-Saharan Africa (e.g. Kassam and Friedrich, 2011; Marongwe *et al.*, 2011). However, there is also increasing recognition that the spread of CA in sub-Saharan Africa has been limited because of diverse agro-ecological and socio-economic factors, and that CA needs to be tailored to local circumstances (Knowler and Bradshaw, 2007; Nkala *et al.*, 2011). The transition from conventional agriculture to CA requires technological and institutional changes, as well as a strong capacity in problem solving from farmers and service providers to adapt CA practices to the local context (Posthumus *et al*. 2011). In this position paper, we reflect on the role of innovation platforms for the adaptation and dissemination of CA in sub-Saharan Africa based on current literature and the authors' various field experiences (e.g. SIMLESA - Sustainable Intensification of Maize-Legume cropping systems for food security in Eastern and Southern Africa, ABACO - Agroecology-based aggradation-conservation agriculture, and Farmer Learning Centres) to date.

Innovation approaches for agricultural development

Farmers in sub-Saharan Africa operate in an increasingly complex and uncertain socio-economic and agro-ecological environment, which requires continuous adaptation and innovation. Over time, thinking about agricultural change has shifted from a focus on the objects of change (knowledge or technologies), towards the organizational arrangements that have to deliver those objects and bring about change. Linear approaches such as the Transfer of Technology model, which has underpinned many agricultural interventions – including the Green Revolution in south Asia - since in the 1950s and 1960s have yielded disappointing results elsewhere, notably Africa. Over subsequent decades, the importance of local farming systems, indigenous knowledge and institutional factors were increasingly recognized, resulting in new, more participatory approaches such as Farming Systems Research and Farmer Field Schools (Röling, 2009; Sumberg *et al.*, 2012). It became apparent that the roles and knowledge of other stakeholders within the agricultural system should also be taken into account, as well as the status of the "enabling environment" such as roads and communication systems and local institutions (e.g. markets, property rights and legal, policy and fiscal frameworks). Eventually, these different approaches and changes in thinking evolved into a paradigm shift from 'technology transfer' to 'innovation systems'. The innovation systems theory (World Bank, 2012) sustains that innovation in agriculture often requires a combination of changes in technology and infrastructure (hardware), knowledge, skills and information (software) and organization of agricultural systems (orgware). An agricultural innovation system (AIS) is the complex of actors (farmers, researchers, NGOs, service providers, agri-businesses, traders, agro-dealers, policy makers) and their interrelations that contribute to innovation. Innovation platforms are one of several instruments to operationalize the innovation system. These platforms provide a specific space for information exchange, negotiation, planning and action by bringing different stakeholders together to work towards a common vision or goal (Wongtschowski *et al*., 2012).

Innovation platforms for conservation agriculture: contradiction in terms?

The successful adoption of a CA package of agronomic practices not merely requires knowledge transfer, but presupposes radical changes at farm-level and beyond, including new farm implements, different on-farm labour allocations, new cropping patterns and market outlets, different institutional arrangements regarding residue management and, notably, access to different inputs and more fertilizer (van Lauwe et al, 2014). Weak institutions resulting in, for example, inefficient supply of agricultural inputs, inadequate extension services, limited access to capital and markets, and contradicting policies, obstruct potential livelihood benefits potentially derived from implementing CA (Nkala *et al.*, 2011). Furthermore, CA can increase gender and social disparities in some cases because of social and institutional factors (Beuchelt and Badstue, 2012). The introduction of CA, like any technological change in agriculture thus requires not merely adjustments at cropping system level, but ‘innovation’, that is, changes in the ‘software’ and ‘orgware’ of the entire agricultural sector. In order to address the persistent bottlenecks to CA adoption, innovation platforms are increasingly being proposed as a way to develop, adapt and promote CA practices (e.g. Tittonell *et al.*, 2012).

There is mounting evidence that CA innovation platforms currently tend to devote too much energy and resources to the technical aspects related to CA and not enough on tackling the underlying more generic problems and constraints. There is a risk that CA innovation platforms make presumptions about the problems that need addressing, and that the introduction of CA is the only way to solve these problems. In such situations, CA innovation platforms tend to lean towards the linear technology transfer model, since their aim is to promote large-scale adoption of CA. In doing so, they fail to tackle the non-linear, multi-dimensional and unpredictable nature of any innovation process. Innovation platforms, however, are not the most suitable organizational arrangement for technology delivery and adaptation, since they are premised on the idea of joint problem and opportunity identification by different stakeholders, and an interactional notion of knowledge generation.

Because of the above risks and problems, we suggest that innovation platforms should not focus narrowly on CA, but rather on broader issues and challenges, which impinge on sustainable agricultural intensification and agricultural sector development. Focusing more broadly furthermore enables innovation platforms to come up with a wider range of innovative solutions than purely technological ones – potentially (but not necessarily) supporting further work on CA-related practices. Innovation platforms should therefore:

- Experiment with possible solutions to address problems related to soil fertility, drought, limited resources and institutional constraints in order to achieve sustainable farming systems, where CA may be one of the options;

- Facilitate access to, and development of, a variety of technologies (CA being one of many) from which farmers can chose;

- Work towards creating an enabling environment that facilitates sustainable agricultural intensification and development of the agricultural sector;

- Facilitate connections of different actors at all levels so collaboration becomes more natural;

- Improve access to services, credit, transport, markets, knowledge, technologies, seeds, and agricultural inputs.

- Identify strategies that link income generation with land rehabilitation.

Innovation platforms are instruments to reduce barriers to innovation in the agricultural sector. The key issue for agricultural development is not low adoption rates of CA per se, but reducing or removing the underlying problems and constraints that farmers face. Solutions may include farming systems that are based on elements of CA, but do not adhere to all CA principles. More efforts need to be made to create a dynamic interaction between researchers, farmers in their diversity, agri-businesses, NGOs and policy makers at multiple levels and addressing constraints to innovation. This includes creating access to markets, access to agricultural inputs, and access to knowledge and multiple technologies for a diverse group of farmers. This may require a revision of agricultural policies and capacity building for institutional development and facilitation of innovation processes. Researchers have the important job to co-develop possible solutions with other actors to real problems. Experimentation and adaptation to local realities, taking diversity into account, is an intrinsic part of this process.

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Conception et mise en œuvre des plateformes d'innovation multi-acteurs autour de l'Agriculture de Conservation (AC) au Burkina

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Mots clef: forum des acteurs, comité de concertation villageois, champ-école des producteurs, résidus de culture

Introduction

En Afrique sub-saharienne, l'agriculture de conservation (AC) est promue ces dernières années comme une des alternatives possibles pour améliorer les niveaux de productivité des systèmes de production et leur résilience face aux aléas climatique dans un contexte d'accroissement des phénomènes climatiques extrêmes (Cooper et al., 2008) et de renchérissement de la demande en produits agricoles en zone urbaine. Regroupant une famille de systèmes de culture, l'agriculture de conservation s'appuie sur les processus écologiques pour produire en conservant les ressources naturelles via la mise en œuvre de trois principes complémentaires: le travail minimal du sol, la couverture végétale permanente du sol et la diversification des cultures par associations ou rotations (FAO, 2012). Au Burkina Faso, cette agriculture de conservation est expérimentée depuis 2011dans le cadre du projet de recherche ABACO (Tittonel et al., 2012). Mais, ce projet intervient dans un contexte problématique où le modèle technique promu par l'agriculture de conservation est en contradiction avec le modèle technique dominant (monoculture, usage d'engrais et labour) d'une part et le libre accès aux résidus de culture en saison sèche est un droit pour tous d'autre part (Nkala, 2011; Giller et al., 2011; Wall, 2007; Knowler et Bradshaw, 2007). Ce qui implique non seulement de démontrer aux producteurs, la pertinence d'un modèle technique AC et de faire la preuve qu'elle permet une amélioration de la sécurité alimentaire et des revenus des producteurs mais aussi de contribuer à renouveler les interactions entre producteurs au niveau des territoires. Dans ce contexte, l'enjeu est de (1) de produire des références techniques locales en adaptant les principes de l'AC aux conditions locales et de (2) favoriser la mise en réseau des acteurs afin de résoudre certaines contraintes d'appropriation de l'AC telles que l'accès des producteurs au marché des intrants et des équipements ou à l'usage du foncier et des résidus de culture en saison sèche. Pour ce faire, nous avons fait l'hypothèse que le concept de plateforme d'innovation était pertinent relever simultanément ces deux défis.

Souvent définie comme une « *situation artificielle dans laquelle un ensemble de parties prenantes relativement interdépendantes sont identifiées et invitées (généralement à travers leurs représentants) à se rencontrer et interagir dans un forum pour la résolution des conflits, la négociation, l'apprentissage social et la prise collective de décision pour une action concertée* » (Röling, 2002), le concept de plateforme d'innovation est mise en œuvre dans plusieurs projets de recherche-développement agricole en Afrique Sub-saharienne. Cependant dans les exemples de mise en application de plateforme d'innovation, ce concept renvoie à l'idée de mise en réseau et de coordination des acteurs d'une chaîne ou un maillon d'une chaîne de valeur en vue de valoriser un produit spécifique et faciliter l'accès des producteurs au marché (Tenywa et al., 2011; Nederlof et al., 2011; Adekunle et Fatumbi, 2012). Or, la mise en application des principes de l'agriculture dépasse l'échelle d'une chaine de valeur et touchent l'ensemble du système de production agropastorale. Dans un tel contexte, se pose la question de comment appliquer le concept de plateforme d'innovation pour favoriser l'adaptation des principes de l'AC ? quels contours donnés à cette plateforme? Cette communication présente notre démarche de construction de plateformes villageoises d'innovation dédiées à l'AC dans trois villages: Koumbia, situé en zone soudanienne et les villages proches de Sindri et Yilou, situés tous 2 en zone soudano-sahélienne.

Démarche méthodologique

Zone d'étude: cette communication est basée sur les données d'enquêtes réalisées dans trois villages du Burkina dont les principales caractéristiques sont présentées dans le tableau I. le village de Koumbia (12° 42' 207'' nord et 4° 24' 010'' est) qui présente un bon potentiel de production de biomasse. Les villages de Sindri (13° 41' 844'' nord et 13° 740' 72'' ouest) et Yilou (13°0'020''nord et 1°32'777''ouest) qui ont un potentiel limité de production de la biomasse.

Méthodes et techniques de collecte des données: les données ont été collectées en trois étapes:

une enquête de base a été réalisé en 2011 pour caractériser les formes d'organisation existantes dans chaque village en utilisant une grille d'entretien semi-structuré (Pound et al., 2011) auprès de 36 informateurs clés dont 27 responsables d'organisation de producteurs, 5 représentants des collectivités locales et 4 leaders coutumiers (chefs de terre et chefs du village),

des ateliers participatifs ont été organisés par zone d'étude avec les acteurs des différents niveaux du découpage administratif (niveau provincial, communal et villageois) dans le but d'impliquer les acteurs locaux dans la conception de ces plateformes. Les participants à ces ateliers incluaient en tout 22 représentants des organisations de producteurs, 8 chercheurs, 9 agents publics de vulgarisation, 5 chefs coutumiers, 9 représentants des collectivités territoriales, 1fournisseur d'intrants, 3 artisans locaux et 9 commerçants pouvant commercialiser les produits de l'agriculture de conservation,

une grille d'observation (types d'activités, types de participants, jeux d'acteurs) a été renseignée pour suivre le fonctionnement de ces plateformes tandis qu'un questionnaire d'enquête a été utilisée pour apprécier leurs effets sur le renforcement des connaissances techniques des producteurs et la mise en réseau des acteurs du système d'innovation à l'échelle du village

Résultats et discussion

Diagnostic des formes d'organisations existantes: dans les trois villages, une diversité de formes d'organisations a été identifiée (Tableau II) que l'on peut caractériser pour certaines d'endogènes (Balandier, 1971) car issue de la dynamique locale, et pour d'autres d'exogènes c'est-à-dire inspirées par des dynamiques externes au village.

Les formes d'organisation endogènes sont composées des groupes d'entraide culturale, des groupes de prestation de service et des tontines qui naissent pour répondre à un besoin ponctuel en main d'œuvre ou à un besoin d'argent liquide pour faire face à certaines dépenses (mariage, habillement des enfants, scolarité, etc). Ce sont aussi les organisations coutumières qui interviennent dans la gestion des conflits à l'échelle du territoire villageois (le conseil des délégués coutumiers à Koumbia, le conseil des sages à Yilou et Sindri), dans les cérémonies initiatiques des jeunes par les aînés, ou dans l'accompagnement de la saison des cultures. De natures diverse, ces organisations endogènes poursuivent une même finalité à savoir organiser l'action collective, renforcer la cohésion du groupe et reguler les relations intra et inter groupe.

Les formes d'organisations exogènes rencontrées sont de cinq natures: les conseils villageois de développement initiés par les pouvoirs publics, les chambres d'agriculture, les organisations de producteurs, les comités de concertation villageois (CCV) et les champs-école des producteurs (CEP). Mais, elles poursuivent également la même finalité à savoir impliquer les acteurs locaux dans les projets de développement ou recherche-développement.

Structuration et composition des plateformes d'innovation AC : sur la base de ce diagnostic, nous avons élaboré un modèle générique de plateforme d'innovation basé sur trois choix méthodologiques :

se concentrer sur l'échelle locale en n'impliquant que les seuls acteurs opérant au niveau d'un village. Ce choix est justifié par l'objectif de vouloir privilégier l'adaptation des principes de l'AC aux conditions locales compte tenu de l'absence de références techniques,

donner une place de premier ordre au CCV et au CEP compte tenu de leur expertise pour la co-conception d'itinéraires techniques innovants,

mais les élargir en incluant d'autres organisations pertinentes identifiées lors du diagnostic afin d'aborder des questions non seulement de lien au marché mais aussi d'accès au foncier et aux résidus de culture.

Notre modèle propose aussi une structuration de la plateforme en deux organes: un organe technique et un organe institutionnel (Figure 1). L'organe technique sert à générer des références techniques sur l'AC à travers la co-conception et l'expérimentation des itinéraires techniques. Il regroupe les CCV ou les CEP, la recherche et les services techniques, en particulier le service d'agriculture. L'organe institutionnel, aussi appelé « forum » a pour rôle de permettre la rencontre et l'interaction entre tous les acteurs ayant un lien avec l'AC. Il a pour vocation à faire du plaidoyer auprès des décideurs politiques locaux c'est-à-dire à l'échelle du village ou de la commune en faveur de la promotion de l'AC et de réfléchir à des thématiques et actions collectives telle que la gestion des résidus de culture, l'accès au marché, aux intrants et aux équipements, à la terre. La coordination entre les membres de la plateforme est basée sur le mode informel dans le but de prendre en compte les habitudes et routines des acteurs locaux. Le fonctionnement des plateformes se fait à travers les rencontres de négociation en 2 temps des protocoles et des expérimentations (d'abord lors de comités de pilotage, puis en sessions plénières avec tous les expérimentateurs); les rencontres d'évaluation collective des résultats de ces expérimentations lors d'assemblées générales en fin de campagne agricole et à travers des formations, des visites commentées, des échanges inter villageois et l'organisation de concours inter-producteurs visant à récompenser par des prix les producteurs démontrant la bonne compréhension des principes de l'AC et l'application de son itinéraire technique. L'organisation des fora est basé sur le principe de la flexibilité où les différents acteurs se réunissent au gré de leur intérêt pour les questions à aborder collectivement. Ces fora sont animés en mobilisant des outils spécifiques tels que des travaux de groupe, des fonds de cartes ou des modèles de simulation pour faciliter la participation et la communication entre les participants.

Implication des acteurs locaux dans la conception des plateformes d'innovation: l'ensemble des acteurs pressentis pour participer à ces plateformes a été impliqué dans la conception des plateformes au cours d'ateliers participatifs. Ainsi, ils ont apprécié le fait que ce modèle intègre l'ensemble des acteurs intervenant dans le développement agropastoral à l'échelle du village. Certains participants de Koumbia ont suggéré d'intégrer les emboucheurs et les transformateurs des produits laitiers dans la structure de la plateforme en estimant qu'il s'agit des acteurs en phase d'émergence qui valorisent les produits animaux. A Yilou la chefferie coutumière à travers son représentant s'est proposé pour animer le forum en estimant qu'il s'agit d'une initiative importante qui concerne la vie du village. Tous les acteurs semblent partager par ailleurs une même vision de la plateforme d'innovation comme un cadre de rencontre, d'échanges d'information et d'expériences, et d'apprentissage sur les nouvelles techniques agropastorales dont l'AC. Mais, sans surprise chaque type d'acteur a aussi une vision propre, voire opportuniste de la plateforme. En effet, les producteurs voient en la plateforme un moyen d'acquérir des intrants et équipements agricoles et les femmes y voient un moyen d'émancipation en mettant en avant la valorisation d'activités féminines telles la production et vente du lait, du beurre de karité, du soumbala, des arachides et du niébé. Pendant que les décideurs politiques locaux y voient un canal pour améliorer leur pouvoir, les commerçants y voient un moyen d'élargir leur réseau de client. Les chercheurs et les conseillers agricoles y voient aussi un moyen d'améliorer leurs connaissances sur les systèmes de production agropastoraux et diffuser des propositions techniques. Les acteurs ont tous été à même de faire des propositions en termes de contribution au fonctionnement d'ensemble de la plateforme mais là encore sans surprise ils se sont cantonnés dans leurs rôles classiques. Toutefois, certains producteurs bien que prêts à l'expérimenter ont émis des doutes sur la faisabilité de l'AC en raison de la vaine pâture en saison sèche, de la taille élevée des superficies des champs à Koumbia et leur dispersion géographique. De même, les agents publics de vulgarisation agricole et en particulier celui de l'agriculture à Koumbia ont émis des doutes sur la possibilité d'intensifier les systèmes via ce modèle technique en opposition avec avec le modèle conventionnel. Quant aux agents publics de l'environnement, leur réticence est fondée sur l'usage des herbicides pendant la transition. L'enjeu est alors de pouvoir répondre à ces différentes attentes et convaincre tous les acteurs sur le potentiel de l'AC à travers les essais agronomiques, les campagnes de sensibilisations, la définition d'une problématique commune et la facilitation des complémentarités entre acteurs.

L'approche privilégiée dans les travaux existants pour la mise en œuvre des plateformes d'innovation est la filière avec l'hypothèse qu'elle va permettre de relier les producteurs au marché et par conséquent favoriser des changements techniques permettant d'accroitre la production. Mais cette approche filière ne peut être suffisante pour favoriser l'adaptation des principes de l'agriculture de conservation car elle exclut d'une part une partie de la réalité des organisations existantes dans les villages et jouant des rôles complémentaires dans la production agropastorale et d'autre part elle ne favorise pas une analyse systémique des défis posés par l'AC (Coughenour, 2003). Ainsi, la question des intérêts économiques ne serait plus le moteur, mais plutôt celle de la question des règles d'accès aux résidus de culture et au foncier à l'origine de nombreux conflits sociaux dans ces zones et susceptibles d'être accentués par l'AC. La durabilité d'une telle plateforme serait assujettie à l'intérêt des acteurs de vouloir définir des règles collectives innovantes.

Mise en œuvre des plateformes d'innovation: depuis la mise en place des plateformes en 2012, il y a eu 2 formations sur les principes de base de l'AC et la gestion de la biomasse, 2 échanges inter villageois, 8 visites commentées et 1 concours inter producteur dans les trois villages à l'exception de la formation sur la gestion de la biomasse qui a eu lieu à Koumbia à la demande des producteurs. En plus des producteurs, d'autres catégories d'acteurs ont bénéficié de ces formations: chercheurs, agents de vulgarisation (agriculture, élevage et environnement), leaders coutumiers (chefs de terre et chefs du village), agents de l'administration publique (préfet) et agents des collectivités locales (maire et conseillers municipaux).

Positivement appréciées par les producteurs, ces activités de formation ont contribué à renforcer les connaissances des acteurs sur l'AC (principes de base, rôles, avantages et contraintes). Une analyse comparée des connaissances des producteurs de deux villages (Koumbia et Yilou) avant le démarrage des activités en 2011 et après une année en 2013 montre une évolution de leur connaissance sur l'AC. Par exemple 8% des producteurs de Koumbia savaient citer les trois principes de l'AC en 2011 contre 97% en 2012. De même, 60% de producteurs de Yilou savaient citer les trois principes de l'AC en 2011 contre 95% en 2012.

En outre, il y a eu 3 rencontres par village et par an: une au début de la saison des pluies afin de discuter des protocoles d'expérimentation de systèmes de cultures, une avant les récoltes afin de discuter des modalités de conservation des résidus de culture en saison sèche et une évaluation collective à la fin de la campagne agricole (après les récoltes). Les discussions de protocoles suivaient la même démarche à savoir une proposition de différents systèmes de cultures ou de différents modes de gestion des résidus de culture et la sélection par les producteurs présents de ceux ayant leur préférence ou alors de nouvelles modalités. Ces discussions ont abouti dans certains cas à la validation des propositions de la recherche, dans d'autres cas au rejet conduisant à la recherche de compromis comme dans les exemples du sorgho et pois d'angole refusé à Koumbia ou de la crotalaire refusé à Sindri et Yilou.

Quatre fora ont été organisés à Koumbia et trois à Sindri et Yilou. Ces fora ont porté respectivement sur la validation du modèle de plateforme proposé par la recherche; l'élaboration d'un plan d'action et l'insertion de l'AC au sein des territoires. Les principaux groupes d'acteurs ayant un rôle à jouer dans la diffusion de l'AC ont participé à ces fora (Figure 2). Mais d'un forum à un autre, on constate que les effectifs évoluent. Le nombre des agents de l'administration publique (Préfet à koumbia en particulier), des leaders coutumiers (chef du village et chef coutumier) et des agents de vulgarisation publique (agent d'agriculture, d'élevage et d'environnement) diminue. La faible participation du Préfet de Koumbia représentant l'administration publique peut se comprendre par le fait qu'il n'est pas convié à toutes les rencontres parce qu'il n'a pas été inclus dans la structure de la plateforme au départ. Quant à celle des agents de vulgarisation et des leaders coutumiers qui sont régulièrement convié à toutes les rencontres forum, cela peut s'expliquer par les doutes et réticences exprimées par ces groupes d'acteurs lors des sessions de validation et les insuffisances de preuves sur les bénéfices de l'AC. Néanmoins on constate que ces PI arrivent pour le moment à tenir le pari de mobiliser plus de producteurs dans la conception et la mise en œuvre des itinéraires techniques de l'agriculture de conservation.

L'observation des jeux d'acteurs au cours de ces fora montre que dans l'interaction entre participants, la majorité reste peu active. Dans le groupe des producteurs, les jeunes et les femmes parlent rarement contrairement à leurs responsables et leaders coutumiers qui monopolisent souvent la parole. Quant aux agents de vulgarisation publique, agents de l'administration publique et agents des collectivités locales, leur prise de parole dépend de leur intérêt avec la question en discussion. Par exemple, ces acteurs ont peu parlé lors du forum sur la cartographie des pratiques agricoles en estimant que la question en débat concerne plus les producteurs. Ces constats préliminaires montrent quelques insuffisances de ces PI à faciliter la communication entre acteurs.

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Figures et tableaux

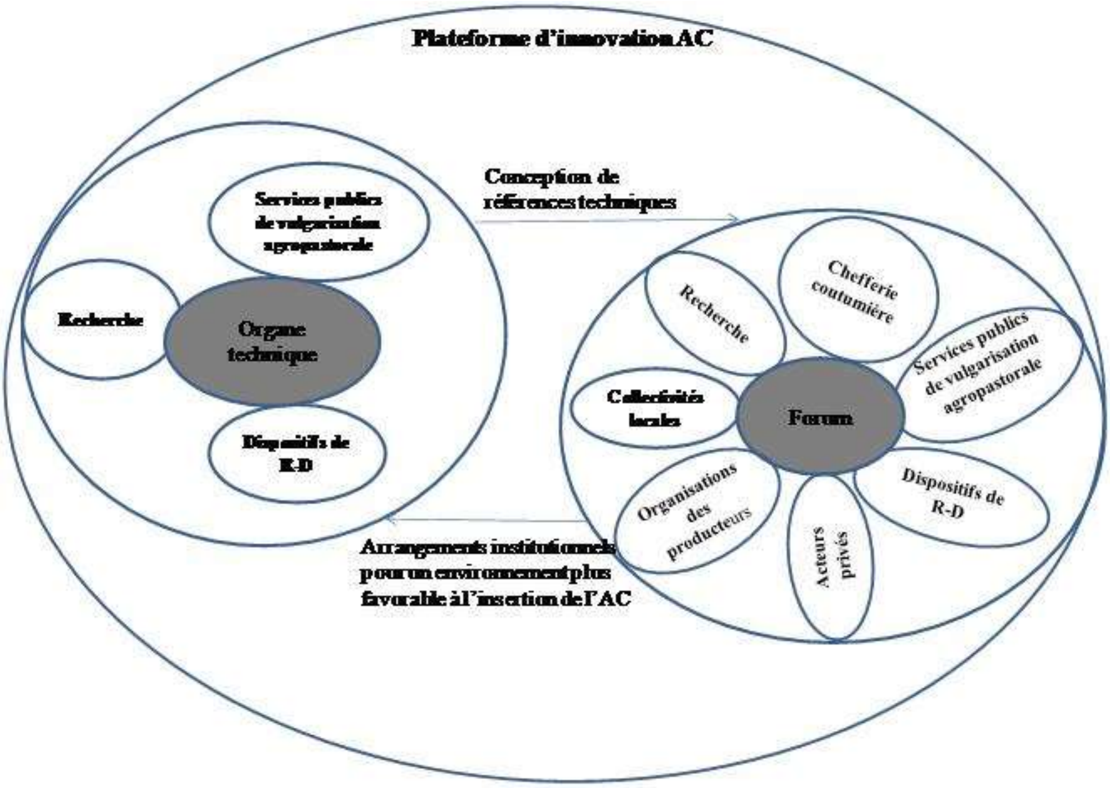

Figure 1: Structuration et composition des plateformes d'innovation autour de l'AC au Burkina

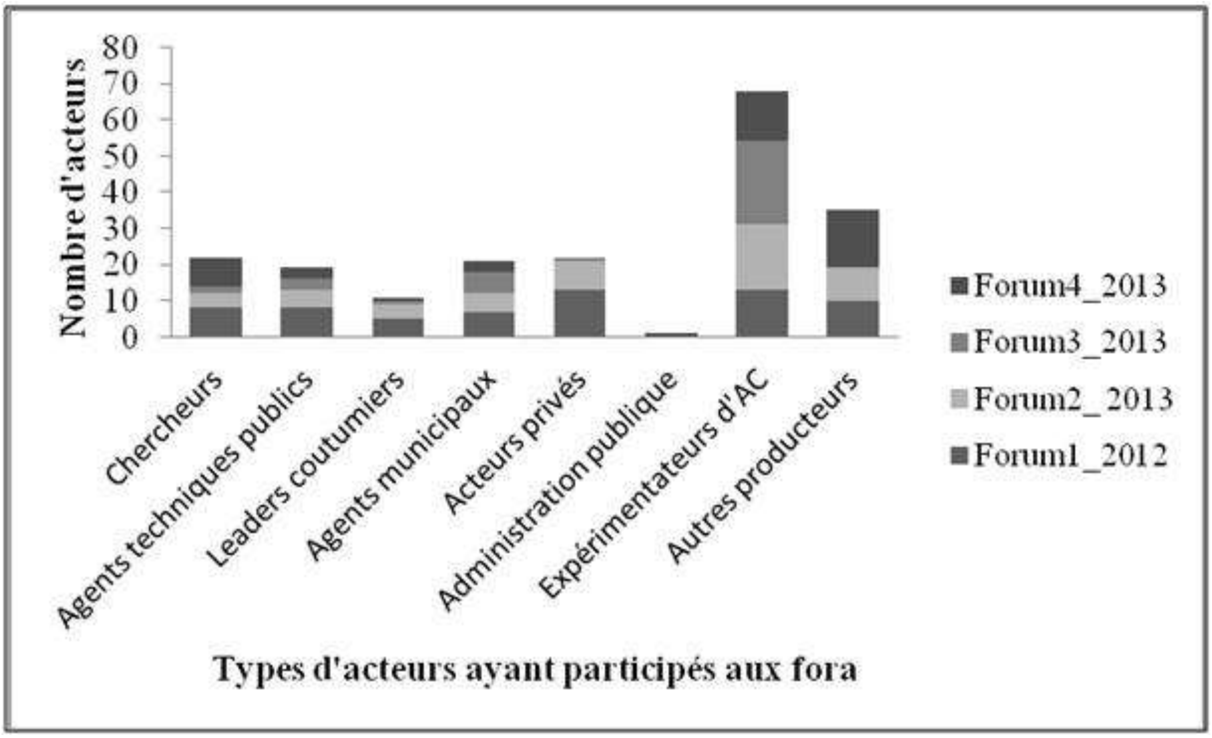

Figure 11: Nombre et types d'acteurs ayant participés aux fora par an

Tableau I: caractéristiques des villages d'étude

Caractéristiques	Zone soudanienne	Zone soudano-sahélienne	
	Koumbia	**Yilou**	**Sindri**
Climat	Soudanien Pluies : 1200 mm/ an Saison de culture : Mai-octobre	Soudano-sahélien Pluies : 900 mm/an Saison de culture : Juin-octobre	
Population (habitants)	7 000	5 000	3 023
Groupes ethniques autochtones	Bwaba,	Mossi	
Groupes ethniques allochtones	Mossi, Peulh	Peulh	
Organisation sociopolitique	Communauté villageoise	Chefferie coutumière	
Histoire AC	2010 avec les SCV	2009	2010
Principales cultures	Coton, Maïs, Niébé, arachide	Sorgho, mil, Niébé, arachide	

chargement animal	4 UBT/hectare	2 UBT/hectare	3 UBT/hectare

Tableau II: caractéristiques principales des organisations existantes dans les villages de Koumbia, Yilou et Sindri

	Dynamique d'origine	**Type d'acteurs concernés**	**Echelle d'action**	**Durée de vie**	**Composition**	**Objectif**
Groupes d'entraide culturale	endogène	producteurs	quartier	saison	Amis et voisins	Aider à la réalisation des travaux agricoles
Groupes de prestation de services	endogène	producteurs	quartier	saison	Amis	offrir une prestation de service rémunéré
Tontines	endogène	producteurs	quartier	Pluriannuelle	Parents ou amis	Avoir une rentrée d'argent
Cadres de concertation coutumiers	endogène	producteurs	Quartier et village	Pluriannuelle	Chef du village, chef de terre et chef de ménages	Gérer les conflits et les cérémonies traditionnelles
Chambre régionale d'agriculture	endogène	producteurs	Village, province, région et pays	5 ans	Représentants des organisations de producteurs	Défendre les intérêts de la profession agricole
Groupements de producteurs	exogène	producteurs	Filière	Pluriannuelle	producteurs	Défendre les intérêts des producteurs
Conseil Villageois de Développement	exogène	producteurs	village	Pluriannuelle	Population générale	Exécuter le plan de développement du village
Comité de concertation villageois	exogène	Producteurs chercheurs conseillers agricoles	village	6 ans	Groupements d'agriculteurs et d'éleveurs/conseillers agricoles	Associer les producteurs dans la recherche en partenariat
Champ-Ecole des Producteurs	exogène	Producteurs chercheurs conseillers agricoles	village	3 – 4 ans	Chefs de ménages	Faciliter les apprentissages des innovations

Conservation Agriculture in Zambia, Malawi and Ethiopia – the opportunities and constraints to adoption

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Keywords: planting basins, ripping, mulching, adoption, livestock integration, soil properties

Introduction

This paper discusses the experiences with Conservation Agriculture (CA) in Zambia, Malawi and Ethiopia. The paper shows that there are clear differences between the countries with regard to how CA is practiced. This has implication on the labour demand and the impact of CA on soil properties. The positive as well as the challenging aspects with regard to introduction of CA in these countries is discussed. The paper is based on a review of research papers from these countries and the examples presented are mainly taken from research project where the author has been actively involved.

CA in Zambia

The tillage method in CA in Zambia is either planting basins or ripping. The basins are 30 cm long 15 cm wide and 15 to 20 cm deep. The time to make the basins is similar to that of a hoe tillage (Umar al. 2012). A special hoe called the chaka hoe has been developed to simplify the digging of basins in Zambia. However, the chaka hoe is heavier than the traditional hoe and particularly the women find it harder to work for hours using this hoe (Aune et al. 2012). The original idea when introducing planting basins and ripping in Zambia was that these methods should enable the farmers to prepare the land prior to the rainy season. However, a survey that was undertaken showed that the farmers are not accepting this because they find the soil too hard to work in the dry season. They rather prefer to start land preparation after the first rains. Farmers practicing basins therefore do not sow their land earlier than those that till the land with the hoe (Umar et al. 2011). Ripping consists of opening a furrow 15 to 20 cm deep. Oxen are used to pull the ripper. The main advantage of ripping is the low labour demand for land preparation. In Zambia it has therefore been observed that farmer practicing ripping sow earlier than those not practicing ripping (Aune et al. 2012). The idea with ripping was also that this land operation should be completed before the rainy season starts. However, the farmers have not been willing to rip the land with oxen traction prior to the rainy season because of the workability of the soil as previously mentioned. One of the objectives of both planting basins and ripping has been to break the hard pan. However, a soil survey was not able to identify ploughpans in the project areas in Zambia (Umar el al. 2011). It therefore seems like the existence of ploughpans has been used as a pretext for introducing these rather deep tillage methods in Zambia. However, both experimental research and survey among farmers have shown that planting basins more than double the yields of maize compared to traditional tillage in Zambia (Umar et al. et al. 2011). There are several causes that may explain the yield benefits of planting basins in Zambia. First of all, the basins have a water harvest effect. Basins have also been found to be particularly beneficial in dry years. Secondly, the fertilizer is also placed adjacent to the seeds in the basins contributing to increased fertilizer use efficiency. The basins therefor create a more favourable microenvironment because the plants in the basins have better water supply and higher availability of plant nutrients. In Zambia it has been found that the farmers seldom establish planting basins on more than one hectare while the average farm size is about 4 hectare (Aune et al. 2012). The main reason for the limited uptake of planting basins is the high labour demand of the method. Farmers use the rest of their farm land for traditional tillage systems. Use of planting basins has been more easily adopted in Eastern Zambia because the farmers in this part of Zambia are traditional hoe cultivators. Use of planting basins has been more difficult to introduce in Southern Zambia because the farmers here are traditionally plough the land with oxen. Those who practice ripping often have more than one hectare under this method. Ripping is often combined with the use of herbicides in Zambia. The combination of ripping and herbicides contributes to labour savings both in land preparation and in weeding. The uptake of ripping has therefore been faster than the uptake of basins (Aune et al. 2012). Use of ripping is still limited by the low availability of rippers. Ripping can also easily upscaled and used on larger farms using tractors. Mulching is only to a very limited degree practiced in Zambia. The effect of CA on soil properties in farmers' fields has therefore not been apparent (Umar et al. 2011). The main reason why mulching is not practiced in Zambia is the free grazing of the animals in the dry season. Mulching therefore does not seem as a feasible practice unless some form of controlled grazing is introduced. CA should therefore be combined with livestock development.

CA in Malawi

In Malawi the traditional form of tillage is to make ridges by splitting the ridges that were made in the previous year by a hoe. This form of tillage is very labour demanding as it involves moving the top-soil. The main form of CA is direct sowing by the use of a dibble stick (Ngwira et al. 2013). This form of manual CA has much lower labour demand than the planting basing method used in Zambia. Mulching is practiced in Malawi as the pressure from grazing animals is much less here as compared to in Zambia. Direct sowing and mulching has been found to increase yield in Malawi, but CA should be combined with use of fertilizer as without fertilizer not enough mulch is produced. In Malawi it has been found that mulch have a weed controlling effect (Ngwira et al. 2013-paper in press). Uptake in Malawi is only partial as farmers use CA on one part of the land while the rest is under traditional tillage. Waterlogging problems have been reported in CA in Zambia and Malawi as mulching and basins increase the retention time of water in the field (Aune et al. 2012).

CA in Ethiopia

In Ethiopia is CA still in the early phase of development. The land is here traditionally ploughed with oxen and there is a strong cultural tradition for this tillage method (Aune et al.

2001). Farmers often plough the land 3 to 4 times before sowing. Farmers without oxen often sow late as the oxen owners will prepare their land first. The price for oxen ploughing is also quite high and in some parts of Ethiopia the oxen owner will take half of the harvest and will in addition also take the straw. Female headed household are in a particular vulnerable situation as it is not culturally acceptable for women to plough. They therefore have to hire the men to plough for them. Experiments on tillage methods in Ethiopia have shown that reduced tillage (one pass with the plough) can be an alternative to the traditional tillage with several passes with the plough (Tulema et al. 2007, Dryland Coordination Group 2012). Zero tillage has given less convincing results. Mulching is difficult in Ethiopia because of the free grazing systems. Changes in the tillage systems will also make it possible to turn livestock production from provision of traction services to more in the direction of meat and milk production.

Conclusion

CA is still quite new in Zambia, Malawi and Ethiopia and it will be too risky for the farmers to suddenly change to CA. CA is also a more demanding form of agriculture in terms of capital and knowledge, and this is probably the reason why we so far seen mostly partial adoption of CA. Partial uptake may also be considered as a risk reduction strategy as CA can give good yields in dry years, whereas traditional tillage may perform better in the more humid years. Partial uptake may also be seen as a way of spreading labour use. CA can have lower labour requirements than tradition tillage for land preparation while it has higher labour requirements for weeding than traditional tillage unless herbicides are used.

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Towards a Conservation Agriculture targeting tool for project implementers in Africa: Identifying the main elements

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Introduction

Targeting Conservation Agriculture (CA) remains a major challenge in the context of Africa's heterogeneous agro-ecologies, farmers and farming systems, socio-economic and institutional environments. Although CA can stabilize and increase yields, conserve and improve soil quality, its outcomes are site-specific (Rosenstock et al, 2014; Rusinamhodzi et al, 2011). In sites where results of using CA are positive, not all farmers achieve the required-level of management – notably early planting, timely weeding and adequate use of chemical fertilizer (Gatere et al, 2014; Aune et al, 2012; Baudron et al, 2014; Grabowski & Kerr, 2013; Vanlauwe et al., 2014).

CA adoption studies potentially provide ex-post insight into the suitability of particular CA practices and packages for particular categories of farmers in specific agro-ecological, socio-economic and institutional contexts. Yet, methodological weaknesses of these studies limit their value for CA targeting. First, data collection in CA adoption studies is often biased as it generally takes place in the context of on-going development projects that incentivize CA adoption through input support (fertilizers, seeds, CA implements).[14] Second, these studies generally use unclear and/or reductionist definitions of what is an adopter or what (set of) practices constitutes 'CA adoption' – often using the implicit definition 'practising minimum tillage on some part of the farm in year *x*'. Third, CA adoption studies tend to be limited to analyses of farm-level 'adoption determinants', largely disregarding higher scale influences affecting CA uptake, such as rural livelihoods, agro-ecological, socio-economic and institutional factors (Andersson & D'Souza, 2014).

Although on-station and on-farm agronomic experiments (e.g. Thierfelder & Wall, 2010 et al, 2013), farm-level economic studies (Pannell et al, 2014), and (market) institutional analyses (Mazvimavi & Twomlow, 2009) have contributed significantly to our understanding of the adoption potential of particular CA practices in African smallholder agriculture, ex-ante targeting of diverse CA packages remains a high priority for donors, policy makers and other

[14] An exception is Arslan et al. (2013).

rural interventionists. This paper aims to contribute to the development of a CA suitability or 'adoption potential' tool that can quickly identify suitable CA options in area, and the categories of farmers that are likely to adopt these practices. Building on the expanding literature on CA use in African smallholder agriculture and experience with the use of qualitative assessment tools – notably the QAToCA[15] tool (Ndah et al, 2010, 2014) – we explore the key elements of a quick identification tool for targeting CA interventions in Africa.

Material and Methods

QAToCA is a simple tool that was built with the aim to enable regional experts, research teams and/or managers of development projects with a focus on CA to assess the 'relative likelihood of CA adoption' (Ndah et al 2010: 2) or 'adoption potential of site-specific CA practices' in Africa (Ndah et al, 2014: 2). The tool consists of a list of questions with answer statements and scores that together determine the potential for CA adoption in a given project region (Ndah et al, 2014). Questions deal with characteristics of CA as an object of adoption, the capacity of the promoting organization(s), attributes of the dissemination strategy; institutional frame conditions at village and regional level, market conditions at the village and regional levels, and the community's perception towards CA. In this way, the tool allows for diagnosing the supporting and hindering factors of CA adoption in a given area. QAToCA has been used as a quick assessment guide in a range of CA research and development projects across Africa (Ndah et al, 2014),

Results and Discussion

From our experience with the use of QAToCA, we identified a number of limitations for its use as an ex-ante identification tool for CA suitability or CA adoption potential. These shortcomings we will address when developing a new tool. First, since it was developed as a self-assessment guide for CA proponents in on-going CA projects, it strongly focuses on the promoting organizations and their dissemination strategy (extension); the underlying assumption being that knowledge is limiting the adoption of CA, rather than the farming context (which receives less attention in the assessment). Second, in its current state, QAToCA treats all assessment criteria with the same level of importance and does e.g. not deal with factors that may fully impede adoption. This unweighed aggregation of criteria makes it difficult to sort priorities in CA targeting. Third, there is a strong possibility of bias in assessments done by stakeholders (interested parties), and as a result of the construction of knowledge in public social events such as focus group discussions (cf. Mosse, 1994). The answers people give are likely to be strongly influenced by their own expectations of, or interests in the project (Andersson and D'Souza, 2013). Lastly, the higher level analysis (at village/region scale) is unable to understand farmers' CA adoption decision-making in the context of diverse CA packages and the heterogeneity of farmers, their production objectives and constraints.

Critical components for an identification tool of CA adoption potential

[15] Qualitative expert Assessment Tool of CA adoption in Africa.

Identifying socio-ecological niches for CA practices/packages – We suggest that a quick identification tool for targeting new CA interventions in Africa uses the concept of the socio-ecological niche (Ojiem et al. 2006, Giller et al. 2009), which provides a practical framework for 'ideotyping' the contexts within which CA has most to offer. As series of bio-physical, socio-economical, and institutional factors and their interactions delineate the socio-ecological niche for a type of CA practice or package. For each factor, several criteria boundaries have to be established and are used to set the limits for the niche.

Need for multi-scale analysis – Following Sumberg (2005), with the tool we will explicitly distinguish *adoption constraints* (farm-scale) from *prerequisite conditions* (higher scales); the former referring to the 'goodness-of-fit' between the CA practice or package and the farmer (type), while the latter focuses on contextual factors, and that cannot be influenced by the CA development and dissemination process. Thus, in comparison with the QAToCA tool, the tool seeks to more explicitly identify the suitability of different CA practices/technologies at farm-level.

Heterogeneity of farmers and different technologies – CA comprises of different practices, each with their specific requirements for labour, equipment, fertilizer, etc., that are suitable to different types of farmers (and farming environments). For example, direct seeders have a high equipment cost, although there are cheaper alternatives such as rippers. In general, CA will be most rapidly adopted by smallholder farmers with adequate resources of land, cash and labour, and not by the most resource-constrained groups. Functional farm typologies based on farmers' production objectives and resource endowments (including the importance of farm size) will help in better targeting CA packages/technologies. To start with, a clear differentiation has to be made between mechanized and manual CA systems; they will clearly match different categories of farmers.

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Increasing surface mulch in African crop-livestock mixed systems

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Introduction

Due to the multiple benefits livestock generates, feeding crop residues to livestock is particularly common in the developing world, where 75% of the milk and 60% of the meat are produced in mixed crop-livestock systems (Herrero *et al.*, 2010; Valbuena *et al.*, 2012). When insufficient quantities of crop residues are retained as surface mulch, minimum tillage alone may lead to lower yields compared with the current farm practices, particularly on soils that are prone to crusting and compaction (Baudron *et al*., 2012). Based on those observations, some authors have concluded that conservation agriculture (CA) would only fit in a limited set of socio-ecological niches in Africa, which is dominated by mixed crop-livestock systems (Giller *et al.*, 2009; Andersson and Giller, 2012). Several studies have quantified and explained crop residue trade-offs in mixed crop-livestock systems (e.g. Erenstein, 2002; 2003; Valbuena *et al.*, 2012), but few have explored alternatives to feed both the livestock and the soil, and thus expand the niche in which CA would fit. The objective of this study was to quantify crop residue use (and soil-livestock trade-offs) and explore alternatives to increase the quantity of cereal residues available as soil amendment in two study sites characterized by mixed crop-livestock farming systems: Western Kenya and the Ethiopian Rift Valley.

Material and Methods

A range of methods were used in this study, to fulfill four interrelated sub-objectives. First, current crop residue uses were quantified, using farm survey data. Second, alternatives were explored to increase the quantity of crop residues retained in the field by (1) increasing the quantity produced and (2) reducing livestock demand. These explorations were made using farm survey data and feed trial data. Third, the impact of crop residue mulching on crop productivity was established using on-station trial data. In Western Kenya, the study was conducted in the Districts of Bungoma and Siaya. On-station research trials in Western Kenya were conducted at Kakamega Agricultural Research Center. In Ethiopia, the study was conducted in four districts of the Ethiopian Rift Valley, namely, Adama, Adami Tulu, Boset, and Dodota Sire. On-station research trials in the Ethiopian Rift Valley were conducted at Melkassa Agricultural Research Center. Data was analyzed by estimating crop residue budget, calculating water-limited yield using the the boundary line method, and analysis of different scenarios of residue production and use. Means were compared using Fisher tests or Student tests, while medians were compared using Kruskal-Wallis tests.

Results and Discussion

Current cereal residue use. In Western Kenya, there appear to be little competition between the use of crop residues as soil amendment and other uses such as feed or fuel (Figure 1). However, only about a third of the farmers retain at least one t ha^{-1} of crop residue in their fields (Table 1). Most farmers retain quantities of crop residues that may be too low to have a significant impact on soil organic carbon and other soil parameters. CA with low mulching rate may also lead to soil crusting and compaction and be detrimental for crop yield (Baudron *et al*., 2012). In the Ethiopian Rift Valley, the bulk of the cereal residues produced is fed to livestock: over 80% of all the tef, wheat and barley straw, and about two thirds of the maize and sorghum stover (Figure 1). As a result, the majority of farmers (69%) do not retain any crop residue in their fields (Table 1). Only 3% of the farmers in this site retain at least one t ha^{-1} of crop residue. The lower use of crop residue for feed in Western Kenya compared with the Ethiopian Rift Valley may be the result of a lower cattle density. It can also be attributed to a more intensive livestock production system. Indeed, reliance on crop residue tends to diminish when livestock production intensifies, as more energy-dense rations become necessary. Thus, retaining adequate rates of surface mulch (more than a tone per ha) is not possible for the majority of farmers in both sites, making the adoption of CA possible. Increasing the quantity of crop residues retained as mulch is critical to expand the niche where CA fits.

Closing the yield gap to increase maize stover yields. Maize yield in both sites is limited by N and P. Increasing application rates in these nutrients increases attainable maize yield (up to 2700 and 6700 kg ha^{-1} in Western Kenya during the short and the long rains, respectively, and up to 8120 kg ha^{-1} in the Ethiopian Rift Valley). However, the efficiency with which N and P are used is low, as the large majority of farmers (78% in Western Kenya and 68% in the Ethiopian Rift Valley) do not produce half of the yield they are expected to achieve given the quantity of N and P applied. This may be the results of a high incidence of yield-reducing factors such as weeds, pests and diseases, and/or of poor response to N and P (Vanlauwe et al., 2010). Assuming a scenario where all the farmers in Western Kenya ‘close the yield gap’ – i.e. achieving 90% of the water-limited yield potential – the proportion of farmers not retaining any residue in their fields would decrease from 19% to 3% and the proportion of farmers retaining at least one t ha^{-1} of crop residue would increase from 36% to 93% (Table 1). Similarly, assuming a scenario where all the farmers in the Ethiopian Rift Valley would close the yield gap, the proportion of farmers not retaining any residue in their fields would decrease from 69% to 13% and the proportion of farmers retaining at least one t ha^{-1} of crop residues would increase from 3% to 60% (Table 1).

Providing incentives to increase livestock productivity. Livestock producers tend to respond to increasing market demand for livestock products by using rations that are poor in cereal residues but rich in energy-dense ingredients, and by selecting for cows with high individual productivity and requiring energy-dense rations to fulfill their genetic potential. If all farmers in Western Kenya were to intensify dairy production to a level where cows would be fed on rations containing no maize residues, the proportion of farmers not retaining any residue in their field is predicted to decrease from 19% to 8% (Table 1), and the proportion of farmers retaining at least one t ha^{-1} of crop residue would increase from 36% to 49%.

Providing substitutes to the current functions of livestock. In Western Kenya, milk production and manure production are important functions played by livestock, as the number of dairy cows and the quantity of manure used in the farm have a significant influence on crop production in the region (Table 1). Livestock intensification – i.e. increasing the productivity per animal - may lead to a reduction in livestock number (Table 1), which may ultimately threatens manure production, the second important function of livestock in this site. However, manure use efficiency could be improved by simple technics such as flooring and roofing of the stall. In the Ethiopian Rift Valley, animal traction is an important function played by livestock, as the number of pairs of oxen owned by a farm had a significant influence on the crop production of the farm (Table 1). Therefore, it was hypothesized that the adoption of mechanization to replace oxen would significantly increase the quantity of crop residues retained in the field. From a sustainability point of view, mechanization is dependent on fossil fuel deposits whilst draught animals are sustained by short-term nutrient deposits. However, the opportunity cost of labour, land and capital for keeping draught animals the whole year while they may only be put to productive work few days per year should also be considered. More than half of the farmers would retain one t ha^{-1} crop residues or more in their fields if tractors were substituted to oxen in this site (Table 1).

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Figures and Tables

Table 1. Proportion of farmers in the Ethiopian Rift Valley and in Western Kenya with no residue available for mulching and enough residue to apply a surface mulch of one tone per hectare or more, under different scenarios. 'Mechanization' refers to the substitution of tractors to oxen. 'Closing the yield gap' refers to achieving 90% of the water-limited yield potential. 'Livestock intensification' refers to feeding cows with rations containing no cereal residues.

Scenarios	**Achievable rate of residue retention in the field**	
	0 t ha^{-1}	**1 t ha^{-1} or more**
Western Kenya		
Current	19%	36%
Livestock intensification	8%	49%
Closing the yield gap	3%	93%
Closing the yield gap + livestock intensification	1%	97%
Ethiopian Rift Valley		
Current	69%	3%
Mechanization	18%	25%
Closing the yield gap	13%	60%
Closing the yield gap + mechanization	5%	83%

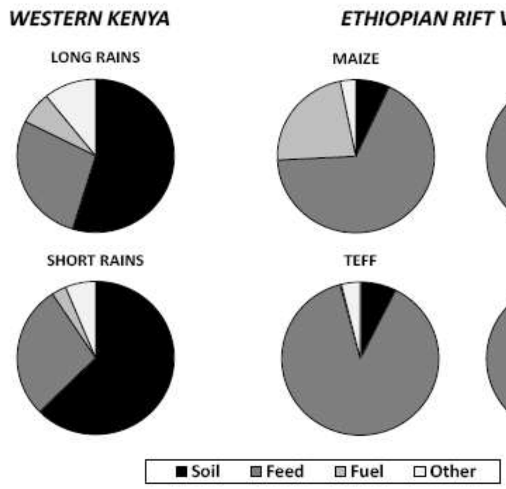

Figure 1 – Mean use of maize stover in Western Kenya during the long rains and the short rains (estimated from 299 farms), and of maize stover, tef straw, wheat straw and barley straw in the Ethiopian Rift Valley (estimated from 344 farms).

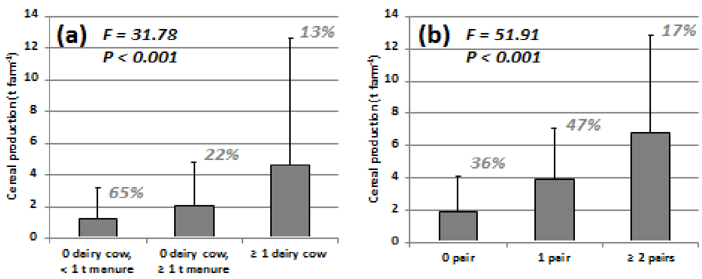

Figure 2. Cereal production during the year 2011 (a) in Western Kenya for farmers having no dairy cow and applying less than one tone of manure in their fields, for farmers having no dairy cow and applying at least one tone of manure in their fields, and for farmers having at least one dairy cow; and (b) in the Ethiopian Rift Valley for farmers having no oxen, for farmers having one pair of oxen, and for farmers having at least two pairs of oxen. Bars represent standard errors. Percentages represent the proportions of the different farm types. For each graph, a summary of the Fisher test comparing the means is given.

Ripper Technology: A gateway to Conservation Agriculture

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Keywords: ripping, conservation tillage, smallholder farmer

Introduction

The depletion of soil organic carbon as a result of intensive soil cultivation causes reduced crop yields, degradation of the soil and low efficiency of added inputs (fertilizers) to the soil. Worldwide, Conservation Agriculture (CA) practices have been implemented in order to combat the effects of intensive soil cultivation. Conservation tillage as one of the ways to soil cultivation is instrumental for sustainable implementation of CA. The Agricultural Research Council -South Africa (ARC) in partnership with the Institute of Agro-technology and food Innovation (A &F) in the Netherlands, initiated a project funded by the National Department of Agriculture (NDA) to develop a ripper implement for smallholder and emerging commercial farmers in South Africa for farming regions where tractors are extensively used: shallow, pulverized topsoil and a compacted plough-pan layer have been created, limiting water infiltration and obstructing root penetration. The study aimed at testing the ARC developed ripper on its impact on crop growth performance.

Materials and Methods

The study was conducted in Spitskop village, Limpopo Province, South Africa from 2004 to 2006 between December and April. Thirteen 0.5ha trial plots from Jack Maferane farmers association were selected. The trial plots were divided into 0.25ha for the following cultivation treatments; 1) ploughing (moldboard plough drawn by tractor) followed by hand planting (control) and 2) ripper planter. Maize was planted in all the field trials. A participatory approach was used for monitoring and evaluation of the trial plots. Farmers were trained on the use of pre-emergence weed control practices (by Knapsack sprayer). The pre-emergence spraying was applied only in the ripped trial plots and manual weeding was done in the ploughed plots. Fertilizers were also applied at recommended agronomic rates on both treatments. Data collected with the assistance of famers was as follows; 1) plant emergence data was collected 3-4 weeks after planting, 2) mid-season data was recorded 3.5 months in fully grown crops, and 3) harvest data was recorded in ripe crops 5-6 months after planting. Rainfall and labour inputs for field operations data was also recorded.

Results and Discussion

Operational inputs: Input cost for ploughed control plots was 14% high than ripper plots; R1260 in ripper plots vs. R1470 in ploughed plots (Figure 1). The high cost was attributed to labour and tractor services. More laborers were required for planting and manual weeding in the ploughed control plots. Less labour was required for the ripper plots because ripping and planting was done at the same time, and weed control was done using herbicides. However, the cost of fertilizer was equal for both treatments as the size of the trail plots were equal.

Plant emergence: There was a delay in plant emergence in both 04/05 and 05/06 season, but the ripper plots had the lowest plant emergence delay. In 04/05 season, a delay of; 7% and 8%, respectively in the ripper plots. A delay of 23% and 23%, respectively in the ploughed control plots. The delay resulted in a significantly higher plant population per hectare in the ripper plots compared to the ploughed control plots in both seasons (Table 1). The early plant emergence was seen to have been contributed by the pre-emergence spraying with Round-up eliminating competition from unwanted weeds.

Mid-season: Overall, the ripped plots were characterized by a better and more vigorous crop stand. Re-planting was done in all the ploughed control plots in an effort to improve the crop stand, resulting in higher % of plants showing (too) late cob-setting: 24 % of non-productive plants as compared to 3 % in the ripped plots; in spite of lower plant density of the ploughed plots in Spitskop, the remaining maize plants lagged behind in growth and crop vigour: on average 44 % of plants yielding two cobs as compared to 65 % on average in the ripped plots.

Grain yield: A highly positive yield effect was recorded due to a better and more vigorous crop stand following ripping (Figure 2). Low yields were recorded in the 04/05 season compared to 05/06 season due to low rainfall (292mm) accompanied by 6 weeks dry spell in the January and February. In the 05/06 season a yield increase of 56% was recorded compared to the 1.8 ton/ha from 04/05 season. A slight increase of 34% was also recorded for the ploughed control plots. This was attributed by the better rainfall (525mm) and reduced dry spells.

It is concluded that ripper technology has more benefits compared to conversional tillage. It results in improved low input cost, early plant emergence, better plant population, healthier crops and increased yields. It is recommended the farmers adopt the ripper technology through the assistance of ARC.

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Figures and Tables

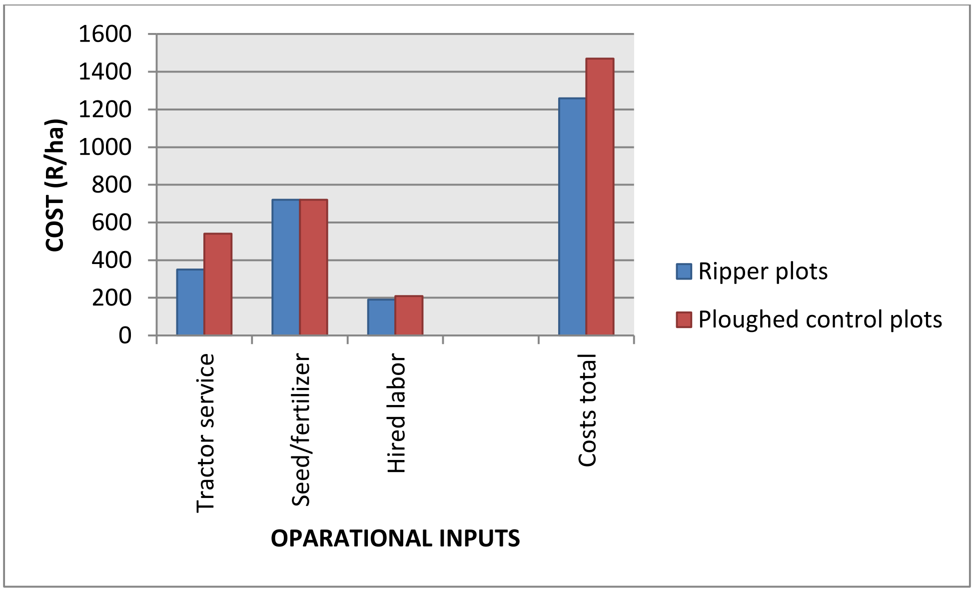

Figure1: Operational inputs for ripper and ploughed plots

Table1: Plant population for ripper and ploughed plots

	Ripped plots		**Ploughed control plots**	
	04/05	*05/06*	*04/05*	*05/06*
Plant population	15,000/ha	24,000/ha	13,700/ha	18,900/ha
Delayed growth (% gaps ≥ 90 cm)	10%	8%	23%	27%

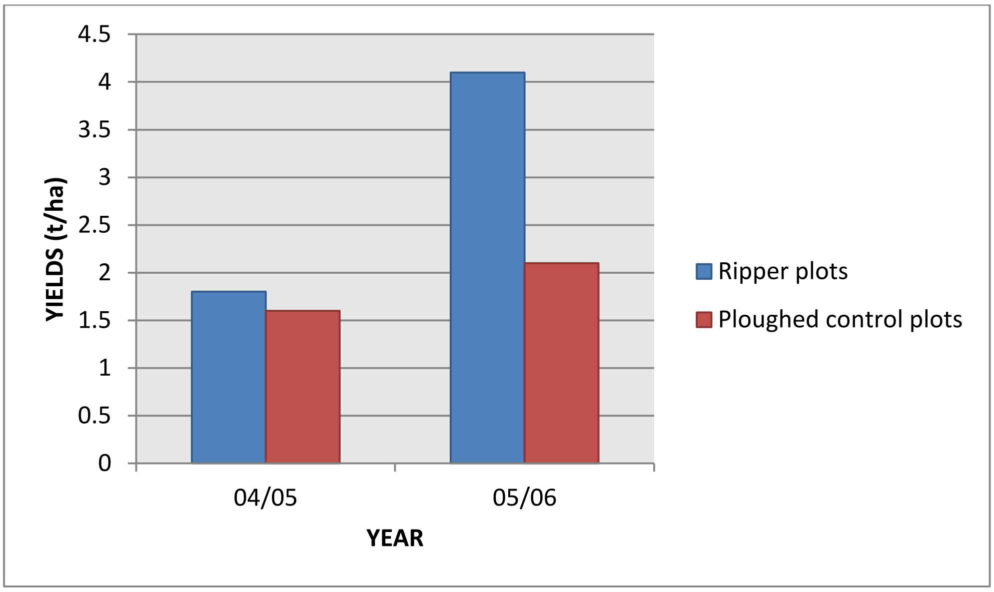

Figure 2: Grain yields from ripper and ploughed plots

CA Mechanisation: A major Technique in Reducing Machinery Input Cost in Crop Production. *Rukuni C, Ndidzano K, Uzande J.*

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Keywords: reduced tillage, conventional tillage, tension cracks, work rates

Introduction

Zimbabwe's population is fast increasing at the same time increasing the demand for food. This has increased the pressure on researchers and farmers to produce enough food for the fast growing population. Government has come up with an agricultural policy (Ministry of Agriculture 2012) with emphasis on increasing productivity and intensifying production. At the same time farmers are crying that crop production is not viable due to high production costs. Therefore the major issue with farmers is viability. This has led farmers to lobby for higher producer prices especially on major grain crops. Tillage systems for crop production recommended in Zimbabwe are conventional, reduced and minimum (Smith 1988) the emphasis was on reducing soil erosion and saving on fuel. The focus in crop production from a mechanization perspective is to reduce machinery input cost. The overall effect is reduction in crop production costs, increasing viability of farming and reduction of food prices. The majority of famer organizations in Zimbabwe call on the Ministry of Agriculture to increase the prices of grain on a yearly basis so that farming business becomes viable. This is contrary to the fact that huge savings can be realized from reducing machinery costs for the benefit of all stake holders. A review and economic analysis of tillage systems including Conservation Agriculture (CA) reveal that energy requirements for tillage are highest with conventional followed by reduced and lastly by direct seeding. Furthermore, carbon dioxide emission from tractors used in agricultural production accelerates climate change. Climatic change has unavoidable effects on food security in Africa (COMESA 2009). Conventional tillage systems uses 73l/ha of fuel energy releasing much more carbon dioxide as compared to reduced tillage systems which uses 48l/ha emitting less CO_2 and direct seeding uses only 8 l/ha thereby emitting much less CO_2. This study was aimed at producing evidence for the promotion of CA mechanization, upscaling CA in Zimbabwe in line with the CA National Strategy and stimulates government policy which promotes CA mechanization.

Materials and Methods

This study is an analysis of data collected during tillage trials at the Institute of Agricultural Engineering (IAE) from 2011 to 2012 season covering an area of 20 ha for each treatment. The data was collected on tractor daily log sheets on which fuel consumption, hours of operation and area covered were recorded using experienced operators and researchers. These operators applied recommended tractor speeds, standard turning system and engine speed for maximum torque; this ensured that fuel consumption was not distorted by use of incorrect engine speed and gears;(Kilgour, Crossely 1982, Rukuni 1996) . All implements used during the study were correctly matched with the tractor size. The study was carried out on clay soil during the dry season in October. This is when the soil resistance is highest based on tillage trials at IAE(Smith 1988).

Treatment 1 (Conventional) involved ripping to create tension cracks in the soil and break the plough pan followed by ploughing which cuts and inverts the soil covering crop residue in the process. The soil was left bare with large clods on the surface. This operation created a condition not suitable for seed placement. Finally discing was done to create a fine seed bed by cutting clods destroying the soil structure further as the disc was pulled through the field and then planting was done. Treatment 2 (Reduced tillage) involved ripping as in treatment one and discing to create a seedbed and then planting was done. There was no ploughing.
Treatment 3 (Direct seeding) involved the use of a planter with a tine which opens a rip line followed by fertilizer and seed placement at different depth along the planting row and covering in one operation. The soil in between rows is not disturbed.

Results and Discussion

Fuel consumption shown inTable1 with conventional systems was very high compared to reduced and direct seeding followed by reduced tillage and direct seeding having the lowest. The results show that conventional systems by their nature use a lot of fuel energy thereby emitting a lot of carbon dioxide into the atmosphere compared to reduced tillage and direct seeding. Ploughing in this case is the highest fuel energy user which emits the highest carbon dioxide. It therefore means that by simply turning to CA using direct seeders, there is a significant reduction in carbon dioxide emission. This is one way of mitigating climate change which should be promoted. An analysis of the time taken to establish a grain crop as indicated in Table 1 show that a total of 6.9 hrs are spend under conventional systems to establish a crop and 4.3 hrs reduced tillage and 0.7hrs on CA direct seeding. Therefore, there is a significant saving on time with CA direct seeding from this analysis. A total of 6 hrs per ha are saved by turning to CA from conventional.

It has been established in the study that the cost of producing a ton of maize at 5 ton/ha under conventional is $20.4 and with reduced tillage at 4.5ton/ha the cost of production per ton is $14.9 and with direct seeding at a yield of 4 ton/ha the cost of producing per ton $7

Table1. Work rates and fuel consumption

System	**Tillage Technique**	**Work Rate (ha/hr)**	**Hours per hactare**	**Fuel Consumption (L/ha)**
Conventional	Ripping	0.38	2.6	15
	Ploughing	0.38	2.6	30
	Discing	1	1	20
	Planting	1.5	0.7	8
	Total		**6.9**	**73**
Reduced Tillage	Ripping	0.38	2.6	20
	Discing	1	1	20
	Planting	1.5	0.7	8
	Total		**4.3**	**48**
Conservation Agriculture (CA)	Direct Seeding	1.5	**0.7**	8

Table 2 Mechanisation Production costs based on fuel

Crop	**Tillage system**	**Production cost $/ton(fuel)**	**Yield ton/ha**
Maize	Conventional	20.4	5.0
	reduced	14.9	4.5
	Direct Seeding	3.5	4
Soya bean	Conventional	40.9	2.5
	reduced	26.9	2.5
	Direct Seeding	7	2.0

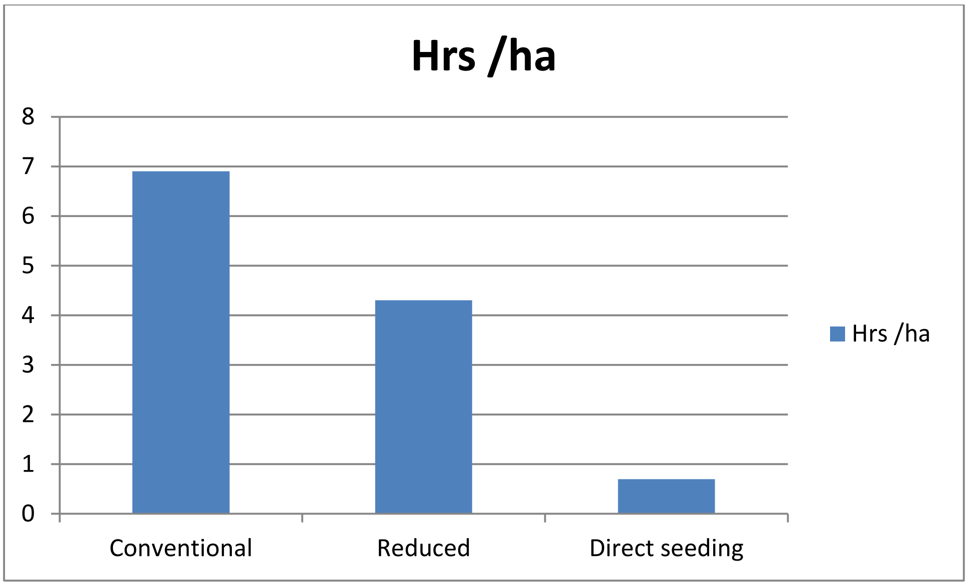

Fig. 1 Time taken on operations to establish a crop

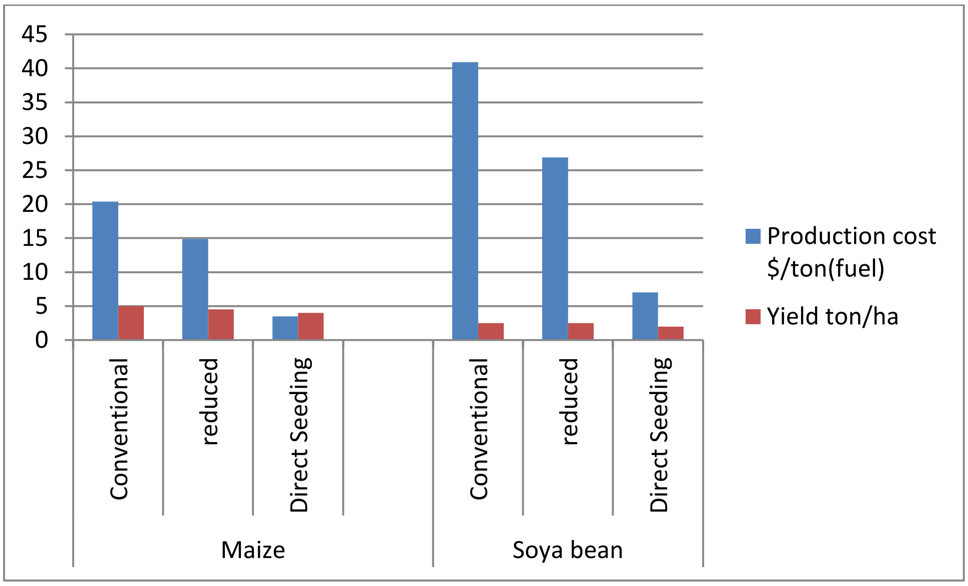

Fig. 2 Production costs

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draught power and tractor use in the small- scale farming sector of Zimbabwe

Two-wheel tractors, Conservation Agriculture and private service providers: A new look at mechanization in Africa

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Keywords: labour, drudgery, energy, sustainable intensification

This paper presents the FACASI (Farm Power and Conservation Agriculture for Sustainable Intensification) initiative, funded by the Australian Food Security Research Centre (AIFSRC) and managed by the Australian Centre for International Agriculture Research (ACIAR) through the International Maize & Wheat Improvement Center (CIMMYT) and its partners in Eastern and Southern Africa. It first describes the problem of declining farm power in sub-Saharan Africa and proposes to use two-wheel tractors (2WT) for conservation agriculture (CA) and other operations to remedy to this problem. It then explores the possibility of using innovative delivery models based on the use of private service providers.

Farm power: the forgotten resource for sustainable intensification in SSA

Food production in sub-Saharan Africa (SSA) is increasing but not as fast as population (ca. 2% vs. ca. 3%). The number of undernourished people in SSA has been rising steadily in the past decades, demonstrating that food import do not meet food demand. Reduced dependency on food imports has also became more desirable for SSA countries, as relying on trade has exposed them to the recent food price volatility. Thus, not denying the role of food import in improving food security in SSA, agricultural production in the region has to increase. Demand for agricultural commodities is also increasing as a result of urbanization. Whereas the rural population of SSA has increased at an average rate of 2% per annum between 1968 and 2000, the urban population has increased at an average rate of 5% per annum during the same period (Tiffen, 2003). Demographic shifts mean that a decreasing rural population is becoming increasingly responsible for meeting the demand of a growing urban population and market. This increase in demand is also reflected in the increase in producer price for agricultural most agricultural commodities, including cereals. In order for the required productivity gains to be reached in a world marked by growing scarcity of resources (e.g. energy, nitrogen, phosphorus, water), it is widely recognized that a new form of intensification is required, often described as 'sustainable intensification', which can be defined as 'producing more output from the same area of landwhile reducing the negative environmental impactsand at the same time increasing contributions tonatural capital and the flow of environmental services' (Pretty, 2011). However, emphasis is clearly placed on seeds, nutrients and water in the implementation of sustainable intensification in SSA, whilst farm power appears as the ‘forgotten resource’. Any increase in production will require an increase in farm power, at least to handle the extra harvest.

Declining farm power in SSA and its implications

In contrast with other countries that experienced the Green Revolution (e.g. India), the farm power available per area of agricultural land in SSA countries has been stagnating in the past half-century (Fig 1). In many countries, the number of tractors in 2000 is identical (e.g. Malawi) or even lower (e.g. Tanzania) to what it was in 1980. During the same period, the number of draught animals on the African continent has declined sharply in many areas due to biomass shortage, droughts, and diseases (e.g. Tanzania, Figure 1b). As a result, agriculture in SSA increasingly relies on human muscle power. However, labour available to agriculture has increased very slowly in SSA in the past decades, and even stagnated in many countries, due to rural-urban migration (Figure 1c). Moreover, rural families - and especially the poorer ones - rely in part on nonfarm income, and nonfarm activities often compete for labourwith farm activities. In addition, the quality of this labour has been affected by an ageing population and HIV/AIDS. Female headed households arealso quite common in SSA and are particularly labour constrained. A consequence of low farm mechanization is high labour drudgery, which affects women disproportionally (in, e.g. weeding, threshing, shelling and transport by head-loading). Moreover, labour drudgery makes farming unattractive for the youth Therefore, (sustainable) agricultural intensification in SSA appears unlikely if the issue of inadequate and declining farm power is not addressed by (1) reducing power demand through adoption of power saving crop production systems such as conservation agriculture (CA), and/or (2) by increasing power supply through appropriate and equitable mechanization.

CA and other operations with a two-wheel tractor

The elimination of soil inversion in CA systems reduces power requirements – typically by a factor higher than two. This reduction in power demand makes the use of lower powered and more affordable tractors such as two-wheel tractors (2WTs) a viable option from crop establishment. On the other hand, a shortage of mechanized options suitable for small holder farmers is creating an impediment to the adoption of conservation agriculture practices (Johansen et al., 2012). Several CA planters adapted for 2WTs have been developed recently, and are now commercially available for 2WTs. These planters are not only manufactured outside the region (e.g. China, Brazil), but also in the region (e.g. in Kenya and Tanzania). When power sources are available (e.g. for direct seeding), mechanization of other operations is much easier (Binswanger, 1984). Conversely, multi-functional uses of the machines is important to maximize the use-hours per year of the 2WTs, and to make small mechanization profitable to a small farmer (Diao, 2012).Transport, along with primary tillage, is one of the first uses of new mobile power sources (Binswanger, 1984). 2WTs can be used to transport inputs and agricultural commodities on the ‘first mile’, which often represent a small fraction of the total distance to the final market, but a large share of the total cost. Improved transport may increase productivity, by lowering the cost of input and the transaction cost of outputs. It can also reduce post-harvest losses that occur before commodities reach the market (typically 30-40%). Operations that are power-intensive and require little human control – such as shelling and threshing – also get mechanized quickly, even at low labour wages (Binswanger, 1984).

Private service providers and business model development

The collapse of virtually all the government-run tractor hire schemes which were popular up to the 1990s in most of SSA demonstrates the need for innovative systems to deliver mechanization to smallholder farmers. The experience of Bangladesh has demonstrated the possibility of doing so by involving the private sector in promoting agricultural technologies through so called ‘business models.’ Although Bangladesh is characterized by small and fragmented fields, 80% of the land is prepared mechanically, using a fleet of ~350,000 2WTs (against only ~15,000 four-wheel tractors). Even though all farmers, even the poorest, have access to 2WT services, only one in thirty farmers actually own one. Since the size and fragmentation of holdings is a restriction in most circumstances, this calls for hiring out, asset-sharing, and careful planning of machinery and equipment use, bearing in mind the seasonality of demand. The rate of increase in the adoption of 2WTs is leading to an increased incidence in hiring services. Individual small and medium scale entrepreneurs and entrepreneurial farmers provide mechanization services to smallholder farmers on a largely informal basis as demand occurs.

It is widely understood that market systems offer the most effective means of replicating, disseminating and ensuring the uptake of new technologies (Magistro et al., 2007). Yet there are often weaknesses in technology market systems which inhibit the uptake of new and innovative agricultural technologies by the poor. In many cases attempts at technology transfer and commercialization can be supply driven and private and public incentives structures do not align to support product commercialization. The business model approach was successfully used by International Development Enterprises (iDE) a non-profit, non-governmental organization(NGO)in the promotion of treadle pumps in Bangladesh with a distribution of 1.5 million units in the country (Magistro et al., 2007). The business development approach could be used to foster adoption of 2WTs and their ancillary equipment in SSA. A key characteristic of the approach is the development or strengthening of services (e.g. information, agricultural training, output aggregation, access to dealers and traders) embedded in the price of the product, in this case the treadle pump. The iDE approach is based on a number of business principles: (1) market linkages (linking farmers to output markets, in order to increase their purchasing power) (2) promotion (through branding), (3) capacity-building of private service providers (manufacturers, installers).

With the right products – appropriately sized, priced, and marketed – the experience in Bangladesh is that private sector can deliver productivity-enhancing and income-generating technologies to small farmers on a sustainable “win-win” basis. The private market place is arguably the most efficient mechanism for widespread distribution of technology to maximize the distribution and impact of such technologies. Market development approaches can lead to the creation of entirely new markets. Products that did not exist previously could be manufactured and sold, generating new income for supply chain members. If designed correctly, products should be made affordable to the rural poor and used to improve production and increase income from existing resources. This design process involves multi-disciplinary approach which seeks not to ‘develop technologies’ but rather to commercialize them as ‘products’. This often requires a deep engagement from product engineers, technical specialists, marketing and branding experts, in an accelerated product design process where the rapid prototyping of a particular solution is undertaken in a ‘fail early and fail often’ strategy.

The challenge is to adapt the iDE experience in south Asia to SSA and to emulate the success of the treadle pump revolution with 2WT and its accessories.

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Figures and Tables

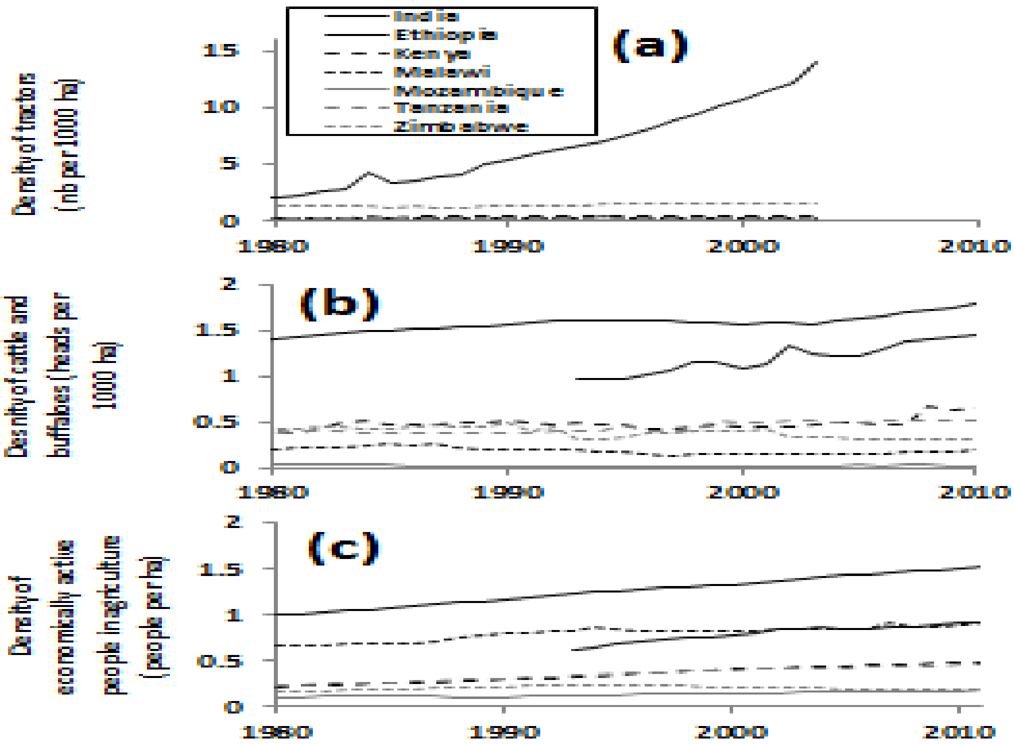

Figure 1. Trend in (a) the density of tractors, (b) the density of cattle and buffaloes, and (c) the density of economically active people in agriculture in six country of SSA compared with India (Source: FAOSTAT). It would be preferable for each fig to have its caption.

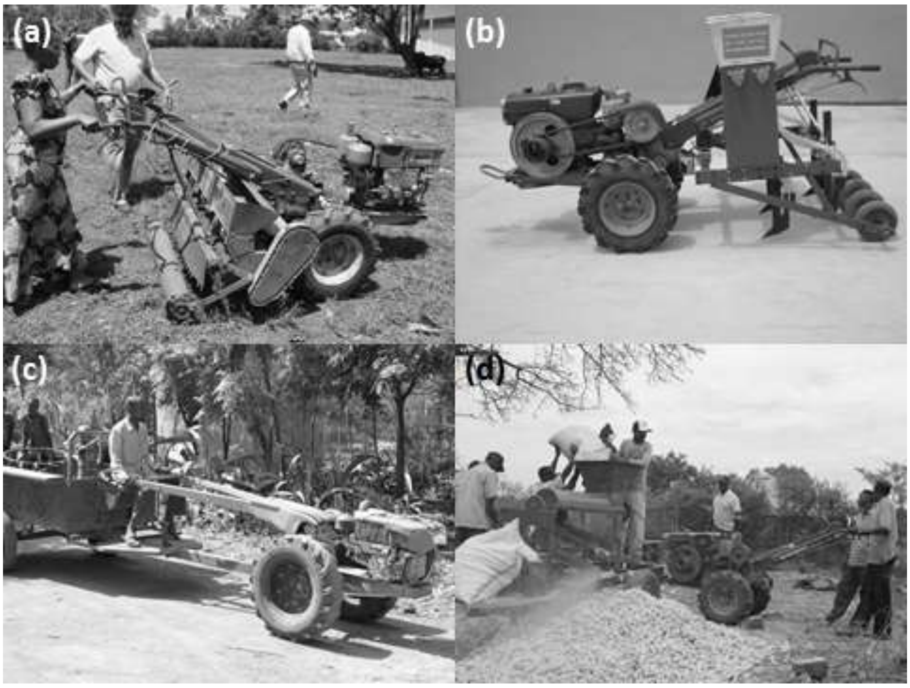

Figure 2. Example of 2WT-based technologies: (a) strip-tillage (a form of CA) using a Danyang seed drill; (b) direct seeding (another form of CA) using the Australian designed Rogro seed drill; (c) transport in Tanzania using a trailers attached to a 2WT; and (d) maize shelling in Tanzania using a sheller powered by a 2WT.

Versatile strip tillage planter: An option for 2-wheel tractor-based smallholders' conservation agriculture in Asia and Africa

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Keywords: seeder, minimum tillage, power tiller, farm machinery

Introduction

Conservation agriculture (CA) has been developed and adopted mostly where large 4-wheel tractor-based minimum tillage planters are applicable and available. However, the adoption of CA in smallholder farmers reliant on 2 wheel tractors (2WT) is very low as the challenge remains to: design planters suitable for 2WT-based minimum tillage and demonstrate their effectiveness, reliability, and durability at a price that fosters adoption in the target market. Mechanization is spreading in Asia and Africa, replacing manual and animal-draught tillage (FFTC, 2005; Mrema et al., 2008). There are now large numbers of 2WT operating in South Asia and Africa (Haque et al., 2013) indicating considerable interest amongst small farmers in mechanized tillage. Most of the single pass minimum tillage systems have confirmed cost savings and increased grain yield (Haque et al., 2011). The building of soil organic matter and soil structure generally depends on minimizing soil disturbance and increasing crop residue retention through the application of CA principles. In Bangladesh the development of minimum tillage 2WT-based planters started in 1995. There are now a range of 2WT-based planters being developed (Haque et al., 2013). Despite these promising developments, except for the Versatile Multi-crop Planter (VMP, Haque et al., 2011) none of the present planters for 2WT have the capability to be modified quickly for different seeding methods (e.g., continuous seeding or precision spaced planting), seed rate, fertilizer rate, row spacing, seed size, and planting depth etc. The challenge was to design a multi-function minimum tillage planter capable of handling many crops and planting methods etc. In this paper we will report the development of a 2WT-based Versatile Strip Tillage Planter (VSTP) that could be useful for smallholding farmers in Asia and Africa.

Material and Methods

The 2WT-based VSTP was fabricated with locally available materials such as MS angle, solid bar, MS sheet, ball bearing etc. The main functional parts of the planter were the toolbar frame, seed and fertilizer metering devices, seed and fertilizer boxes, furrow opener, depth control wheel and chain with sprocket for power transmission from 2WT (Figure 1). Field tests were conducted at Dhaka and Rajbari districts of Bangladesh and Chaibasa district of Jharkhand district of India during June to December 2013 in the farmers' field. The testing of the drill was done by attaching it to a 12-16 HP Dongfeng 2WT manufactured in China. Seeding of rice, wheat, maize, lentil, chickpea, mustard, okra and jute and diammonium phosphate (DAP) fertilizer was used to test the machinery performance for seed and fertilizer placement. We collected field data on emergence of rice, wheat, maize, mungbean, and okra; field capacity; and fuel consumption from the trial at Savar, Dhaka district.

Results and Discussions

Versatile Strip Tillage Planter (VSTP) construction: The VSTP is designed with capability for seeding with fluted roller for continuous seeing and/or vertical disk for spaced planting and with fertilizer meters for drilling in lines. The 1200 mm square rotary shaft is operated by the 2WT at 525 rpm (that allows handling of 5-6 t/ha of rice or wheat residue) through a chain and gear mechanism. The net weight of VSTP is 148 kg and its overall dimensions are length 1270 mm, width 762 mm, and height 840 mm (Figure 1). The furrow openers, with the capacity to separate seed and fertilizers while planting, are attached by nut and bolt with the base cover of the rotary shaft. A pressing roller 1200 mm long with 127 mm diameter (Figure 1), made from 2 mm iron sheet, is attached behind the furrow openers by a pair of arms

Field performance of VSTP: The VSTP was evaluated for up to six rows of strip tillage with 24 blades attached on six brackets. Eight and four-flute type of seed and fertilizer metering, respectively, have been used and regulated seeds and fertilizers successfully in the case of continuous seed delivery of wheat, lentil, chickpea, mustard, etc and basal fertilizer banding in the same strip. Seed and fertilizer in the soil were consolidated by the press roller in a single pass operation. The seeding and fertilizing depth was maintained ranging from two to six cm. The vertical-type seed meters in five different apertures were successfully used for the precision planting of maize, rice, and okra seed.

Effective field capacity of VSTP: The effective field capacity of VSTP ranged from 0.13 to 0.18 ha/hr (Table 1). Effective field capacity was highest for sowing wheat in six rows and chickpea in five rows with fluted type seed meters at 2nd gear position of 2WT; and the lowest was maize and rice at 1st gear position of 2WT with vertical disk type seed meters (Table 1). The latter is nevertheless is higher than the many other 2WT-based minimum tillage planters (Haque et al., 2011).

Fuel consumption of VSTP: Lowest diesel fuel consumption (4.42 l/ha) was reported in the case of chickpea planting and highest in rice (6.08 l/ha) establishment (Table 1) by VSTP, which is lower compared to many 2WT-based minimum tillage planters (Haque et al., 2011).

Performance of VSTP for crop establishment: Both continuous seeding by fluted and vertical disk type seed meters provided optimum plant population. Using recommended seed rates, the average plant population per m^2 after 15 days of sowing was 137, 78, 58, 169, and 9 for wheat, rice, chickpea, lentil and maize, respectively which exceeded the optimum plant population (Table 1). Placement of seed and fertilizer in the optimum moisture zone by VSTP enhanced plant establishment.

Usefulness: In the Eastern Indo-Gangetic Plains, farmers are buying tens of thousands of 2WT (Justice et al., 2004). The use of 2WT for agriculture in Thailand increased by a factor of 6–7 in a-15 year period between 1978 and 1993. Similar trends have occurred in Vietnam, Malaysia, and Indonesia (So, Kirchhof, Bakker & Smith, 2001). Tractors were used initially on large, plantation-type farming systems, but they now serve mostly small farmers under contract operations (So et al., 2001). Successful mechanization can be seen in the Philippines, Thailand, Indonesia, and Bangladesh, where the simple 2WT has proved a viable tool for many small land holder farmers (So et al. 2001). China (10 million), Thailand (3 million), Bangladesh (0.35 million), Sri Lanka (0.12 million), Nepal (one thousand) are estimated to have the highest numbers of 2WT users (Roy et al., 2009 & Anonymous, 2011). Parts of Africa have begun importing Chinese tractors and Nigeria may have close to 1,000.

Hence the potential for application of minimum tillage planters with these 2WTs is potentially very extensive. The VSTP is a feasible option for smallholders implementing CA. In large areas of South and South-east Asia and in Africa where 2-WT are already widely spread this type of planters could play a role in mechanization of planting and fertilizer application as well as being a vehicle for crop establishment by minimum tillage, with residue retention. In Bangladesh, it is not farmers themselves who are purchasing the VSTP, but rather small agricultural contractors who then hire it out for planting services. In attempting to commercialize this technology in Bangladesh, we have learnt the importance of maintaining quality control during manufacture and the use of high quality materials. Operators also need on-going training in the effective use of VSTP to achieve reliable crop establishment outcomes across a range of field types. Planters such as VMP could be used to develop CA practices across a wide range of cropping systems used by smallholder farmers in Asia and Africa.

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Figure and Table

Figure 1. A Versatile Strip Tillage Planter (VSTP) attached on a 2-Wheel Tractor, and major parts (1=seed box; 2=fertilizer box; 3=vertical disk type seed meter; 4=toolbar frame; 5=fluted type seed and fertilizer meters; 6=pressing roller; 7=cover of the rotary parts; 8=driving seat).

Table 1. Performance evaluation of Versatile Strip Tillage Planter to establish wheat (n=3), rice (n=3), chickpea (n=5), lentil (n=4), and maize (n=6) at Savar, Dhaka district, Bangladesh, 2013.

Crop	Seed rate kg/ha	Adjustable seeding depth (cm)	Type of seed meter used	Number of rows planted in each pass	Effective field capacity ha/hr	Fuel consumption l/ha	Plant population per m^2 (15 days after establishment)
Wheat	120	2-4	8 Flutes	6	0.18 (2nd gear)	4.97 (±0.46)	137 (±19)
Rice	27	3-6	Vertical Disk	6	0.13 (1st gear)	6.08 (±0.52)	78 ±11 (24 hills)
Chickpea	30	3-5	8 Flutes	5	0.18 (2nd gear)	4.42 (±0.39)	58±6
Lentil	34	2-4	8 Flutes	5	0.17 (2nd gear)	4.79 (±0.42)	169 ±23
Maize	18	3-5	Vertical disk	3	0.13 (1st gear)	4.47 (±0.35)	9±2

Conservation Agriculture: a sustainable practice for Africa's agriculture

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Keywords: History, benefits, key drivers, challenges, adoption

Introduction

Our World has limited natural resources, never in recorded history have the demand on these resources been so great or resources fully utilised. For both economic and environmental reasons, agriculture in both developed and developing countries is undergoing a gradual shift from conventional to conservation agriculture (CA) and organic agriculture (Dumanski et al., 2006). There is a renewed understanding of mankind's symbiotic relationship with the environment, with greater emphasis being placed on efficient use of natural resources, reducing environmental pollution and greenhouse gas emissions through limited use of external inputs and fossil fuels (Vink et al, 2011).

As CA is a knowledge-intensive practice (Kassam et al, 2009), and coupled with agriculture being a high-risk business, there is great need and scope for research to fully understand and disseminate the technical and financial implications of the process involved in adopting this novel system. Conservation Agriculture is a long-term commitment, not a quick fix; it requires a change in the mind-set and the perseverance to push through the learning curve to enjoy the economic, ecological and biological benefits.

This paper will focus on understanding the concept of Conservation Agriculture and the historical development and progression of Conservation Agriculture as a practice, by method of document review, this paper will review experiences and trends of the path of CA from around the world. Table 1 and figure 1 show the extent of adoption of CA in various regions of the world. Policy development and the role institutions have played in the adoption and progress of CA in certain regions of the world will be highlighted. Specific attention will be placed on the following: the Americas, Europe, Australasia and Sub Saharan Africa (including South Africa).

Conservation Agriculture: Drivers, benefits and challenges

With current projections estimating a world population of 9 billion by 2050, there is growing concern that at current use the natural resources may not feed such a population. Every effort must therefore be made to utilise the available resources in the most sustainable fashion possible. With only an estimated 10-20% additional new land available for cultivation by 2050 (Gardiner and Miller, 2007), it can be estimated that by 2040 the world's agricultural land may well be fully utilised, the key is sustainable and efficient utilisation of these resources. It is estimated that food production must increase by 70% to meet the needs of the projected 2050 population (Bruinsma, 2003).

With 95-97% of population growth expected to occur in developing nations, primarily Asia and Africa, increased production is required in a sustainable manner on the challenging backdrop of increasing urbanisation and industrialisation competing for land and water, poor and depleted soil fertility, access to fertiliser, climate change, improved varieties and quality seeds (Derpsch and Friedrich, 2010).

Agricultural intensification in both developing and developed nations has been marred by negative effects of degradation to the natural resources of soil, water, and biodiversity, resulting in declining crop yields and quality. Agriculture is also responsible for 30% of total greenhouse gas emissions and is directly affected by climate change (IPCC, 2007).

With this in mind, agriculture must focus on intensifying and optimising crop production to cater for the expanding demand. Equal focus must be placed on sustained production through responsible use of resources available.

Key Drivers to the Adoption of CA

The development of herbicides played a pivotal role in early adoption of CA. Minimum and No-till practices initially struggled with high weed infestations, improved selective herbicides overcame these difficulties and paved the way for mechanical planters.

The unintended negative externalities of industrial agriculture following the green revolution, of ground water pollution and soil degradation, has tarnished the farmer's image (Derpsch and Friedrich, 2010). Compounded with a growing world population and limited natural resources, agriculture is left with no alternative but to optimise the use of natural resources in a sustainable manner in order to provide for future generations. Farmers themselves have realised their symbiotic relationship with nature to sustain their livelihood.

By minimising tillage or doing away with it entirely, farmers are able to reduce input costs significantly, through reduced fuel requirements and repairs and maintenance to machinery. Along with reduced input costs, the farmer also benefits from increased yields derived from increased biological structure and water retention in soils. There is a trade-off with increased use of herbicides to supress weeds in the initial phases of adoption, however as the practice matures agrochemical use does decline (Vink et al, 2011).

Benefits of CA

By minimising soil disturbance and maintaining a permanent cover on the soil, the erosive effects of rain and wind can be mitigated. Soil structure is also improved as plant matter decomposes naturally in the soil creating a biologically rich zone of activity. Soil moisture retention is improved as the permanent cover on the soil reduces evaporation from the surface. The soils ability to absorb water is also improved due to reduced compaction and natural drainage from biological organisms in the soil (Derpsch, 2005). Minimum soil disturbance also increases soil carbon levels.

The introduction of crop rotation assists with permanent cover on the soil as well as improved soil fertility and structure by using legumes in the rotation. Through rotating differing plant species, specific herbicides can be used to target competing weeds in alternating crops.

By minimising soil disturbance through no or minimum tillage, the farmer can reduce external input costs such as fuel and repairs and maintenance on tractors and implements, thereby reducing CO_2 emissions and reliance on fossil fuels (Derpsch, 2005). By incorporating residue cover and crop rotations with No tillage (CA), the farmer can optimise labour use, as well as reduce agrochemical use over the long term.

Through the practice of CA, long term sustainability both economic and environmental can be achieved.

Challenges to Adoption of CA

A major difficulty for any farmer is not only to change ones mind-set to adopt a foreign concept contradictory to past wisdom, but to give up the economic value of current assets such as knowledge and machinery, to try a new idea. Change is risky and farmers will need assistance to calculate the expected financial impacts of change and to soften the impacts of acquiring the necessary technology (Friedrich and Kienzle, 2007).

Farmers form tight networks of people they trust. Being primary producers and often price takers, and operating in a high risk environment with volatile weather and markets, they view the world outside their network with scepticism, rendering new technologies difficult to implement. In this case a participatory approach has proved more successful (Abrol et al, 2005).

Farmers need continued support in the form of training and supply of necessary inputs such as herbicides throughout the adoption phase. All too often, support is given and funding runs out before the community are adept and self-sufficient in the new practice.

Local institutions as well as climatic conditions differ for every region or area, as such they have unique requirements. Gender issues are also integral, as women in most developing countries make up a large part of the labour force. Each individual locality has its own unique set of circumstances that affect the adoption of any new and foreign concept.

Conclusion

The challenge of feeding a growing world population from limited resources can only be met by the efficient use of the natural resources.

Conservation Agriculture provides the most holistic approach to a sustainable management system of agricultural land. It may not be the perfect environmentally friendly concept but it does facilitate the continued production needed to sustain farmer's livelihoods as well as production for food security, reducing the use of non-renewable fuels, and reducing CO2 emissions.

The reality of all new technology is that it is adopted when it holds economic value and is socially acceptable, seldom when it is solely environmentally friendly. Conservation agriculture holds both attributes of increasing farmer incomes as well as environmental sustainability. The difficulty in adoption lies in the mind-set of the farmer, a lack of knowledge of how best to adopt the concept, availability of adequate machinery and herbicides, and the potential short-term loss of income and lag time of results. It is difficult to go against traditional knowledge of soil husbandry gained from generations of successful farmers. Farmers will only adopt on mass when they see their contemporaries successfully adopting the concept.

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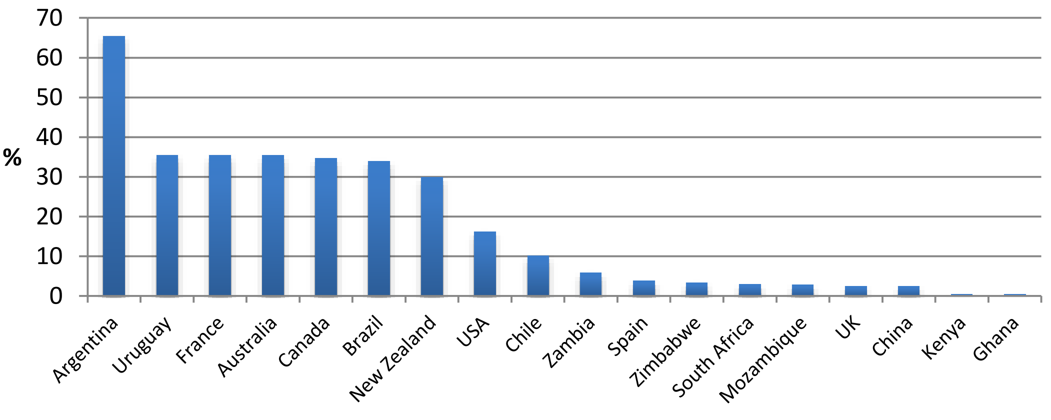
Tables and figures used

Table 1: Area under No Tillage and respective percentage to arable land.

Continent	Area (Ha)	% of Total
South America	55,630,000	47.6
North America	39,981,000	34.1
Australia & New Zealand	17,162,000	14.7
Asia	2,630,000	2.2
Europe	1,150,000	1.0
Africa	368,000	0.3
World Total	116,921,000	100.0

Source: Derpsch and Friedrich, 2010

Figure 1: Percentage of Arable Land under CA as of 2011



Source: FAO AquaStat, 2013.

CONGRESS POSTERS PAPERS

Effects of Conservation Agriculture practices on grain yields and net-benefits of maize and beans in Eastern Kenya

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Keywords: Conventional tillage, Furrows/Ridges, Zero-till, Crop intensification.

Introduction

Maize *(Zea mays L.)* and beans *(Phaseolus vulgaris)* are the two most important food crops to over 85% of households in eastern Kenya (Rockström et al., 2009). Despite their economic importance, production of the two crops has overtime lagged behind at 1.8 and 0.5 t ha^{-1} for maize and beans against expected potentials of 6 and 2.5 t ha^{-1}, respectively (Jagtap and Abamu, 2003). Frequent dry spells and soil fertility depletion coupled with poor farming practices are some of the main biophysical factors limiting per capita food production in the regions (Recha, et al., 2012). As part of the coping strategies, farmers look upon embracing sustainable approaches to whole farm resources such as conservation agriculture (CA) practices that have ability to conserve water and recycle nutrients to revert the low soil fertility situations (FAO 2009). On this basis, a study was conducted to determine the effects of CA practices on grain yields of maize and beans and net-benefits in humid zones of eastern Kenya.

Materials and Methods

Site: The trial was conducted for four seasons starting in short rains 2011 till long rains 2013 at the Kenya Agricultural Research Institute (KARI)-Embu located 00^0 33.18'S; 037^0 53.27'E; 1420 m-asl and in the upper midlands zone. The region experiences 1250 mm average annual bimodal rainfall and warm temperatures, ranging from 21-28 and 16 - 21^{0}C mean maxima and minima, respectively (Jaetzold et al., 2006). The two rainy seasons are March-August [long rains (LR)] and October-January [short rains (SR)]. The soils are mainly humic nitosols; characterized by moderate to high inherent fertility due to their high minerals, available water and cation exchange capacity levels (Jaetzold et al., 2006). The farming system is mainly mixed, with maize grown as sole crop or intercropped with beans (Lara et al., 2012).

Tillage modes: A four seasons trial was conducted in a Split-Split Plot Design with three replicates. One conventional and two CA (Furrows/Ridges and Zero) tillage practices were the main plots (Table 1). Two cropping systems (sole and inter-crop) were the sub-plots while residue management and the rate of nitrogen fertilizer application made the sub-sub-plots.

Tested crops and planting densities: The tested crops were maize (Var. DK 8031) and beans (Var. Embean-14). Maize was spaced at 75x50 cm with 2 plants per hill. Beans spacing depended on cropping systems (sole beans or maize/bean intercrop). Indecently of the tillage mode, sole beans were spaced at 50x15 cm at 1 plant per hill. The inter hill spacing for maize/beans intercrop was 20 cm and

2 plants maintained per hill. Despite the cropping system, a given plot had 5 maize rows each with 8 hills, and 8 bean rows, each with 19 hills were planted on the same plot size as pure stands. While maintaining the same plant population, 4 bean rows were maintained in-between the 5 maize rows in case of maize/beans intercrop.

Data analysis: An ANOVA was conducted for yields of both crops (maize, beans) and inputs/operations and outputs costs, using SAS package (SAS, 2001). Net-benefits for the various treatments were computed to determine profitability of tillage methods for maize-beans production.

Results and Discussion

Maize grain yields: The in-crop rainfalls during the second (LR-2012), third (SR-2012) and fourth (LR-2013) seasons were adequate for crop production leading to over 50% mean grain yields increase with 4.00, 2.91 and 3.65 t ha^{-1} during LR-2012, SR-2012 and LR-2012, respectively (Table 2). The furrow and ridges (FR) tillage mode performed better than either the conventional tillage (CVT) or zero-till (ZT) practices starting from the second season. Higher crop grain yields under FR were associated to extra moisture availability and nutrients due to mulch retention under CA tillage practices. In addition use of Dual Gold *(Metolachlor*) pre-emergence herbicide to manage weeds at their juvenile stage and Basagran *(Bentazon)* post-emergence herbicide for control of most of the broad leafed weeds in already established crops led to weed free environments that might in turn improved crop grain yields under the FR compared to CVT practice.

Bean grain yields: **The** FR tillage had relatively higher yields in the 2 last seasons (Table 3). Like the case of maize performance, improved bean grain yields under FR might have been caused by nutrients concentration and moisture conservation for crop use.

Economic benefits of tillage: Higher net-benefits (NB) were obtained under FR and ZT practices compared to CVT, except for the SR-2011 (Figure 1). Lower profits under CVT practices were associated to costly labour for land preparation and weeding. Higher NB under CA practices were most likely due to increased yields resulting from extra soil nutrients and moisture availability and reduced production cost compared to CVT.

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Table 1: Treatments (tillage methods); detailing land preparation, weeding and residue management practices

Tillage method	Land preparation, weeding and residue management practices
Conventional tillage (CVT)	Complete land tillage every season done involved initial ploughing and harrowing. At least two hand weeding events conducted in a given season. About 75% of the residues removed from the plot at the end of the seasons.
Zero tillage (ZT)	No land tillage done. Instead, no-till activities were effected each season by making and covering small but adequate seed and fertilizer holding holes. Weeds were managed using herbicide(s) as need be. About 75% of all residues were retained from the plots at the end of the seasons.
Furrows/Ridges (FR)	Furrows and ridges were made at a spacing 75cm apart during first season and maintained with minimum repairs or soil disturbance later on. Weeds were managed using pre- and post-emergence herbicide(s) as need be. About 75% of all residues were retained from the plots at the end of the seasons.

Table 2. Average maize grain yield (t ha^{-1}) over four seasons under different tillage modes at KARI-Embu.

Tillage Mode	SR-2011	LR-2012	SR-2012	LR-2013
Conventional tillage	1.71^{a}	3.82^{b}	2.81^{b}	3.30^{b}
Furrows/Ridges	1.42^{a}	4.40^{a}	3.22^{a}	4.53^{a}
Zero-till	1.30^{a}	3.70^{b}	2.60^{b}	3.11^{b}
Mean	1.47	4.00	2.91	3.65
$CV_{(\%)}$	14.50	15.20	15.78	13.62
$LSD_{(0.05)}$	0.47	0.35	0.27	1.01

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = coefficient of variation; LSD = least significant difference.

Table 3. Average beans grain yield (t ha^{-1}) over four seasons under different tillage methods at KARI-Embu.

Tillage Mode	SR-2011	LR-2012	SR-2012	LR-2013
Conventional tillage	1.20^{a}	1.32^{a}	1.26^{ab}	1.42^{ab}
Furrows/Ridges	0.71^{a}	1.31^{a}	1.32^{a}	1.55^{a}
Zero- till	0.92^{a}	1.11^{b}	1.11^{b}	1.21^{b}

Mean	1.00	1.23	1.23	1.23
$CV_{(\%)}$	2.01	8.23	28.05	28.05
$LSD_{(0.05)}$	0.18	0.17	0.10	0.26

Means with the same superscript letter are not significantly different ($p \leq 0.05$); CV = Coefficient of variation; LSD = least significant difference.

Comportement et rôle fonctionnel des larves d'*Heteroconus paradoxus* (Scarabeoidea, Dynastidae) et des vers de terre *Amynthas corticis* (Megascolecidae) selon la matière organique

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Mots clés: vers blancs, ingénieurs du sol, *Stylosanthes guianensis*, *Raphanus sativus*, *Crotalaria grahamiana*,

Introduction

Les insectes terricoles, représentés en particulier par les larves des Scarabaeoidea, plus communément appelés « vers blancs », constituent une des plus importantes familles de Coléoptères tant au point de vue nombre et diversité que du point de vue intérêt économique. Ils sont adaptés à tous les climats et à tous les régimes alimentaires (Hurpin, 1971). Ces vers blancs présentent une diversité taxonomique et fonctionnelle. Leurs dégâts sur la culture se traduisent sous différentes formes et dépendent du stade de l'insecte et de la matière organique.

A Madagascar, cinq principales familles ont été identifiées (Randriamanantsoa et *al*, 2010), parmi lesquelles celles des Dynastidae et des Melolonthidae sont les plus à redouter compte tenu des dégâts que provoquent certains de leurs représentants aux cultures pluviales. Cependant, toutes les larves de Scarabées ne sont pas nuisibles. Certaines d'entre elles peuvent-être classées comme « ingénieurs du sol » au même titre que les vers de terre (Ratnadass *et al*., 2006 ; Brown et Oliveira, 2004 ; Blanchart et *al*., 2008). Si les unes sont des ravageurs importants des cultures, tels *Hoplochelus* sp, *Apycencia waterlotii*, *Encya sikoraï* (espèces rhizophages), d'autres sont indifférentes: *Hexodon unicolor unicolor* (espèce saprophage) et d'autres présentent un comportement de rhizophagie facultative: *Heteroconus paradoxus* (Randriamanantsoa et *al*, 2008). Ce dernier est présent sur les Hautes Terres malgaches. Ce travail a pour objectif de connaître le comportement et le rôle fonctionnel des larves de vers blancs et des vers de terre selon les sources de matière organique.

Matériels et méthodes

Les sources de matière organique utilisées dans cette étude sont des résidus de plantes utilisés en système de culture sous couverture végétale et du fumier de bovin. L'étude a été menée en mésocosme constitué de seau de 21 cm de diamètre sur 21 cm de profondeur, rempli chacun de 5 kg de sol jusqu'à 3,5 cm du bord et dans lequel ont été semés quatre grains de riz. 4 types de résidus: *Stylosanthes*

guianensis (stylosanthès), *Raphanus sativus* (radis fourrager), *Crotalaria grahamiana* (crotalaire) et *Zea mays* (maïs) ou du fumier de bovin ont été ajoutés dans chaque seau
à raison de 44,31 g pour le stylosanthès (soit 12,8 t de matière sèche à l'hectare), 27,70 g pour le radis fourrager (soit 80 Kg/a), 21,29 g pour le crotalaire (soit 6,15 t de matière sèche/ha, 14,54 g pour le maïs (soit 4,2 t de matière sèche à l'hectare) et 34,62 g pour le fumier de bovin (soit 10t/ha)
Des larves de stade L3 d'*H. paradoxus* et des vers de terre : *Amynthas corticis* ont été utilisées pour cette étude. Le dispositif comporte 6 traitements avec 5 répétitions constitués: - des résidus de plantes avec larves ; - des résidus de plantes avec vers de terre ; - du fumier de bovin avec larves et – du fumier de bovin avec vers de terre. A ceci s'ajoutent des témoins sans résidus ni fumier de bovin avec larves ou vers de terre.
Dix jours après la levée des plants de riz, deux larves par seau ont été introduites à 5 cm de profondeur pour les traitements avec larves et quatre vers de terre, introduits à 10 cm de profondeur, pour les traitements avec ver de terre. Les dégâts des larves sur le plant de riz, le gain de poids de chaque individu, le poids de résidus restant ainsi que le changement de la structure du sol sont notés à la fin de la manipulation.

Résultats et discussions

Dégâts et comportement de la larve d'Heteroconus paradoxus

Le comportement alimentaire des larves *d'H. paradoxus* peut avoir une incidence sur les cultures. En effet, selon la disponibilité ou non d'une source de matière organique, les larves d*'H. paradoxus* peuvent changer de comportement. Elles peuvent être nuisibles pour le riz sur sol pauvre et indifférentes à la culture en présence de source de matière organique quelle que soit sa nature. La richesse en matière organique peut diminuer les dégâts des vers blancs (Rabearisoa, M., 2006). Le pourcentage d'attaques est plus élevé sur sol nu que sur sol couvert de résidus (Fig. 1). Aucune différence n'a été observée entre les différents types de résidus. A la fin de la manipulation, le poids des larves vivantes dans le sol sans matière organique est faible par rapport au sol avec des résidus et/ou du fumier. Par ailleurs, le gain de poids des larves est plus élevé avec du fumier de bovin qu'avec les résidus et une très forte mortalité des larves et des vers de terre, même en présence d'une culture, a été enregistrée dans le sol nu (sans résidu ni fumier de bovin) par rapport au sol couvert. Ceci indique que les larves d'*H. paradoxus* ont besoin d'une source de matière organique pour vivre. Cependant les résidus de *R. sativus* et de *C. grahamiana* ont une influence négative sur la survie des larves de vers blancs et des vers de terre. En effet, le radis fourrager a un effet toxique sur les larves. Le fumier de bovin constitue une bonne source de matière organique pour la larve.

Rôle fonctionnel dans le sol : formation de galeries et décomposition de la matière organique

Comme les vers de terre, la larve creuse des galeries dans le sol (Fig. 2). Ces galeries peuvent atteindre jusqu'à 30 cm de profondeur au champ. La larve accumule dans la galerie des résidus de plantes ou d'autres sources de nourriture qui sont incorporés dans le sol (Fig. 3). Le poids des résidus restants pour le radis fourrager et la crotalaire est significativement supérieur à celui du stylosanthes et du maïs car ils sont plus facilement décomposables par les larves et les vers de terre que ceux de stylosanthès et du maïs. Le taux de mortalité des vers de terre est plus important dans les témoins (> à 80%) et avec les résidus de maïs et de radis fourrager. Le maïs est difficile à décomposer et peu apprécié par les vers de terre tandis que le radis fourrager est connu pour ses effets biocides.
Cette étude a pu montrer que les larves d'*H. paradoxus* au même titre que les vers de terre : *A. corticis* aèrent et améliorent le sol par la formation de galeries et en contribuant à la décomposition et à la minéralisation des résidus.

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Figures

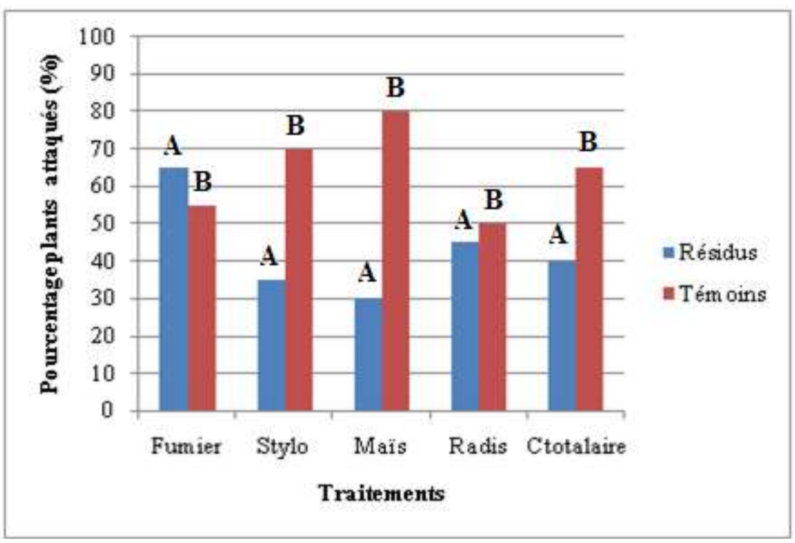

Figure. 1 Pourcentage d'attaques des larves *d'Heteroconus paradoxus*

Figure. 2 Galerie de la larve sur sol nu et sol de couleur rouge

Figure. 3 Résidus accumulés dans une galerie et sol devenu un peu noirâtre

Evaluation of the likely agronomic and economic effects of conservation agriculture under the influence of climate change in Malawi

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Key words: conservation agriculture, maize yields, DSSAT, climate change

Introduction

Conservation agriculture (CA) is increasingly being promoted as one way of adapting production systems to irregularities in rainfall patterns. Traditional experiments aimed at deriving appropriate cropping practices for the wide variety of soil types and climatic conditions are time consuming and expensive. Crop simulation models (CSMs) are often considered useful for simulating different soil and crop management and climatic scenarios, and to develop the most suitable and site-specific strategies (Thornton et., 1998). Decision Support System for Agro-Technology Transfer (DSSAT) (Jones et al., 2003) is a collection of several such models, connecting the decision support system to crop simulation models. DSSAT 4.5 has been used to assess the effects of CA on crop yields and soil water balance elsewhere (Liu et al., 2013; Nangai et al. 2010) and not southern Africa. The objectives of the present study were: (1) to evaluate the ability of DSSAT 4.5 CERES-Maize to predict maize yield for conventional tillage (CT) continuous maize, CA (no-till and mulch) continuous maize, and CA (no-till and mulch) maize-cowpea rotation; and (2) to assess the effect of climate change on yield in CT and CA using long-term future projected weather data.

Materials and Methods

Data for this study was collected from the long-term CA trial located at the Chitedze Research Station in Malawi. Chitedze is located in the mid-altitude agro-ecological zone of Malawi on the Lilongwe-Kasungu plain, with a mean annual rainfall of about 900 mm, 85% of which falls between November and March. DSSAT 4.5 was calibrated using field-measured values of weather parameters, crop management and soil properties during the 2007-2008 cropping season. Genetic coefficients were estimated by using observed silking and maturity dates, and grain yield of the maize variety SC627 for all treatments during the growing season. An iterative approach was used to obtain reasonable genetic coefficients through trial and error adjustments until there was a match between the observed and simulated dates of silking and maturity, and grain yield (Ma et al., 2006; Mavromatis et al., 2001). Using the calibrated model, simulations were carried out with projected weather data for 20 years in the future, from 2010 to 2030, in order to evaluate the effects of CA and CT practices on productivity under the influence of climate change. The statistics used for the performance evaluation of the DSSAT model were the Root Mean Square Error (RMSE) and the mean percentage difference (the difference between the predicted (P_i) and observed (O_i) (Ahuja et al., 2000) as described in the following equations:

RMSE = $[(\sum_{i=1}^{n}(P_i - O_i)^2)/n]^{0.5}$ and %D = $\left[\frac{O_i - P_i}{O_i}\right]$x100.

The value of RMSE equal to zero indicates the goodness of fit between predicted and observed data.

Results and Discussion

Maize grain yield during the experimentation period: Maize grain yield averaged across season showed significant ($p<0.05$) differences between treatments. CA maize-cowpea rotation gave 1335 kg ha^{-1} greater yield than CT continuous maize. Maize grain yield showed no significant differences between treatments in the first four seasons (Table 1). In the fifth season, CA maize-cowpea rotation gave 1953 kg ha^{-1} greater maize grain yield than CT continuous maize. In the six seasons, CA maize-cowpea rotation and CA continuous maize, gave respectively 3012 and 1370 kg ha^{-1} greater maize yield than CT continuous maize. The highest yield observed in CA maize-cowpea rotation plots may be attributed to the combined effect of multiple factors including reduced pest and weed infestations, improved water use efficiency, good soil quality (higher SOC) and greater biological activity (Nyamangara et al., 2013; Thierfelder et al., 2013). The results confirm the time lag before farmers can expect significant benefits by adopting CA in this Lilongwe plain implying some incentives or start up support will be required to farmers to drive adoption of CA.

DSSAT calibration and validation: The calibration process revealed that the model predicted maize grain yield ‘well’, as the mean difference between simulated and observed values was found to be 2.6% and RMSE was 400 kg ha^{-1} (Table 2). This implies that the model was successfully calibrated for the three treatments in question. There was generally ‘good’ agreement between predicted and observed anthesis date and date of physiological maturity, as the error was very low for all the treatments. The error in predicting cereal yield for all CA and CT treatments was below 12% which is considered ‘good’ (Bakhsh et al., 2013; Liu et al., 2013; Nangia et al., 2010).

Predicted grain yield: Simulations conducted from 2010 to 2030 using projected weather data predicted that maize yields varied with seasonal rainfall, with greater variation observed in CT fields. While the largest variation in yield in CA treatments was from 3863 kg ha^{-1} to 4905 kg ha^{-1}, yields for CT varied from 3131 kg ha^{-1} to 5023 kg ha^{-1} (Fig 1). These results suggest that CA practices have the ability to stabilise maize yields in uncertain rainfall patterns. The differences in crop yields between CA treatments and CT were generally small in high rainfall seasons, but were much larger in low rainfall seasons, thus suggesting yield advantage of CA under low rainfall compared with CT, thus CA has the ability to reduce vulnerability to climate change (Fig 1). Similar DSSAT simulation results have been reported in Shouyang County in China, where no-till with whole maize stalk mulching resulted in 17-23% greater yield than CT in a dry spring. Those researchers attributed the yield advantage to early plant establishment (Cai and Wang, 2002).

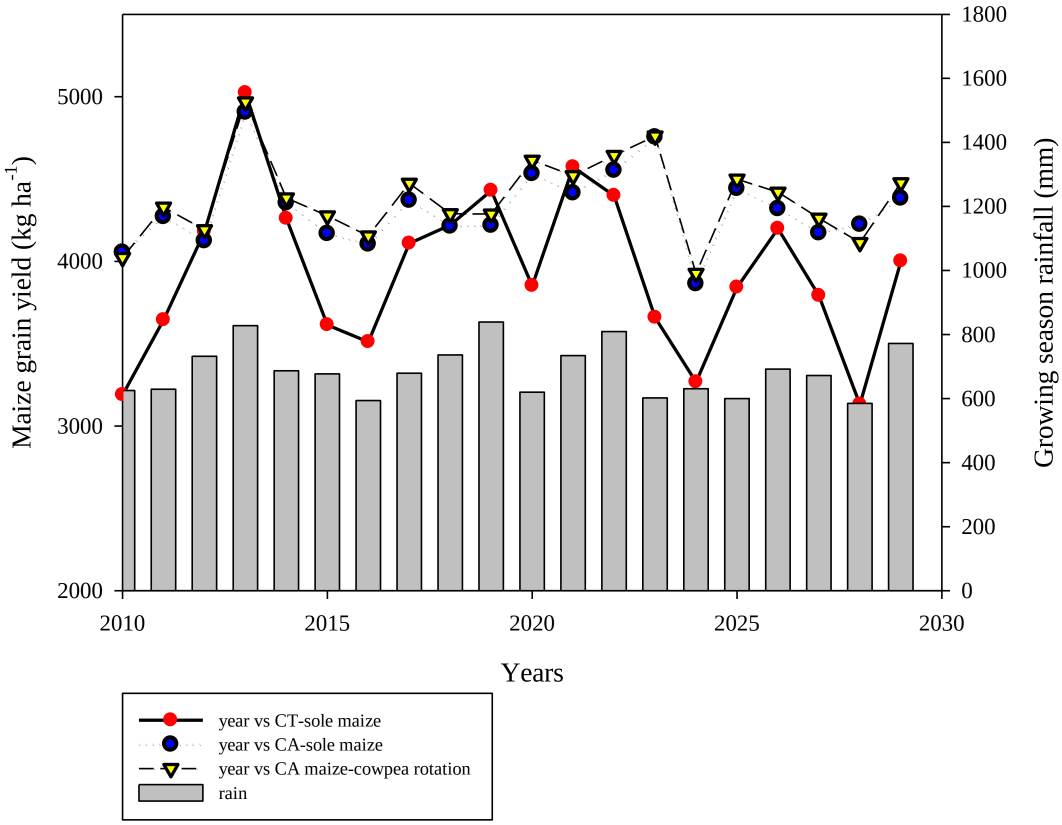

Figure 1. Comparison of predicted crop yields for conventional tillage, CA directed seeded sole maize and CA directed seeded maize-cowpea rotation from 2010 to 2030.

Table 1. Maize grain yield in different conservation agriculture systems and one conventional ridge-and-furrow system, Chitedze Research Station, Malawi, 2008-2013

System	Crop	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	Mean
CT	Maize	4832a	4568a	4964a	6321a	5118b	5057c	5143b
CA	Maize	5259a	4589a	4780a	6365a	4906b	6427b	5388b
CA rotation	Maize - Cowpea	5545a	4272a	5766a	8144a	7071a	8069a	6478a
	LSD($P \leq 0.05$)	1082	1483	928	1507	1611	1293	
	F-statistic	1.06	0.23	1.5	1.66	2.96	4.78	
	p-value	0.415	0.961	0.228	0.18	0.03	0.004	

Table 2. Calibration data

	Anthesis date			Maize grain yield (kg ha^{-1})		
Treatment	Observed	Predicted	Error (%)	Observed$^{\%}$	Predicted	Error (%)
CT sole maize	70	71	1	4832	4271	-12
CA sole maize	70	71	1	5259	5002	-5
CA maize-cowpea rotation	70	71	1	5545	5190	-6
RMSE (kg ha-1)				*400*		
MPD				*2.6*		

% Values marked by the same letter are not significantly different at p=0.05.

* Negative sign represents under-prediction

Adoption of Indigenous Soil and Water Conservation Strategies as Climate Change Adaptation among Crop Farmers in Sudan Savanah Agro – Ecological Zone of Borno State, Nigeria

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Keywords: Indigenous knowledge, Socio – economic factors, Variability, Vulnerability

Introduction

It is anticipated that climate variability and change in Nigeria will have overwhelming impacts on agriculture and land use, ecosystem and biodiversity, human settlements, diseases and health and water resources. With respect to agriculture and land use, climate change will likely elicit a significant change in agricultural production both in terms of the quantum of products as well as the location or area of production. For instance, the change is expected to lead, among other things to a shift in rainfall belts. Since agriculture is largely rain-fed in Nigeria, this will be accompanied by a shift in the traditional areas of production of certain crops with all the possible negative consequences that this may bring to the rural people (Achiando *et al*, 2013). Farmers have developed several adaptation measures that have enabled them to reduce vulnerability to climate variability and extremes. These farmers have developed intricate systems of gathering, prediction, interpretation and decision-making in relation to weather. Farmers are known to make decisions on cropping patterns based on local predictions of climate and decisions on planting dates based on complex cultural models of weather. The study, therefore, focused on adoption of indigenous knowledge soil and water conservation as a strategy for climate change adaptation among food crop farmers in the Sudan savannah agro – ecological zone of Borno State, Nigeria. The specific objectives were to: (i) determine the socio – economic factors influencing the adoption of indigenous soil and water conservation strategies as adaptation strategies to climate change among respondents; and (ii)assess the factors required for improved adoption of soil and water conservation strategies as an adaptation to the impact of climate change by respondents.

Materials and Methods

The study was carried in Sudan agro - -ecological Zone of Borno State, Nigeria. Borno State is located in the extreme north-east corner of Nigeria. Sudan savannah agro – ecological Zone of Borno state comprises 14 Local Government Areas (LGAs). Borno state has a hot climate for most part of the year especially in the Northern part of the state, while the Southern part is slightly milder in climatic temperature. The rainy period varies from the extreme North to the Southern part of the state with the former having about 250mm per annum, while the later records about 1000mm per annum (Daura, 2001; Odo and Oleghe, 1998).

The Sudan Savannah Agro – ecological Zone is found between the Sahel savannah and the Guinea savannah in Borno state. The zone consists of Sahel affinity mixed with broad leaved species of Guinea affinity. There is a more or less continuous grass cover, grasses being short and feathery, contrasting with the tall grasses of the Guinea savannah (Maryah, 2004). Common trees in this area include *Acacia spp,* palm, silk cotton and the Baobab. Rainfall in the Sudan savannah is on the average between 500 — 1000mm per annum (NATS, 1992), with a dry season between 6 — 8 months a year.

Agriculture is the main stay of the economy of Sudan Savannah Agro – ecological Zone of Borno state. The major crops cultivated include: millet, sorghum, groundnut, maize, cowpea and vegetables (onion, pepper, tomatoes). Gum Arabic production is one of the major farming activities in the area. The major livestock reared in the area are cattle, sheep, goats and poultry.

Primary data was mainly used for the study. Multi - stage sampling techniques was used to select the respondents for this study. At the first stage, random selection of four LGAs was made. At the second stage, three villages were randomly selected from each of the selected LGAs making a total of 12 villages sampled. At the third stage, 11 food crop farmers were purposively selected from each of the villages selected. Therefore, a total of 132 food crop farmers served as the total sample size for this study, however only 128 were used for analysis. The list of the villages was obtained from the LGAs that served as the sampling frame for this study. Both descriptive and inferential statistics were used to analyze the data for this study. Descriptive statistics such as frequency distribution and percentages were used to achieve objective two (ii).

Logit model is one of the most commonly used models in agricultural technology adoption research. It has been employed in climate change studies because of the conceptual similarities with agricultural technology adoption studies (Nchemachena and Hassan, 2007) The Binary Logit (BNL) model was employed due to the nature of the decision variable. For such a dichotomous outcome, the BNL model was the most appropriate analytical tool (Benedicta, *et al.,* 2010). The implicit form of the model was expressed as:

$Y_i = \beta_o + \Sigma\beta_i X_i + e$ --(i)

Where:

Y_i = Dependent variable (i.e, the binary variable; Y_i = 1 for a household that adopted soil/water conservation strategy and Yi = 0 for otherwise, β_o Intercept, β_i = Parameters to be estimated, X_i = Explanatory variables, i = 1,2,3,------n number of explanatory variables, e = Error term. This model was used to achieve objective one (i).

The BNL model was explicitly expressed as:

$$Y_i = \beta o + \beta_1 X_1 + \beta_2 X_2 + \text{--------------------------------} + \beta_{11} X_{11} + e \text{--} (ii)$$

Where;

Y_i = Dependent variable (i.e, the binary variable, Y_i = 1 for a household that adopted soil/water conservation strategy and Yi = 0 for otherwise.

In this study, three separate equations were run to model the influence of factors on adoption of soil/water conservation strategy in the study area. The soil/water conservation strategies considered were: (1) Drought-tolerant varieties, (2) Zero tillage technique, and (3) Dry planting. Y_i = Dependent variable (i.e, the binary variable; Y_i = 1 for a household that adopted soil/water conservation strategy and Yi = 0 for otherwise, β_o Intercept, β_1 - β_{11} –= Parameters to be estimated, X_1 - X_{11} = Explanatory variables, e = Error term

Results and Discussion

Socio – economic factors affecting adoption of soil/water conservation strategies among respondents. To identify factors which affect the likelihood of adoption of indigenous soil and water conservation strategies against climate change among the respondents were analysed using the logit model. Some of the maximum likelihood estimates of the binary logit model are presented in Tables 2, 3, and 4 with respect to the variables; drought-tolerant varieties, zero tillage techniques, and dry planting respectively as significant coefficients.

Socio – economic factors affecting adoption of adoption of drought - tolerant varieties among respondents. Table 1 showed that all the identified variables were significant and positive at 1% level with the exception of farmland ownership which was significant at 5% level. This implies that an increase in and one of the variables studied could have an increase in adoption of drought-tolerant varieties by the respondents, which consequently increases their adaptive capacity to climate change and hence their living standards.

Socio – economic factors affecting adoption of zero – tillage technique among respondents. Results in Table 2 indicated that all the variables considered were significant and positive at 1% level among the respondents. The implication could be that as any of the variable studied increases in unit, there was the tendency for increase in the unit of zero – tillage techniques by respondents. This might enhance their productivity and hence their standard of living.

Socio – economic factors affecting adoption of dry planting among respondents. Socio-economic factors that influenced the adoption of dry planting were presented in Table 3. The study reported that farming experience and age were significant and positive at1% level, while farm size was significant and positive at 5% level. That is, all the variables considered were significant and positive, indicating that an increase in any one could have an increase on the likelihood of adoption of dry planting among the respondents.

Factors required sustainable adoption of soil and water conservation strategies. Table 4 presented the results for the factors required for sustainable adoption of soil and water conservation strategies against the impact of climate change in the study area. The result indicated that the most important factor to be considered in adopting soil/water conservation strategy as credit facilities (76.56%), which were closely followed by improved extension services (69.53%) as identified by the respondents. The implication could be that the respondents were small scale/poor farmers who need credit facilities and improved extension services to enhance their productivity and income in the changing climatic conditions.

Conclusion and Recommendations

The study indicated that indigenous knowledge practices have been employed in adapting to climate change impacts among farmers in the study area. However, the study noted that not all indigenous practices are sustainable; and not all indigenous knowledge can a priori provide the right solution for a given problem. Therefore, before adopting indigenous knowledge, integrating it into development programs or disseminating it, practices need to be scrutinized for their appropriateness just as any other technology. Incorporating indigenous knowledge into climate change policies can lead to the development of effective adaptation strategies that are participatory and sustainable**.** There is the need therefore to integrate this local knowledge into formal adaptation policies. Institutional support is also needed in the form of information on cropping patterns; credit; crop insurance and government subsidized seeds.

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Table 1: Logistic regression of socio – economic factors affecting adoption of drought - tolerant varieties among respondents

Factors	β	Std error	Significance	β (Exp)
Years of schooling	0.114	0.032	0.001	1.118
Cooperative membership	2.382	0.477	0.000	0.072
Farmland ownership	0.124	0.076	0.004	0.645
Access to credit	0 .119	0.044	0.000	1.000
Household size	0.138	0.035	0.000	0.076

Source: Field survey, 2012

Table 2: Logistic regression of socio – economic factors affecting adoption of zero – tillage technique among respondents

Factors	β	Std error	Significance	β (Exp)
Extension contact	0.373	0.060	0.000	1.220
Years of schooling	0.119	0.044	0.000	1.000
Cooperative membership	2.817	0.665	0.000	0.060

Source: Field survey, 2012

Table 3: Logistic regression of socio – economic factors affecting adoption of dry planting among respondents

Factors	β	Std error	Significance	β (Exp)
Farming experience	0.054	0.023	0.019	1.000
Farm size	0.123	0.071	0.030	1.055
Age	0.066	0.015	0.000	1.131

Source: Field survey, 2012

Table 4: Distribution of respondents by factors required for sustainable adoption of soil and water conservation strategies against climate change (n = 128)

Factors	Frequency	Percentage
Integration of indigenous and modern knowledge	52	40.63
Improved extension services	89	69.53
Credit facilities	98	76.56
Climate information	68	53.13

Source: Field survey, 2012

Beans growth and yields response to short-term Conservation Agriculture practices in Eastern Kenya

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Keywords: conservation agriculture; conventional tillage; furrows/ridges; zero tillage,

Introduction

Frequent dry spells and soil fertility depletion coupled with poor farming practices are some of the biophysical challenges faced by smallholder farmers in eastern Kenya in their effort to improve bush bean (*Phaseolus vulgaris* L.) yields (Recha, et al., 2012). As part of the coping strategies, sustainable approaches such as conservation agriculture (CA) practices that according to (Giller et al., 2009) have ability to conserve water and recycle nutrients to revert the low soil fertility situations are embraced by smallholder farmers. While encouraging results from adoption of CA practices have been reported worldwide, scanty information is available in eastern Kenya where over 80% of cultivable arable land is managed by smallholder farmers (Muchena et al. 2005). A three season trial was therefore established in October 2011 at the Kenya Agricultural Research Institute (KARI-Embu) farm to establish the response of beans growth and grain yields resulting from short-term conservation agriculture practices.

Materials and Methods

Study Site: The study was conducted during short rains 2011 (SR2011), long rains 2012 and short rains (SR2012) at the KARI-Embu farm (00^0 33.18'S; 037^0 53.27'E); 1420 m asl and in the upper midlands zone (Micheni et al., 2011). The site is further characterized by 1250 mm average annual bimodal rainfall and temperatures averaging at 25 and 18^0C maxima and minima, respectively (Jaetzold et al., 2006). The two rainy seasons are the LR (March to August) and SR (October to January). The soils are mainly humic nitosols which have moderate to high inherent fertility (Jaetzold et al., 2006). Over time the soil fertility has declined due to nutrients depletion caused by inappropriate farm management practices (Gitari and Friesen, 2001). The farming system is of dairying and production of food crops such as maize (*Zea mays L.)* and beans (Lara et al., 2012).

Experimental design and treatments allocation: The trials were based on a randomized complete block on split-split plot design with three replicates. One conventional tillage (CVT) method and two CA tillage practices, namely furrows/ridges (FR) and zero tillage (ZT) were the main plots (Table 1). Either sole or inter-crop of maize and beans were the sub-plots while residue incorporation or removal together with nitrogen fertilizer application rate of 0 and 20 kg N ha^{-1} $season^{-1}$ were the sub-sub-plots. The test crops were maize (var. DK 8031) and bush bean (var. Embean14). Maize was spaced at 75 cm between rows and 50 cm from hill to hill while maintaining 2 plants per station. Beans spacing depended on whether the crop was grown as sole or as an intercrop with maize. Sole beans were spaced at 50 cm (between rows) and 15 cm (hill to hill) while maintaining 1 plant per hill. Beans inter hill spacing in intercrop configuration was 20 cm while maintaining 2 plants per station. This was interpreted to13.3 plants m-^{1} (same as in sole bean configuration).

Data Analysis: The crop growth and yield parameters were collected and subjected to ANOVA following statistical analysis procedures (Gomez and Gomez, 1984) using SAS statistical software version 8.2 (SAS Institute, 2002). Differences among treatment means were compared at 5% significance level and separated using Fisher's Least Significant difference (LSD) test.

Results and Discussion

The mean number of fertile flowers at anthesis was 21.1 and significantly ($P \leq 0.05$) differed between tillage practices (Table 2). Plants under CVT exhibited higher (25.3) number of flowers compared to FR (18.8) and ZT (19.4). Mean number of branches and pods per plant had similar trends as those of flowers where the CVT performed significantly better than the CA based tillage practices. However, mean number of effective nodules was significantly ($P \leq 0.05$) higher at 45 days compared to 15 and 65 days after crop emergence (Figure 1). On the other hand, the zero nitrogen (N0) input plots had a higher number of nodules than the plots that received nitrogen *ex-situ* (N20) at the rate of 20 kg N ha^{-1} at sowing time.

The average crop grain yield was 1.2 t ha^{-1}, which was approximately 50% lower compared to the expected 2.5 t ha^{-1} for the variety (Embean 14) when well managed in the environment that the study was conducted. The low yields could have been due to crop competition with maize for growth resources under intercropped configuration. Grain yields equal to or slightly higher than the mean were recorded over the three seasons where 20kg N ha^{-1} nitrogen fertilizer was applied *ex-situ* at seeding time (Figure 2). This confirmed that the bush bean requires starter nitrogen to boost plants during early stages of development before nodulation process. The relatively poor crop performance under the FR and ZR was associated with the short-term period of the study. Similarly, biomass retention did not have significant effect on the average bean growth and yield parameters. As observed elsewhere (Jasa et al., 2001), significantly higher soil and crop yield impacts of CA may be realized from medium/long-term rather than short periods on managing CA systems. More data sets are therefore required to provide conclusive information on the CA effects on bean growth performance in the target region.

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Table 1. Tillage methods; detailing land preparation, weeding and residue management practices

Tillage method	Land preparation, weeding and residue management practices
Conventional tillage	Complete land tillage every season involving initial ploughing and harrowing using conventional tools. At least two hand weeding events per season conducted using hand tools. About 75% of crop residues removed from the plots.
Zero tillage	No-till activities were effected each season by digging seeding holes. Weeds were managed using pre- or post-emergence herbicide(s). About 75% of crop residues retained on the plots at the end of the seasons.
Furrows/ Ridges	Furrows and ridges made at 75 cm apart at trial establishment and maintained with minimum repairs later on. Weeds were managed using pre- and post-emergence herbicide(s). About 75% of crop residues retained on the plots after harvest.

Table 2. Effects of tillage methods on average bean growth and yield parameters

Tillage Practice	**Considered average bean growth and yield parameters**					
	Average plant height (cm) at anthesis	**No. flowers/ plant at anthesis**	**No. nodules/ plant at anthesis**	**No. branches/ plant at harvest**	**No. pods/ plant**	**Grain weight (t/ha)**
CVT	46.1a	25.3a	12.2a	3.6a	7.7a	1.3a
FR	41.3a	18.8b	13.7a	3.0b	6.0b	1.1a
ZT	42.8a	19.4b	14.0a	3.3ab	6.6ab	1.0a

Mean	43.4	21.1	13.3a	3.3	6.8	1.2
CV%	12.85	12.41	16.6	7.64	10.67	10.92
LSD (0.05)	3.26	2.90	7.53	0.68	1.39	0.79
P- value	0.164	0.001	0.610	0.043	0.031	0.060

CVT = Conventional tillage; Furrows/ridges; ZT = Zero tillage; CV = Coefficient of variation; LSD = Least Significant Difference. Means with the same superscript letter are not significantly different (P≤0.05)

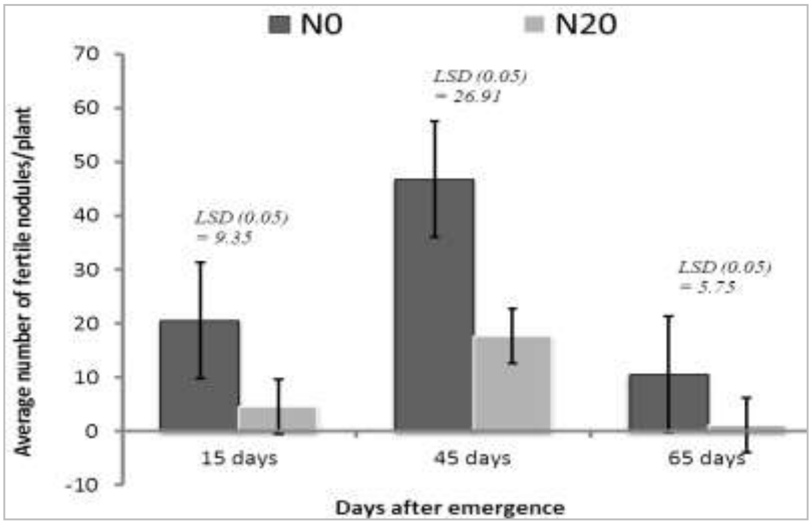

Figure 1. Three seasons (SR 2011, LR2012 and SR 2012 average number of fertile root nodules at 15th, 45th and 65th day after bean crop emergence. *N0 = No nitrogen fertilizer applied at planting; N20 = Nitrogen applied at 20 kg N ha^{-1} at planting*

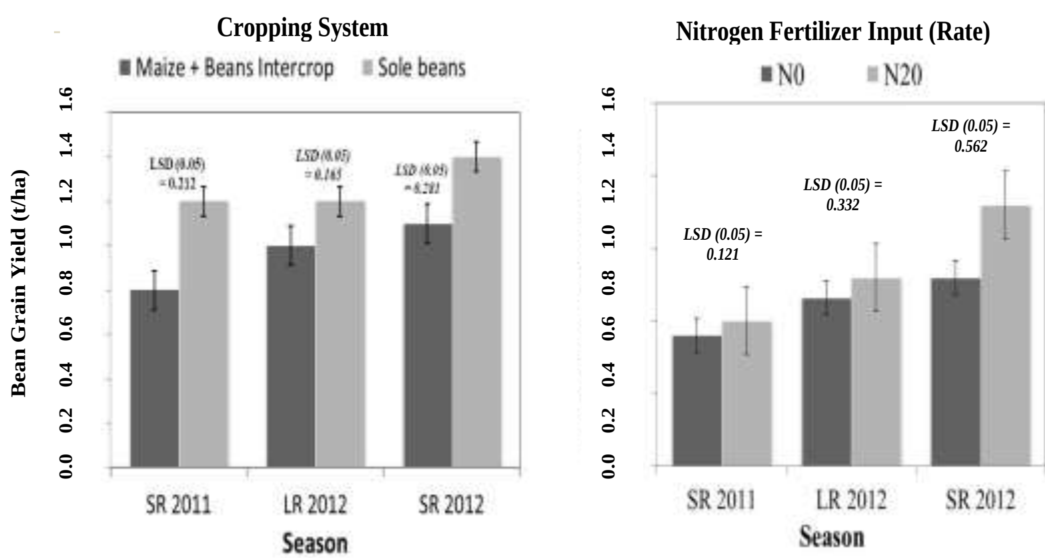

Figure 2. Thee seasons average beans grain yields (t ha^{-1}): maize/beans cropping system *(left)* and nitrogen fertilizer application rate *(right)*. *SR = short rains; LR = long rains; N0 = Nitrogen applied at 0 kg N ha^{-1}; N20 = Nitrogen applied at 20 kg N ha^{-1} at planting*

Mechanization inputs for sustainable Conservation Agriculture

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Keywords: powered seeders, sprayers, carts, weed control, fertilization

Introduction

Established CA cropping will produce field conditions with old-crop residues partially-to-fully covering the soil surface. Old-crop stalks may be standing, lying across the rows, or rolled-down by a crimper-roller. In addition, FYM and minerals may have been distributed on the surface. CA field implements, the CA "tools" of mechanization, must be successfully operated in these field conditions with minimum disturbance of the soil coverage to maximize soil-water conservation. At this time, for smallholder village farmers, cropping mechanization may involve manual, animal-draft, and/or 2-wheel tractor (2WT) methods and power sources.

CA-Mechanization Tools

I) Tasks to be performed in the field to conduct CA-cropping are:

a) Between-season or pre-seeding weed control/killing to create a "stale-seedbed";

b-1) Row-crop seeding with application of starter fertilizers;

b-2) Drilled-crop seeding with application of starter fertilizers;

c) Between rows control of escaped and late-germinating weeds and grasses;

d) Haulage of inputs and products to and from the field with a cart-type item.

II) In answer to the above field tasks, the visualized array of CA field implements is:

A) Boom-type broadcast sprayer for herbicide applications between cropping seasons;

B-1) Row-crop seeder [if row crops are to be grown in rows typically 60-80 cm apart];

B-2) Drill-type seeder [if drilled crops are to be grown in rows typically 15-25 cm apart];

C-1) Shielded "directed-sprayers" for herbicide applications between rows of growing crops;

C-2) Low disturbance sweep-type cultivators to uproot weeds [if 2WT traction is adequate];

D) 2-Wheeled cart with a seat for the operator.

III) Descriptions of the above mechanization implements:

A) Boom-type broadcast sprayers should be of the pull-behind design so that for the good health of the operator/farmer, he/she is not in contact with the herbicide or other chemical being applied. Sprayers may be:

1) Manual pull-behind booms attached to knapsack hand-pumped sprayers (Fig.1);

2) Animal-draft pull-behind booms on sleds or wheels; with ground-driven pressure pumps;

3) 2-Wheel Tractor (2WT) pull-behind booms on wheels; with ground-driven or 12vdc electric pressure pumps [some 2WTs have 12vdc];

4) Boom and tank of sprayer mounted at rear of haulage cart for 2WT or for animal-draft; pressure pump powered by ground drive or 12vdc.

B-1) Row-crop seeders for CA are now available. The typical configuration is as a 1-row seeder for rear-mounting on a 2WT (Fig. 2); 2-row configurations are possible if 2WT traction is not limiting. New animal-draft versions are forthcoming. [Disclaimer: the authors are designers and distributors of the "*CA-Seeder, Model-1"*, manufactured by SMTI of Erwin TN, USA].

B-2) Drill-type seeders for CA are currently 4-6 row machines that are limited to being used in fields without typical CA-cropping residues on the soil surface. These drills are mounted on the rear of 2WTs. A few models are available from Asia and equipped with powered rotary trash cutters, but these machines may not be appropriate for use in upland soils with stones. Traction limitations with 2WTs may be a factor in the successful use of these drills in the firm, non-plowed soils of CA.

C-1) Shielded "directed sprayers" are comprised of a shielded pressure-sprayer nozzle which is located under a covering shield to keep herbicide spray from contacting the crop plants as the sprayer is pulled on sleds/skids down the middles between crop rows. They are used to eliminate escaped or late-germinating weeds and grasses in established row-crops. Protective soil-covering residues are not disrupted by the directed sprayer. Single units can be attached to hand-pumped knapsack sprayers (Fig. 3) and manually pulled down the crop row middles. Single or multiple-row units can be pulled by animal-draft of by 2WTs, with either ground-driven or 12vdc pressure pumps. The same supply tanks and pressure pumps may be used as used for (A), above. Directed sprayers do not stress traction limitations.

C-2) Low disturbance sweep-type cultivators can be used in CA to undercut weed roots in the middles between crop rows. Flat-running sweep tools are used to minimize surface residue disturbance. The sweeps are mounted on shanks and must be preceded by devices such as residue rakes and rolling coulter blades to clear and cut paths for the shanks, to avoid blockages (Fig. 4). Depth control wheels must be used to control cutting depth and to minimize disturbance. Limited traction with 2WTs may impact the adoption of this technology. Cultivator configurations may be different for 2WT and animal-draft applications, because the 2WT must straddle the crop row and cultivate on either side.

D) 2-Wheeled carts are currently available from manufacturers in Asia for use with 2WTs. They can be adapted for use with animal-draft. These carts typically have a seat for the operator and some have brakes for use with 2WTs w/o brakes. See references to cart in-field uses in (A) and (C-1), above.

Some of the above mechanization implements above are commercially available, some are in the prototype-demonstration stage, and some are in early design stages. Selection of appropriate mechanization implements for particular needs should be done under advisement.

Summary

The understanding of CA cropping is fairly broad in definition, but when it comes to the selection of field implements to accomplish CA cropping, there are but a few technical options. Depending upon the crops being grown and the field conditions, some mechanization implements are currently available from several sources. If a few cases, there are choices between manufacturers for competitive implements.

As developers, distributors, and advocates for CA, we in the professional agricultural community have the responsibility to provide appropriate technologies at affordable prices to support the training programs and initial-adopter farmers, as CA moves into the main stream of crop production on smallholder village farms.

Fig. 1. Manually-pulled broadcast sprayer, attached to a knapsack sprayer.

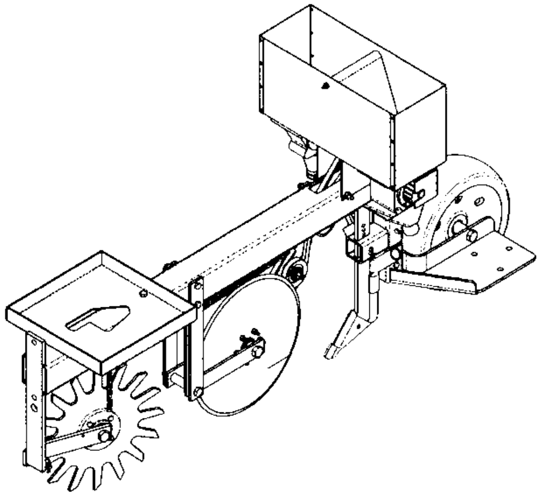

Fig. 2. One-row seeder for seeding row crops when attached to a 2WT [*CA-Seeder, Model-1*, by SMTI].

Fig. 3. Shielded directed-sprayer, attached to a knapsack sprayer, for between-row weed control.

Fig. 4. Low-disturbance sweep-type weed cultivator with path-clearing devices.

Mealie Brand – Bridging the gap between Conservation Agriculture technology and the CA machinery requirements for small scale farmers in Zimbabwe

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Keywords: Conventional Farming (CF), CA principles, ripper, Direct Seeder planter, Chaka hoe

Introduction

Mealie Brand as an ISO 9001:2008 certified organisation which does the sourcing, design, supply, manufacture, and distribution of Animal-drawn agricultural implements, for Conventional Farming (CF) as well as Conservation Agriculture (CA). The company develops efficient CA products and educates CA farmers in Zimbabwe and the rest of Mealie Brand's market share, Sub-Saharan countries. Mealie Brand puts much emphasis on poverty alleviation in both small and medium scale farming where poor land management, inadequate inputs and resources, inadequate extension materials, inconsistent rainfall patterns, and unattractive producer prices and liquidity crunch befall the farmers. The company's products which advocate for minimum soil tillage, recognizing and promoting soil coverage, encouraging crop rotation, and higher farming management practices promote the adoption of these CA principles in Zimbabwe.

In Zimbabwe, less than 40% of farmers have draught power, with women responsible for planting, weeding and harvesting. Also, soil productivity is reducing and prevailing climate changes demand efficient techniques and farming implements to improve outputs. While CA technology is the definite solution, Mealie Brand seeks to intervene with the affordable and efficient CA products ranging from hand tools (basin making Chaka hoes and Mealie Brand hand Planter) to animal drawn tools (Rippers and Direct Seeders).

As a company we therefore have a *Vision* to be the dominant player in the provision of agricultural equipment solutions for all our stakeholders with a *Mission* of availing quality affordable and reliable agricultural equipment solutions on time every time to the farming sector. In this paper therefore, the company's experiences and technical involvement in the design and distribution of CA equipment and knowledge dissemination is discussed.

Materials and Methods

As early as year 2002, Mealie Brand (A division of Zimplow holdings) initiated CA equipment design and development targeting Zimbabwean and Southern African countries. Research and development innovations were and still are executed in collaboration with various Agricultural Colleges, Agriculture Research Centers, Technical Universities, and several international Non-Governmental Organizations (NGO's) and agricultural institutions. Developments are tested and validated for functionality, quality and principle by the same collaboration platform named above. The company has a continuous engagement with customers in all ten provinces of

Zimbabwe to gain product performance feedback and to train famers through Market research questionnaires, 2nd party audits and visits, field days and demonstrations throughout the calendar year in conjunction with the Department of Agriculture – AGRITEX and Institute of Agricultural Engineering (IAE) Zimbabwe.

The same market intelligence is captured through participation in Agriculture Shows and conferences where the company has the opportunity to discuss available products and their performance with end users. Having several concepts on CA farming, Mealie Brand aims to support developments for various CA technologies applicable to various climates, available resources, regions and crops.

Results and Discussion

Impact of Mealie Brand on CA adoption by small and medium scale farmers. Mealie Brand relentlessly promotes the adoption of CA in Zimbabwe, as indicated by an increase in the number of implements sold by the company between year 2012 and 2013. The percentage increases of the despatched implements ; 64%, 33%, 123% and 21% for the Chaka hoes, Direct Seeders, Rippers, CS2 and CS3 cultivators respectively can be attributed to the increasing awareness and hence adoption rate of CA technology by more than 350 000 farmers out of more than 700 000 potential CA farmers in Zimbabwe. However, the majority of the current CA farmers have implemented incomplete CA packages and not fully realised the benefits thereof (e.g. only 20% farmers in Shamva fully adopted CA by 2011). Furthermore, new players are being discouraged by the seemingly high CA labour requirements which are actually lower than conventional farming in the 4th season onwards and the unpopular and/or unavailability of CA equipment to which Mealie Brand seeks to close the gap.

CA products. Rippers are the widely used CA product, followed by Chaka hoes. The Ripper attachment was designed to easily replace the soil turning, conventional plough bottom (at less than $25 USD in Zimbabwe) hence reducing the uptake cost to new CA farmers while fostering ability to break soil hard pans in narrow furrows with higher water retention as a merit. In 2002 Chaka hoes were introduced for digging planting basins (plant stations) and now a basin digger has been developed for farmers with draught power.

A Direct seeder is fairly new, however there was a 33% increase in its sales in the year 2013 farming season due to its ability of cutting trash with the coulter wheel, ripping, fertilizer/manure application, seeding, and covering of seed/fertilizer functions in one implement and hence reducing labour requirements per season. The various seed plates it carries for maize, sugar/soya beans, small grains (sorghum & millet) and cow peas support crop rotation using the same of implement.

The hand planter has also emerged superior to most hand tools due to its light weight, efficient and consistent planting action, and its less complicated working principle which acts like a hand hoe. It is being supplied with 12 seeders, promoting crop rotation and accommodates the wide varieties of seed and inconsistent seed grading on the market.

The company works closely with all its collaboration partners to promote these implements in a fair and unbiased manner to the farmers' convenience.

CA and labour requirements. The myth "CA technology is labour intensive on weed control" is slowly being transformed by a greater adoption of herbicides and changes realised in the 3rd and 4th season by CA by farmers in such areas as Gokwe, Hope Fountain, Masvingo, Binga and other parts of the country in II – IV farming regions. Further studies to establish versatile solutions and revealing advantages of CA which include better labour productivity, higher yields, water conservation, soil fertility, saving inputs, reduction in soil erosion, generally reduced production costs and improved nutrition and food security for households in these climate changes, should be advocated. In line with weed control, Mealie Brand is developing Minimum Tillage cultivators.

Bridging a gap between CA technology and machinery requirements. The range of CA products that Mealie Brand has developed and are continuously developing have successfully adopted the minimum tillage concept while maintaining the required planting depths. Implements are designed to be versatile in high crop residue fields even though this aspect has not yet been fully adopted due to the traditional use of crop residue as communal pastures in Zimbabwe. Mealie Brand also considers the relatively smaller animals now available as draught power and thus develops lighter implements at affordable prices to the needs of today's farmers. Training Material and product pamphlets on CA are constantly updated to present the best use of the implements and CA technology through the 'Train the Trainer' courses with AGRITEX with initial training for Matabeleland completed in 2013. Cases of spontaneous adoption of CA have therefore been observed in areas where demonstrations have been conducted.

Collaborating partners
Matopo Research - Zimbabwe, Conservation Farming Unit (CFU) - Zambia, Department of Agriculture and Mechanization (AGRITEX, IAE) - Zimbabwe, National University of Science and Technology (NUST) - Zimbabwe, University of Zimbabwe, Afritrac - South Africa, Moquip- South Africa, Agricultural Research Institute (ARC) - South Africa, NGOs, etc.

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Figures and Tables

Figure 1. Mealie Brand Personnel educating farmers on the use of zero tillage equipment

Table 1. CA Equipment sales by volume

Implement	YEAR		
	2011	2012	2013
Chaka hoe	1200	2220	3655
Direct Seeder	0	171	227
Rippers	521	529	1179
CS2 / CS3 Cultivator	66	79	95
Hand planter	0	6	326

Source: Mealie Brand Sales, year 2011 – 2013

Zinc supply capacity of organic nutrient resources: Implications of mulching for cereal biofortification under Conservation Agriculture systems

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Key words: human nutrition, maize grain zinc uptake, quality of mulching materials, smallholder farming, soil fertility management

Introduction

Nearly 50% of areas where cereals are grown have soils with low plant available zinc (Zn) (Graham and Welch 1996) with Zn concentrations in grains of as little as 5-12 mg kg^{-1} against a requirement of 40-60 mg kg^{-1} (Pfeiffer and McClafferty, 2007). This impacts negatively on nutrition of families of resource poor farmers in Africa whose staple diets are mostly cereal-based. Zinc is important for the functioning of >300 enzymes in humans, including detoxification of harmful oxygen free radicals (Broadley et al., 2007). Food diversification, supplementation programs, molecular biology and industrial biofortification are avenues to improve Zn nutrition but require high financial investments and social acceptance (White and Broadley, 2005). Soil fertility management approaches that include application of organic nutrient resources and Zn fertilizers to improve Zn soil availability to food crops will therefore offer an opportunity to reduce this burden (Rupa et al., 2003). To date, studies that have been conducted in Zimbabwe have concentrated on general Zn distribution in soils (Tagwira, 1991), effects of Zn on maize productivity under controlled conditions (Zingore, 2006), with little attention on farmers' production circumstances and management practices.This study was conducted to evaluate the influence of farmers' diverse soil fertility management practices on grain yield and effect on uptake patterns and nutritional value in maize (*Zea mays L.)* Implications of the emerging patterns on improving nutritional quality of cereals grown under different tillage options for enhanced human nutritional needs will be discussed.

Materials and Methods

Over 60 soil samples were collected from farmers` fields under conventional tillage in two smallholder communities in semi-arid and sub-humid areas of Eastern Zimbabwe. The two smallholder communities are high potential areas receiving rainfall of between 650-800 mm $annum^{-1}$ (Department of Surveyor-General, 1984) and the dominant soils are granite derived sands low in nitrogen (N), phosphorus (P) and organic carbon (OC).Common farmer soil fertility management practices under conventional tillage were identified using household questionnaire surveys and the management practices included use of legume-cereal rotations, cattle manure, leaf litter and recommended rates of sole mineral NPK fertilizers (AGRITEX, 1985). Some farmers consecutively planted maize with no fertilization hence these fields were established as control treatments (Table 1). These management practices constituted the treatments for evaluating farmers' soil fertility management practices on maize grain yield and Zn uptake, and were defined as follows: inorganic or mineral fertilizer; combined organic and inorganic fertilizer; legume – cereal rotations treatment; and the non fertilized treatment category. From each of the randomly selected farmers` fields under the different soil fertility management treatments, 10 soil samples were randomly collected for laboratory analysis. The samples were analyzed for soil chemical properties including EDTA extractable Zn. The designated fields were planted to maize and yields assessed at physiological maturity from net plots measuring 9 m^2. Grain subsamples were taken for determination of grain Zn concentration following digestion with nitric acid (HNO_3) and 50% hydrogen peroxide (H_2O_2). All experimental fields were geo-referenced. Analysis of variance was done using GENSTAT 8. Different farmers` fields were used as replicate blocks while the least significant difference (LSD) at P = 0.05 was used to statistically differentiate means.

Results and Discussion

Soil fertility management effects on maize grain yields. In Wedza, an old communal area, quantification of grain yield involving farmers showed that a combination of cattle manure and inorganic fertilizers produced maize grain yield of 2.3 t ha^{-1}, sharply contrasting <0.5 t ha^{-1} obtained when no nutrients were applied. In Makoni, organic-inorganic fertilizer combinations attained grain yields of 2.2 t ha^{-1} compared to 0.75 t ha^{-1} for the control (Figure 1). This could be attributed to improved nutrient use efficiencies often associated with positive interactions derived from combinations of organic and mineral nutrient resources (Palm et al. 1997).

Soil fertility management effects on maize grain Zn concentration and uptake. Up to 64% and 46% increase in grain Zn concentration was measured against the control in Wedza and Makoni respectively (Table 2). Fields receiving regular applications of manure and woodland litter, as well as those under legume-based rotations had higher Zn concentrations than those receiving mineral fertilizers alone or no fertilizer. This was also reflected in maize grain Zn uptake. Total grain Zn uptake ranged from 7.1 – 49 g Zn ha^{-1}, the highest uptake being a function of combined use of organic and inorganic fertilizers (Table 2). Results are similar to other findings recorded in lentil plants (Verma and Panday, 2008). There was a significant linear relationship between extractable soil Zn and maize grain Zn concentrations (R2>0.80), with maize grain Zn concentration increasing with increasing concentrations of extractable Zn in the soil (data not shown). Use of organic nutrient resources potentially alleviates Zn deficiencies in smallholder farming communities.

Implications of research findings under CA systems: Results showed the capacity of locally available organic nutrient resources to supply Zn and improve grain Zn concentrations under conventional tillage systems. The results suggest that the use of different organic resources as mulch options in CA systems could influence micronutrient dynamics, particularly Zn, and this is likely to be influenced by the type of organics used. Conservation agriculture principles have been widely promoted for improved maize grain yields and soil conservation among other factors (African Conservation Tillage Network, 2008), but its role in enhancing micronutrient availability to major staple crops such as maize has remained unexplored. This paper provides insights into the potential role of different organic materials potentially used as mulch in CA systems to improve Zn nutrition in staple maize under smallholder cropping.

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Figures and Tables

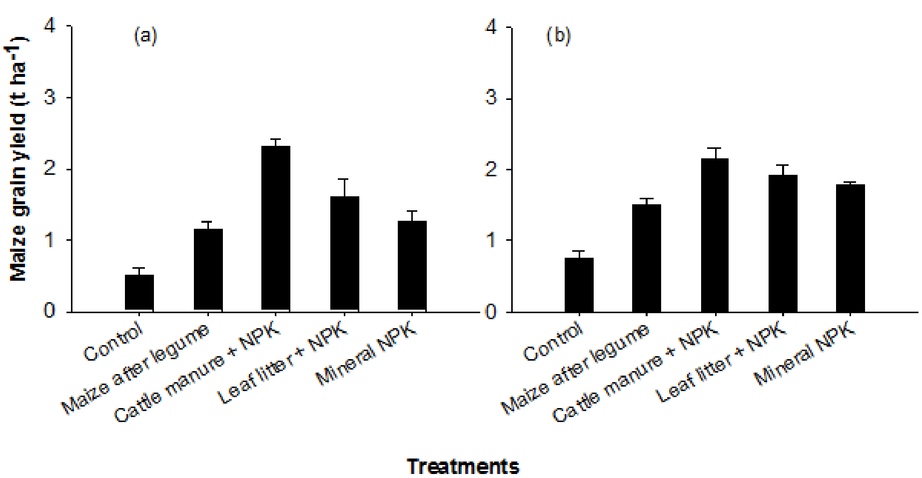

Figure 1. Grain yields attained in farmers` fields in (A) Wedza and (B) Makoni. Bars represent SEMs.

Table 1. Common soil fertility management practices as recognised by smallholder farmers in Wedza and Makoni districts of Zimbabwe

Management practice	Characteristics
Non-fertilized control	Comprised fields that had been consecutively cropped to maize in the previous three seasons, but with no fertilization
Maize after legume	Area under maize was supposed to be the same as area under legume in the previous season. Field was considered to have effective rotational benefits if legume grain yields of at least 1 t ha^{-1} were obtained.
Cattle manure + mineral NPK	Organic fertilizer application rate of at least 5 t ha^{-1}
Leaf litter + mineral NPK	Organic fertilizer application rate of at least 5 t ha^{-1}
Mineral NPK only	Farmer applied a rate of about 90 kg N ha^{-1}

Table 2. Zinc concentrations and uptake measured in maize grain

	Wedza	Makoni	Wedza	Makoni
Treatment	Grain Zn (mg kg^{-1})		Grain Zn uptake (g ha^{-1})	
Unfertilized maize	14^{a}	13	7^{a}	10
Maize after legume	19^{b}	15	22^{a}	23
Cattle manure + NPK	21^{b}	17	49^{b}	37
Leaf litter + NPK	23^{c}	19	37^{b}	37
Mineral NPK only	16^{a}	14	20^{a}	25
Mean	18.5	15.4	27	26
SED	1.7	2.2	8	9.5
F test	*	ns	*	ns

ns = treatments not significantly different. Means followed by same letters within the column did not differ significantly at $P < 0.05$.

Indigenous farming practices: A path for green food production in Sudan

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Key words: Green Production, Indigenous farming practices, Agroforestry

Introduction

Four **main** types of farming systems are practiced in Sudan and each has its a specific, set of environmental impacts: mechanized rain-fed agriculture; mechanized irrigation schemes; traditional irrigation; and livestock husbandry/pastoralism. Based on this classification, Traditional indigenous practices as well as modern technology have been adopted. Adoption of modern technology was found to result in beneficial and adverse impacts. Merits can be summed up in: increase overall production, saving time and costs. Nevertheless, the adoption of such technology has resulted in excessive removal of forests which was followed by enhancing soil erosion, reduction in annual precipitation, soil compaction, and depletion of soil nutrients, drought and desertification. Drought and desertification had resulted in serious socioeconomic impacts on rural population as well as urban centres. However, adoption of indigenous cultivation practices are seemed to be more sustainable and consequently the country can achieve green food production or food security

This paper focuses on identifying threats to green food production in Sudan as well as the green indigenous farming practices for sustainable agriculture.

Materials and Methods

This study is based mainly on critical review of the available literature and personal experience. Sources of literature are: UNEP and FAO documents, Official government reports, M.Sc. and Ph.D. Theses and research activities such as University of Khartoum. It covers the period from late nineties up to date

Threats to green food production in

According to previously mentioned farming types these threats can be summarized as follows:

Mechanized rain- fed agriculture

They are resulted in the destruction of natural forests and pre-existing social systems instead of supported either traditional shifting cultivation; pastoralism; or wildlife habitats, principally open wood land and treed plains (Deforestation). Moreover, it is now encroaching on legally protected areas like Dinder National Park. And depletion of soil fertility, yield collapse, deforestation and abandonment.

Traditional rain-fed agriculture

Food production in Sudan is faced by: population pressure and poor infrastructure development and deterioration of the existing community services

-unsustainable land clearing and drop in yield observed especially in marginal land due to over-cropping and absence of crop rotation.

Mechanized irrigation sector

This sector suffers from excessive use of pesticides. Ongoing pesticides management problem is an example Hasahysa Pesticides, graveyard. The obsolete pesticides in Gezira Schemes had resulted in serious respiratory and skin diseases and abortion of ladies, potentially unsustainable expansion plans of irrigated modern agriculture into desert regions, and -Water pollutions from Sugar Factories' canal situation, soil Stalinization and yield reduction

Traditional irrigation system is threatened by

- Sand encroachment; -River bank erosion including down stream erosion;
Mesquite (Prosopis species) invasion on fertile flood plains

Livestock husbandry

This farming system suffers from explosive growth in livestock number, particularly in central Sudan;
; major reduction in the total area of available range lands; and deterioration of the remaining rangelands caused largely by drought, climatic changes and overstocking.

Sustainable indigenous farming practices (Green Food Production) in Sudan

Traditional farming practices which are proved to be friendly with environment (green) and produce sustainable crop production include a very wide range of traditional or indigenous farming knowledge concerning the practice of farming especially multiple and intercropping practices in Western Sudan. These green practices can be summed up as follows:

- Indigenous seeding knowledge: developing seeds, conserving them, collect most appropriate and most productive ones. Traditional farmers in Sudan have an accumulated knowledge that enables them to have traditional varieties which are tolerant to drought and pests and diseases as well as more productive than breeding seed varieties
- Traditional weeding practices by using indigenous plough in farming (for weeding, thinning and inter-culturing of the crop)

- Traditional crop rotation practices : These refers to practices which are adopted by Sudanese traditional farmers to farm particular crops each year, or combination of crops in the same field or a number of crops in one hole, etc. example: inter-cropping water melon with millets, growing groundnuts with sorghum
- Traditional farming tools: include all of the tools used in land preparation, sowing, planting, weeding, watering, harvesting and storing.
- Water harvesting practices and technologies: There is a growing evidences in Sudan of the economic usefulness and environmental viability and soundness of indigenous water harvesting practices and techniques
- Traditional harvesting techniques and practices: timing of harvesting of various crops based on climatological and agronomical and traditional knowledge.
- Traditional storing techniques: Developing of means of storing up the surplus produce in earthen mounds and holes or building of traditional store house for local materials in the dry season(6)
- Coping Strategies for combating Environmental Stress – this can be summarized as follows: practicing shifting cultivation as a safeguard against low yields in the drought periods; migration is considered another prominent element in the coping mechanism; the last alternative for the farmers, when all choices are not attainable to move towards towns I the camps of displaced people; another traditional storage method which is used by people to adapt to the environmental stresses is sale of animals; using traditional storage method to preserve food to lessen the risk of food shortage during the drought periods; during drought, short handled tools are used more often than long handled ones (7)
- Agro-forestry: growing a field crop inter spaced by a leguminous tree such as acacias
- Zero tillage with minimum disturbance of soil using hand tools for sowing, weeding and harvesting.
- Traditional practices to control pests and diseases
- Traditional farmers are used to practice the following activities to control pests and diseases: land clearing normally completed well in advance of the growing season; early sowing to adapt for variable nature of rainfall and to avoid crop pests; intercropping (e.g. Sesame with Sorghum or Millet) as a safeguard against wind damage and to avoid damage of one crop since the other crops might produce some yields; wider Spacing and Low crop density per unit area to reduce pest infestation; weeding. Two or more is quite important for the control of weed pests especially Buda (Striga hermanthica) and finally seed dressing and improved seeds to control seed- borne diseases and as protection against insect pests

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Les conditions territoriales d'appropriation de l'agriculture de conservation: Le diagnostic préliminaire, *Diallo M. A[1], Karambiri S[1], Dabire D[1], Kalifa Coulibaly K[1], Djamen P[2], Jean-Marie Douzet J-M[3], Andrieu N[3]*

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Mots clés : système agropastoral, résidus de culture, zonage, charte foncière locale, Burkina Faso

Introduction

Les travaux d'analyse des performances de l'agriculture de conservation (AC) se font en général à l'échelle de la parcelle (Luo et al. 2010) et très peu à l'échelle du territoire villageois. En Afrique de l'Ouest, les premières analyses menées à cette échelle relèvent des contraintes importantes (Nkala, 2011 ; Wall, 2007 ; Knowler et Bradshaw, 2007) dont la résolution dépasse les seules compétences du producteur et requiert une action collective. La mise en œuvre de l'AC en milieu paysan dans le contexte des systèmes agropastoraux se heurte au prélèvement des résidus de culture ou des plantes de couvertures en saison sèche lors de la vaine pâture qui constitue un droit tacite et conduit à une faible productivité des systèmes testés (Giller et al. 2009). Concevoir des systèmes à base d'AC nécessite alors de changer d'échelle en passant de la parcelle au territoire villageois et d'identifier les modalités d'organisation et de gestion adéquates. L'objectif de cette communication est de présenter les résultats préliminaires d'une recherche visant à analyser les modalités d'insertion de l'AC au sein d'un territoire villageois de l'Ouest du Burkina Faso. Nous avons cherché à déterminer dans quelle mesure il était possible d'identifier au sein du village des zones favorables à l'insertion de l'AC et quels outils organisationnels pouvaient être mobilisés pour piloter ces zones.

Matériel et méthodes

Cette étude a été menée à Koumbia dans l'Ouest du Burkina Faso. L'AC y est expérimenté depuis 2011 dans le cadre du projet ABACO (Tittonel et al., 2012) mais avec des résultats mitigés du fait notamment des difficultés qu'ont les producteurs pour maintenir une couverture du sol.

Cette étude se base sur trois étapes complémentaires:

- une typologie des parcelles agricoles en fonction de la proximité des pratiques agricoles qui sont appliquées et les principes de l'AC (enquêtes sur un échantillon de 60 producteurs) ;
- une proposition de zonage du territoire basée sur la distribution des différents types de parcelles et les échanges avec les acteurs identifiés (cartographie à dire d'acteurs) ;
- une identification du lien fonctionnel entre acteurs villageois autour des résidus de culture (entretien semi-structuré avec les autorités coutumières, l'administration locale (services d'appui technique, préfecture), les élus locaux, les organisations de producteurs) afin de déterminer les outils et dispositifs à mobiliser pour assurer la gouvernance des zones à identifier. La charte foncière locale adoptée en 2010 est l'un de ces outils qui pourrait être mobilisé (Diallo et al, 2011). Il s'agit d'un ensemble de règles inspirées des coutumes et pratiques fonciers locaux élaborées et adoptées au niveau local pour favoriser la responsabilisation des populations dans la gestion des ressources naturelles de leur terroir.

Résultats et discussion

La typologie a mis en évidence quatre types de parcelles : T1, T2, T3 et T4. Les deux premiers types de parcelles (T1, T2) correspondent aux parcelles conduites de manière conventionnelle. T1 (38% des observations) correspond à des parcelles qui sont labourées, où aucune rotation céréale –légumineuse ni paillage n'a été pratiquée ces trois dernières années. T2 (27% des observations) est proche du précédent toutefois il se caractérise par la rotation céréale-légumineuse. Les types T3 (24 % des observations) et T4 (11% des observations), considérés comme les plus proches des principes de l'AC, sont caractérisés par un travail minimal du sol et des cultures associées (T3) mais aussi par la pratique du paillage (T4).

Les échanges avec les producteurs ont montré que les associations de cultures ou le paillage sont des pratiques conjoncturelles pour pallier à un problème de disponibilité de la main d'œuvre ou d'installation tardive de la campagne. La pratique du semis direct est davantage liée à un manque d'équipement du producteur qu'à une logique d'intensification écologique.

Toutefois les producteurs ont fait ressortir que les pratiques proches des principes de l'AC sont plus faciles à réaliser sur les sols sableux ce qui est en relative contradiction avec nos observations d'une distribution prioritaire sur sols gravillonnaires.

Les sols sableux ont alors été retenus comme clé d'entrée pour le zonage. Nous avons alors superposé aux données concernant les types de sols, celles concernant les types d'occupation, les servitudes proches desquelles la charte foncière mise en place à Koumbia et sensée réglementer l'usage des ressources agro-pastorales prohibe le développement d'activités agricoles ainsi que celles des campements peuls où on fait l'hypothèse que la pression sur les résidus sera trop importante. La Figure 12 représente les zones qui ont ainsi été identifiées. Elles se situent dans la couronne proche des habitations, ce qui pourrait constituer un atout pour la surveillance ou le transport des résidus de culture

Afin d'identifier les outils et dispositifs potentiels pour gérer ces zones nous avons analysé les liens fonctionnels entre les acteurs enquêtés autour des résidus de culture. Quatre types de liens fonctionnels ont été définis :

- exploitation des résidus de culture ;
- régulation des usages des résidus de culture ;
- médiation en cas de conflit d'usage ;
- promotion de modes de gestion alternatifs.

L'exploitation des résidus de culture: 39% des agriculteurs de notre échantillon affirment développer des stratégies d'appropriation pour limiter l'usage des résidus de culture par des tiers. Ces stratégies remettent en cause le principe de vaine pâture libre des résidus de culture et montrent une évolution des perceptions paysannes concernant cette ressource commune.

La régulation des usages des résidus de culture: Pour 60% des agriculteurs interrogés, la vaine pâture n'est soumise à aucune règlementation. La mise en application de la charte foncière locale qui règlemente l'accès aux résidus de culture n'est pas encore bien opérationnelle.

La médiation des conflits d'usage: elle est assurée par les autorités coutumières avec en particulier le conseil des délégués coutumiers composé de chef de lignages sous l'animation du chef de village ou de terre qui jouent à la fois le rôle de régulation et de médiation.

Les projets de recherche-développement tendent eux à *promouvoir des modes de gestion alternatifs* des résidus de culture et sont très souvent à l'origine de la dynamique d'appropriation des résidus de culture identifiée chez les producteurs (Corbeels et al., 2014). Cette analyse des relations fonctionnelles entre acteurs autour des résidus de culture montre alors que les résidus de culture sont encore perçus par une majorité de producteurs comme un bien commun et que la charte foncière locale et les instances traditionnelles de médiation peuvent servir de dispositifs et outils pour piloter d'éventuelles zones d'insertion de l'AC.

Au même titre que le compostage des résidus de culture ou la constitution de stocks fourragers promus par la recherche (Andrieu et al. submitted), l'AC se situe dans une gamme d'alternatives techniques visant à intensifier écologiquement les systèmes de production mais basées sur une appropriation individuelle des résidus de cultures. Pour les systèmes agraires ouverts, intensifier écologiquement les systèmes de production via de telles alternatives va nécessiter de les inscrire dans une dynamique de développement territorial. L'enjeu est alors de définir un projet collectif entre les acteurs de ces territoires et de se doter d'outils de gouvernance au service de ce projet (Chia et al., 2010).

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Figures

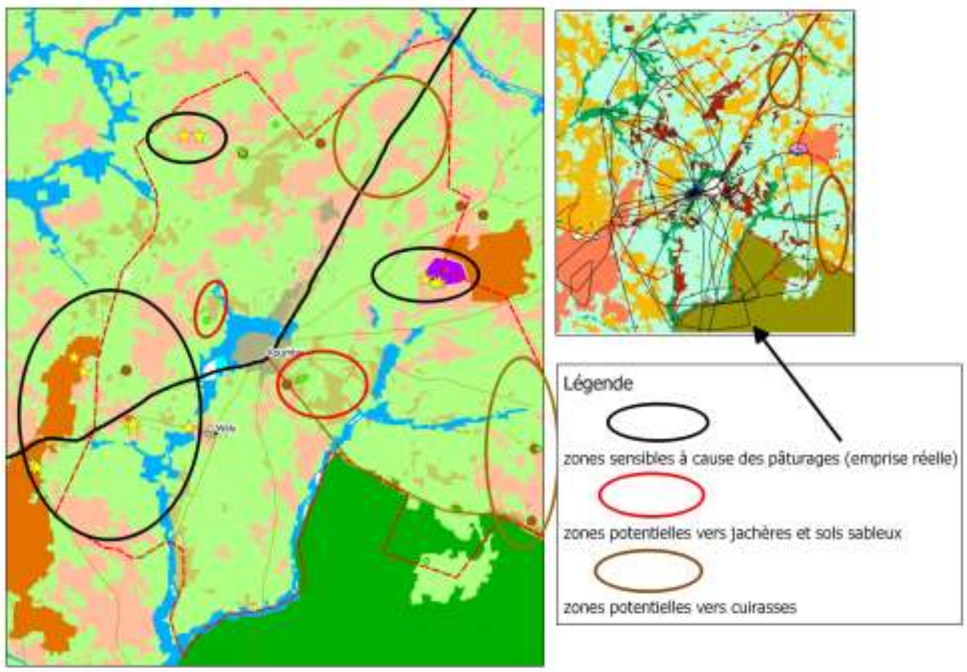

Figure 12 : zones favorables à l'insertion de l'AC en fonction du type de sol et de la pression de l'élevage

Soil organic carbon build-up on soils under NT variants in semi-arid Districts of South Africa and Lesotho

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Keywords: Soil organic carbon (SOC), Conservation Agriculture (CA), cover crops, No-till (NT)

Introduction

Soil degradation is largely related to the decline in soil organic matter. Monoculture cereal production, intensive tillage, short-to-no fallow periods and limited crop rotation have contributed to this in the commercial sector. Tillage results in soil erosion and land degradation (Decker et al., 2011). The research in this paper is based on a wider definition of soil quality, and goes beyond the focus on the productive potential of the soil. Definitions of soil quality have expanded from being associated only with productive potential, to the soil acting as an environmental buffer, protecting watersheds and ground-water from agricultural chemicals and industrial and municipal wastes, and sequestering carbon that would otherwise contribute to global climate change. Soil organic carbon sequestration through CA can reduce carbon dioxide (CO_2) emissions (O'Dell et al., 2013). SOC is the most often reported characteristic identified in long-term studies.

Material and Methods

This soil quality research had two components: on farm trials and a comparative assessment.

Firstly, on farm trials were three variables are being compared: NT, NT with mulch and NT with cover crops. The trials included four treatments, each with four repetitions. Treatment blocks were 3.6m wide (width of the NT planter) and 40m long. The blocks were randomly selected. The first treatment was NT wheat followed by maize. This reflects the conventional NT farming operations past 2004. The main crop rotation under conventional farming (CV), before converting to NT, was wheat followed by maize. NT has initially been implemented without significant soil cover (40-50%) and sound crop rotations (2 grain crops). Treatment two was the NT maize-wheat rotation with grass mulch after planting maize. Treatment three and four referred to the maize-wheat rotation including cover crops. Treatment three's cover crop mix was oats *(avena sativa)* /grazing vetch *(Vicia dasycarpa)* /fodder radish *(Raphanus sativus)*. Treatment four's cover crops included stooling rye *(Secale cereal)* / grazing vetch /fodder radish.

Secondly, a comparative assessment was carried out on different NT farmers' fields. The reason for conducting this extended assessment was to include conventional farming practices which were omitted in the trials. In addition, this assessment would open up more sites assessing short- and long terms effects of NT and ley crops.

The methodology used for comparing soil quality was comparing treated with a nearest possible untreated reference site and within 50m from the cropland sample site. This methodology allows the research to be ecotype specific ensuring a high level of reliability of homogeneity of sites. The few (9) existing NT pioneers in the Eastern Free State were purposively selected. Maphutseng, a CA research site in Lesotho (O'Dell et al., 2013) has been included in the comparative assessment. Neighbouring sites, where farmers were practicing CV, were then selected for comparison. Natural veld, often growing under the fences, was utilized as examples of relatively native and undisturbed vegetation.

Results and Discussion

Trials:

SOC sequestration increased in three years under NT. The highest build up of SOC was at the 0-5cm level under NT with CC (T3) of 0.135% yr^{-1}. The highest build up of SOC at 5-20cm was under NT mulch at 0.027% yr^{-1} (see table 1).

Comparative assessment:

SOC sequestration rates measured through the comparative assessment between NT, CV and veld as benchmark was highest under veld followed by NT and CV (see graph 1 and 2). SOC% of >0.1% yr^{-1}, at 0-5cm depth, where highest under veld followed by NT (see graph 3). The highest percentages of decline of SOC were under 5-20cm CV, followed by NT and veld. The sudden increase and decrease of results can only be explained in terms of the spatial variation in soils.

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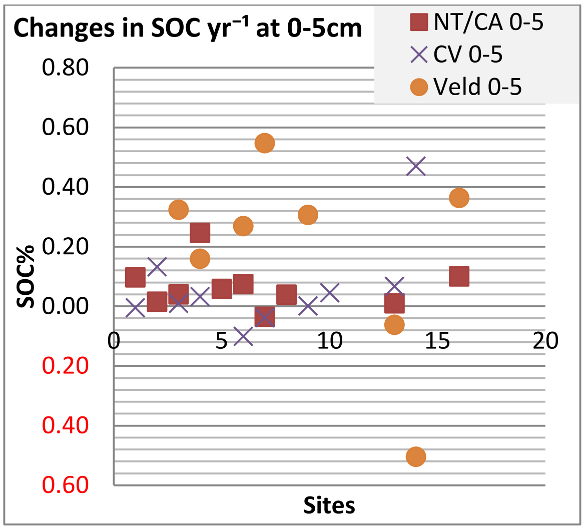
Figures and Tables

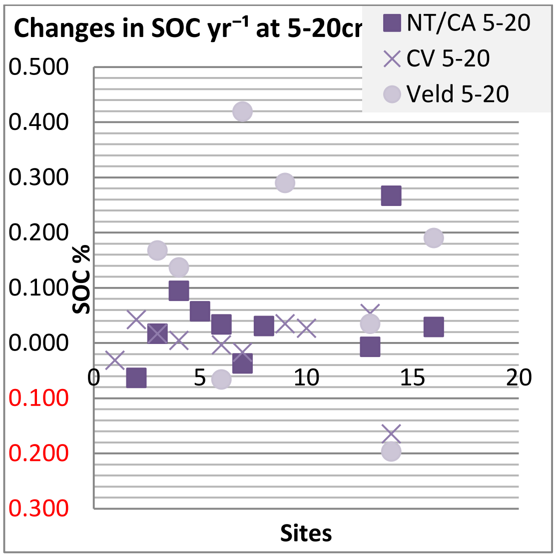
Table1: Ranges of increased SOC yr^{-1} at 5-20cm and 0-5cm levels under different NT variants

Treatment	SOC (0-5cm) 3 year increase (%)	(0-5 cm) SOC% yr^{-1}	SOC (5-20cm) 3 year increase (%)	(5-20 cm) SOC% yr^{-1}
T1- Conventional NT	0.249	0.083	0.017	0.006
T2 – NT + mulch	0.133	0.044	0.08	0.027
T3 – NT + CC1	0.406	0.135	0.06	0.020
T4 – NT + CC2	0.023	0.014	0.04	0.014

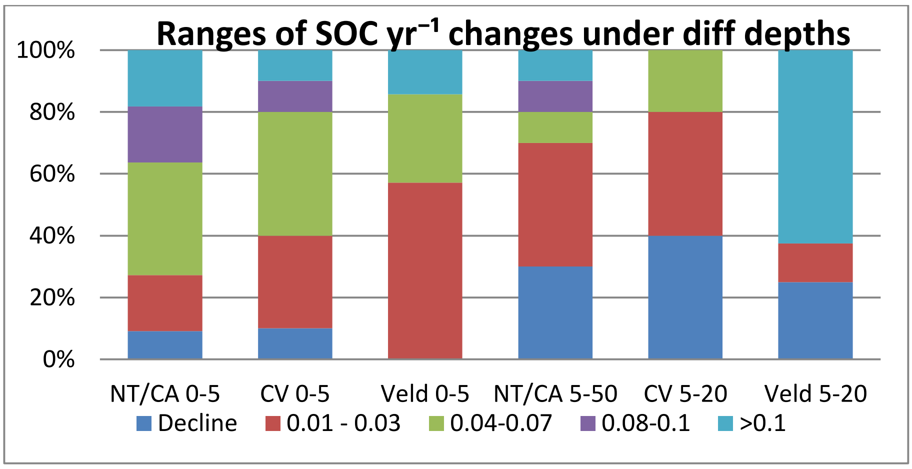
Graph 1: Changes in SOC % yr^{-1} at 0-5cm under different cropping systems



Graph 2: Changes in SOC % yr^{-1} at 5-20 cm under different cropping systems



Graph 3: Indication of changes in SOC yr^{-1} at different depths for NT, CV and veld



Environmental impact of external inputs under different production systems in semi-arid districts of South Africa

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Keywords: Environment, Conservation Agriculture, cover crops, inputs, GHG, CO_2

Introduction

Conventional crop production systems (CV) are characterized by low species and management diversity, high use of fossil energy and agrichemicals, and large negative impacts on the environment (Davis et al., 2012). Without heavy chemical fertilizer applications, good crops yields are generally not possible (Reeves, 1997, p. 132). CV relies heavily on tillage i.e. land preparation, planting and weed control. No-tillage (NT) involved less tillage but require an increased use of herbicides for weed control. NT is therefore not regarded as an environmental friendly practice by Gattinger et al. (2011). Gattinger et al. (2011) pointed out some environmental side effects of NT: groundwater pollution due to increased herbicide use; herbicide resistance in weeds; adverse effects on terrestrial wildlife; direct toxicity effects on human health as a result of increased herbicide use, and the use of genetic modified food crops. The objective of this study is to reflect what inputs i.e. diesel, fertilizers, pesticides or herbicides contribute most to direct and indirect greenhouse gases (GHG) under different crop production systems? This paper assesses the load of different tillage systems to the environment in terms of GHGs, without being able to show all supporting tables and data due to conform to the specifications of a condense paper. This paper advocates for an increased awareness of the impact high external farming has on to the environment.

Material and Methods

Economic modelling is based on the local crop rotations with local adapted crops in the Eastern Free State of South Africa. This modelling is done by constructing an Excel-based model with input costs and prices based on fixed 2012 costs. Different crop enterprise budgets are collated. Crop income is derived from Waterfall farm's crop yield history multiplied with 2012 SAFEX-related product prices that the Waterfall farmer received for the crops in 2012. This paper modelled four crop rotations under CV, NT, Conservation Agriculture (CA) with cover crops (CC) partially- (2-4 years out of 7) and fully (every year) incorporated and lastly Organic CA (OCA) over a period of 7 years. The rotations modelled were: 1) M-W-M-W-M; 2) *M-S-M-S-M-S-M*; 3) S-M-SF-S-M-SF-S and 4) *M-S-W-S-M-S*. The abbreviations M, S, W, and SF stand for maize, soya, wheat and sunflower respectively. Different tables were omitted for the purpose of this paper. The tables reflected number of (tillage) passes per crop, quantity of chemicals used, and rates and types of fertilizer under different crop rotations.

The environmental cost refers to a direct and or indirect load of the cropping system on the environment. The indicator here is the quantity of diesel used under the different crop rotations over seven years. The quantity of diesel used is converted determining the greenhouse gas emissions as a direct and indirect load on the environment; and also converted to Rand value (ZAR). The conversion calculations are based on a British system (Defra, 2012) due to the lack of similar tables in SA. It should be noted that actual figures might differ from SA's situation, but the British figures are used in assuming the environmental costs. The environmental cost is expressed in both kilogram carbon dioxide equivalent (kg CO_2e) and in a monetary value. The calculations are based on total litres per hectare used over seven years derived from the OVK input model mechanization cost list. The actual litres per hectare is multiplied with a conversion factor of 2.6769 and 0.5644 determining the total direct and indirect GHG in terms of CO_2 (in kg CO_2 e) of the different crop rotations under the different production systems. The total kg CO_2 e is divided by 1000 to obtain the quantity in tons.

The shadow price used as a so called carbon tax levy based on SA's proposed figure of the cost of R120 CO_2e t (Stafford, 2013 and DNT, 2013, p15). The price for a ton of CO_2 in Australia and British Columbia is R221 and R255 respectively (Stafford, 2013).

The formula (own analysis) used determining the total direct and indirect cost of GHG for the use of diesel ha^{-1} 7yrs is:

$$(X * Ci) + (X * Cii) = Y$$

$$\frac{Y}{1000} * R = Z$$

With:

X = liters of diesel ha^{-1} 7yrs

Ci = conversion rate indirect GHG of diesel ha^{-1} 7yrs

Cii = conversion rate direct GHG of diesel ha^{-1}7yrs

Y = Grand Total GHG (Direct and indirect loading of diesel) in kg CO_2 e ha^{-1} 7yrs

R = proposed cost per t CO_2

Z = Total direct and indirect environmental cost of the use of diesel in ZAR ha^{-1} 7yr

Similar calculations are done determining the total indirect GHG in terms of CO_2 (in kg CO_2 e) of the amounts spent over 7 years on fertilizer, pesticides and other chemicals.

The formula (own analysis) used determining the total indirect cost of GHG for the use of fertilizer, pesticides and herbicides ha^{-1} 7yrs is:

$$(Ai * Fi) + (Aii * Pi) + (Aiii * Hi) = W$$

$$\frac{W}{1000} * R = T$$

R = proposed cost per t CO_2
T = Total indirect environmental cost of the use of fertilizer, pesticides and herbicides in ZAR ha^{-1} 7yr

With:
Ai = Amount spent on fertilizer ha^{-1} 7yrs
Fi = conversion rate indirect GHG for the use of fertilizer ha^{-1} 7yrs
Aii = Amount spent on pesticides ha^{-1} 7yrs
Pi = conversion rate indirect GHG for the use of pesticides ha^{-1} 7yrs
Aiii = Amount spent on herbicides ha^{-1} 7yrs
Hi = conversion rate indirect GHG for the use of herbicides ha^{-1} 7yrs
W = Total indirect GHG of fertilizer, pesticides and herbicides in kg CO_2 e ha^{-1} 7yrs

Herbicides were not mentioned explicitly in the British conversion tables (Defra 2012) and therefore the category ‘other chemicals’ were used. The conversion factors of 2.25, 0.97 and 0.76 for fertilizer, pesticides and other chemicals respectively were used when multiplying it with the amounts spent over seven years on those respective products. The total kg CO_2 e was here also divided by 1000 to obtain the quantity in tons. The shadow price used as a so called carbon tax levy based on SA’s proposed figure of the cost of R120 CO_2e t (Stafford, 2013 and DNT, 2013, p15).

The profitability of a crop rotation is measured in highest net returns over seven years. Net returns per hectare are influenced by variable input costs. This is expressed as Gross margins above specified costs (GMASC). This is done pure economically as well as with the inclusion of abovementioned load to the environment.

Results and Discussion

OCA has the lowest GHG load to the environment followed by CV and CA_{LEI}. Conventional NT (i.e. range 1.97 – 2.43 t CO_2 e ha^{-1} yr^{-1}) has a higher TOTAL load to the environment than CV (i.e. 1.61 – 2.06 t CO_2 e ha^{-1} yr^{-1}).

Gross margins above specified costs:

Conventional No-till (NT) i.e. lacking adequate soil cover, had on three out of four rotations the highest returns on investment measured in highest gross margins above specified costs over 7 years ha^{-1}. This reflected per annum is R488; R3366; R3106 and R2059 yr^{-1} ha^{-1}. Crop rotations with winter wheat scored lower as compared to summer-summer crop rotations. GMASC for CA_{HEI} scored three out of the four rotations higher than CV.

Diesel:

On average, NT had a 47% saving on fuel, as compared to CV. NT had lowest direct and indirect GHG for diesel use i.e. 0.092; 0.138; 0.138 and 0.113 t CO_2 e ha^{-1} yr^{-1}. Conventional cropping had highest diesel use i.e. 0.182; 0.253; 0.253 and 0.216 t CO_2 e ha^{-1} yr^{-1}. The cover crop (CC) alternatives had a slightly higher rate of diesel use ha^{-1} as compared to conventional NT. This is due to the fact that CC were casted (i.e. fuel aeroplane) or drilled (i.e. diesel NT planting) despite savings in spraying actions applying chemicals.

Herbicides:

Conventional NT however had the highest indirect GHG emissions to herbicides are ranging from 0.44 – 0.48 t CO_2 e ha^{-1} yr^{-1}. Both CV and OCA were found zero. Low external input NT cover cropping (CA_{LEI}) reduced indirect GHG emission to herbicides to 0.27 – 0.406 t CO_2 e ha^{-1} yr^{-1}.

Fertilizer:

Fertilizer rates were modelled as fixed for all crop rotations. The indirect GHG emissions to fertilizer are ranging from 1.37 – 1.77 t CO_2 e ha^{-1} yr^{-1}. OCA, applying no synthetic fertilizer, had no GHG emission on fertilizer. Future modelling should include savings on fertilizer due to the use of legumes and CC in the rotations. Savings in N through biological nitrogen fixation was translated in this study in increased yields of following crops and not in reduced fertilizer rates for those specific crops.

In conclusion: the highest indirect loading to the environment in t CO_2 e by all crop rotations was undoubtedly caused by the use of chemical fertilizer (1.37-1.77 t CO_2 e ha^{-1} yr^{-1}) followed by the use of herbicides (0.44-0.48 t CO_2 e ha^{-1} yr^{-1}) and use of diesel (0.182-0.253 t CO_2 e ha^{-1} yr^{-1}). Fertilizer use is the biggest contributor to the GHG of the different crop rotations. In fact, it even overshadows the savings on pesticides and herbicides under CA_{LEI}. Reeves (1997, p. 132) stated that without heavy chemical fertilizer applications, good crops yields are generally not possible under CV. That is, however, not applicable to CA_{LEI} and OCA with the highest legume ratio and where inorganic fertilizer can be reduced even to the extent of eliminating fertilizer completely (Davis et al. 2012). Future crop rotations should therefore be low (or omit) in the use of fertilizer and chemicals. CA cover cropping is playing a crucial role in achieving that.

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Increasing Conservation Agriculture adoption and up-scaling: The Zimbabwe Community Technology Development Organisation experience

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Keywords: Farmer Field School, Conservation Agriculture, Lead Farmer Approach, Demonstration Plots, Participatory Extension Approaches

Introduction

Agriculture is the back-bone of the economy of Zimbabwe. However, close to 6 million people are currently food and nutrition insecure (UN, 2012). The main reasons for this state of affairs are the continuing low agricultural productivity, deteriorating soil fertility (Donovan and Casey, 1998; Mupangwa et al., 2008), dysfunctional input and output markets (Jama and Pizzaro, 2008) and the unfavorable macro-economic environment. Smallholder farmers in the drier areas are most affected by this situation. Over the years, the response to this crisis has been large-scale distribution of food aid and direct agricultural input assistance without a suitable exit strategy for sustaining some of the new technologies promoted within the context of food aid (DFID, 2009). One technological option for promoting soil fertility and water management has been the conservation of soil fertility, water, and nutrients using a variant of conservation agricultural techniques, namely mechanized and manual Conservation Agriculture (CA). Over the years, Community Technology Development Organization (CTDO) has been promoting conservation agriculture in its operational areas. This promotion, however, has been characterized by a mixture of positive experiences and some challenges. This paper presents CTDO experiences in promoting conservation agriculture with regard to improved productivity among smallholder farmers, innovative and effective approaches, and supportive infrastructural and policy support.

Materials and methods

The materials and methodological approaches applied in the promotion and cascading of CA by CTDT included:

Training of government agricultural extension staff on the principles of CA

Conducting baseline surveys to identify current smallholder farming practices and information gaps with regard to soil management and productivity. The survey also looked at the yields per district against the national average and factors responsible for the disparity.

Identification of potential farmers with requisite capacity, primarily labour and/or draft power to adapt the technology Stratifying and categorizing farmers in relation to productivity potential into High, Medium and Low

Selection of 10 on-farm demonstration sites to compare CA with conventional farming practices. During the initial stages of CA promotion, comparisons were done on 0.25 ha plots of which 0.2 ha was devoted to cereal while 0.05 ha had legumes. Later, the plot size was increased to 0.5 ha and finally to 1.0 ha.

Establishing farmer clusters of 10 farmers per cluster to facilitate farmer-to- farmer extension. This approach has allowed for greater adoption of CA since it allows for cross-learning and also close monitoring of the 9 farmers by the lead farmers.

Training at least one high potential farmer per cluster so as to train other farmers and provide technical backstopping. Deliberate efforts were made to select successful and popular farmers who also doubled as community opinion leaders in order to facilitate buy-in and voluntary adoption of CA practices by other farmers within the community. This led to a constant increase in the number of farmers adopting CA.

Establishment of 20 Farmer Field Schools (FFS) of at least 30 members per groups.

Introduced water harvesting technologies such as pit traps/ fanya ju, contour ridges and pot holing

Results and Discussions

Experience over time has shown that manual/non-mechanized CA is initially practiced by all farmers, the economically-endowed and the poor. Due to the high labor demand of non-mechanized CA, the economically-endowed farmers tend to drift towards the practice of mechanized CA. Poor farmers have continued practicing manual CA but on small pieces of land in most cases not exceeding 0.2 ha.

In order to address the issue of labor constraints, CTDO in collaboration with CIMMYT carried out studies on mechanized CA in 2006. The organization availed different types of machines which included ripper-tine, jab planters and ox-drawn direct seeders and planters. The equipment that was favored by farmers was the ripper tine because farmers can easily convert their plough into a ripper tine. The results of these trials were remarkable. The jab planter reduced the time spent on fertilizer application and planting by 50% relative to manual methods. However the jab-planter is not user friendly to the elderly and women due to the high energy requirement in using it. The direct seeder and planter reduced planting time by 70% and labor cost by 50% compared to manual methods. The biggest challenge for farmers to move towards mechanized CA has been availability and the high cost of such equipment for smallholder farmers. For instance, direct seeder cost US$600, the jab planters US$150 and the ripper tine US$15.

Demonstration sites which were done over five seasons clearly showed the benefits of CA. A total of 10 sites were setup (2 in Mutoko; 3 UMP; 3 Murewa and 2 Chiredzi) with each plot being 0.4 ha then divided equally between CA and convectional practices. In all the plots fertilizer application rates were 300 kgs/ha of compound fertilizer and 250kgs/ha top dressing. The plots that was being practiced CA resulted in change of soil color and quality. There was also evidence of change of soil structure and colour in the CA plots. Initially, the soils had poor soil structure and were light brown in colour. By the end of the third season there was a marked difference in the soil structure with the CA plot having a darkish color and had multiple types of insects.. The difference in the soil structure clearly showed the benefits of CA towards soil fertility. As shown in the graph 1 below, the first and second years the yields were not significantly different between CA and conventional but from the fourth year following marked differences in yields were showing.

One key strength of CA promotion by CTDO has been the use of Participatory Extension Approaches (PEAs) such as the Lead Farmer approach and Farmer Field Schools (FFS). These have been pivotal in cascading CA even to hard to reach populations and groups. PEAs were able to reach 10 times more farmers than traditionally done using the extension staff and were more effective and efficient in training. In ward 3 of UMP District, for example, there were 5 farmers who had adopted CA in 2003 but the number had jumped to over 650 households in 2010.

In conclusion, the ultimate benefit of adoption of CA is its potential positive impact on food security and household income from sale of food. There is however need to promote crops that are easily marketable and create market linkages. CDTO started to promote soya-bean production in Goromonzi and Chegutu. The farmers were linked to multiple markets and generally the demand of the crop increased. The result was rapid increase in plot size with farmers doubling plot size in the first year from 0.5 ha to 1 ha. Anecdotal information and farmers opinions showed that productivity of soya bean under CA was higher compared to convectional farming methods.

CA is a viable option for smallholder farmers in Zimbabwe particularly for those smallholder farmers in high potential areas. The mechanization of CA will definitely encourage more smallholder farmers to adopt CA as it will substantially reduce the labor required in the first three years of adoption

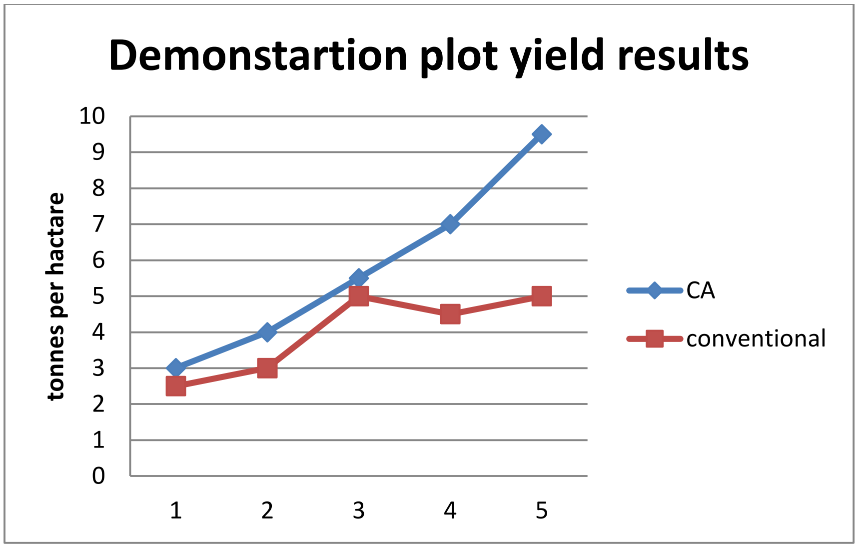

Fig. 1. Yields obtained in demonstration plots using CA and conventional tillage

Capacity building in Conservation Agriculture in Southern and Eastern Africa -the SIMLESA Experience

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Keywords: capacity building, conservation agriculture, cropping systems, smallholder farming, training

Introduction

Approximately 400 million people live in the eastern and southern African (ESA) region, with 75% of these residing in rural areas characterized by poor infrastructure, poor market access, soil degradation, and vulnerability to climate variability and change Agriculture constitutes the basis of livelihoods and income for more than 70% of the people (IFAD Report, 2012).

Conservation Agriculture (CA) is a modern agricultural technique, which combines increased production with protection of the natural resources. Other benefits of CA include increased yield stability and reduced vulnerability. CA thus has potential to bring about positive change in agricultural production systems and rural livelihoods (FAO, 2007)

Material and Methods

The Sustainable Intensification of Maize-Legumes based Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) focuses on African 5 countries – Ethiopia, Kenya, Tanzania Malawi and Mozambique – with spill over to another 5 neighboring countries (Rwanda, South Sudan, Uganda, Botswana and Zimbabwe). The program, which is funded by the Australian Centre for International Research (ACIAR) and executed by the International Maize and Wheat Improvement Center (CIMMYT), aims to improve the maize and legume productivity by 30% and to reduce the expected downside yield risk by 30% for approximately 500,000 farmers within 10 years. The project is carried out through participatory research and development with farmers, extension agencies, non-governmental organizations, universities and agribusinesses along the value chain with the support of sub-regional research organizations. Through existing networks the program fosters spill-over of improved crop systems management practices and improved germplasm to neighboring areas and countries.

The capacity building component of SIMLESA aims to increase the efficiency of agricultural research. The program focuses on short-term training to build capacity amongst the present and future generation agricultural researchers. The capacity building program intends to increase the understanding and knowledge of CA principles including pest and disease management as well as skills required for data management and analysis; and participating and managing Innovation Platforms.

The Agricultural Research Council (ARC) is one of the capacity building partners for the SIMLESA program. The ARC training courses developed for SIMLESA scientists and extension personnel were custom designed to accommodate the needs of each country or group of trainees. For in-country training, ARC experts travel to those countries to conduct practical training. In-house training involves travelling of participants from different countries to ARC in South Africa. The interactive learning approach was the major style of learning utilized during the training, which has proved very effective.

Results and Discussion

During the 3 years of the SIMLESA program 230 scientists were trained in all 5 participating countries. The ARC visited all target countries and identified capacity building needs together with the country coordinators. Two in-house training programs were conducted at ARC in South Africa in February 2012 and May 2013. The focus of this training was on agronomy for young scientists. Modules for these training programs were: principles of applied biometry, conservation agriculture, soil health and innovation platforms. In-house training afforded an opportunity to identify similar capacity challenges in the different countries and have participants share experiences on how to tackle them. Participants had an opportunity to tour some ARC facilities relevant to their work in Pretoria and Potchefstroom; visit agribusiness specializing in conservation agriculture products and implementation and also attended the National Maize Producers Organization (NAMPO), one of the largest agricultural fairs in the southern hemisphere.

In-country training workshops were held in Nazret (Ethiopia), Chimoio (Mozambique), Kigali (Rwanda), Arusha (Tanzania) and Moshi (Tanzania). The focus of this training was on the Principles of CA, Pest & Disease Management, Biometry, Introduction to Innovation Platforms and Extension Principles. Table 1 below shows the detailed modules requested by each group of trainees. All the training provided was 80% practical session such as the knap-sack sprayer calibration (Fig 1) and electron microscopy work (Fig 2).

Introduction to Innovation Platforms, which involved role-playing (Fig 3) was the most popular and requested training module in 2013. This resulted in the development of a resource book that can assist facilitators and extension officers with skills to establish innovation platforms.

The 230 scientists trained during the 3 years of the project are expected to facilitate the dissemination of skills to both extension and farmers in order for the SIMLESA programme to reach its goal of 500 000 trained in 10 years.

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Fig: 1 Knapsack sprayer calibration – Kigali Rwanda

Fig: 3 Plant pathology training – Young scientist Potchefstroom

Fig: 2 IP Training – Arusha Tanzania

Table 1: Training conducted

MODULES	VENUE	COUNTRIES TRAINED	# TRAINED
In-house Training			
CA, Soil Classification, Mapping, Analysis, Stat Guidelines, Introduction to Innovation Platforms	Pretoria	Malawi, Tanzania, Mozambique, Kenya	16
CA, Weed management, Pest & disease management, Stats, Introduction to IP, soil nutrition management	Potchefstroom	Young scientist from Mozambique, Rwanda, Kenya, Malawi, Tanzania, Ethiopia, Uganda,	15
In-country training			
CA, weed management, Land preparation & planting, integrated soil nutrition management, soil sampling and IP	Ethiopia	Ethiopia	29
CA, integrated weed & pest management, soil nutrition management IP	Mozambique	Mozambique	39
CA, integrated weed & pest management, soil nutrition management, Land preparation & planting IP	Rwanda	Rwanda, Uganda, South Soudan	23
Innovation Platforms Workshop	Arusha	CIMMYT, ASARECA, Malawi, Tanzania, Mozambique, Kenya, Ethiopia, Botswana, Uganda ,South Soudan, Rwanda	50
Statistical Guidelines; data analysis using EXEL and Weed Management	Moshi	Tanzania	55
Post Graduate Training			
PhD in Economics	University of KwaZulu Natal	Mr Frank Mbadno (Tanzania)	1
Masters in Agronomy	University of the Free State	Mr Costodio Jorge & Gabriel Braga (Mozambique)	2
		TOTAL	230

Mixed extension model: the village development organization´s role in the dissemination of conservation agriculture in Cabo Delgado

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Keywords: Aga Khan Foundation, Conservation Agriculture, Development Village Organization, Mixed Extension Methodology

Introduction

In Mozambique, the dissemination of techniques and technologies have been taken through the networks of public extension services and backed by private networks (organizations, non-governmental) (MINAG, 2007). These services are costly which means sometimes there is no money for an efficient operation (Sambo, 2003). In the search for sustainable solutions to address this problem, the Aga Khan Foundation (Mozambique) has spread the techniques of conservation agriculture involving all stakeholders in the community, which has shown excellent results in the diffusion of conservation agriculture and other techniques in rural communities on the coast of Cabo Delgado[16].

The Aga Khan Foundation (Mozambique) is an international non-governmental non-profit organization working in various social areas such as civil society, education, health, agriculture and habitat. The civil society component works with communities in governance, creating Development Village Organizations (VDO). VDOs are assumed to be participation and community consultation institutions that act as the basis of transparency and providing accountability positioning itself at the forefront addressing all issues of local development. The VDO role for communities is to have a tool to develop initiatives, promote meetings, discuss the problems of the community, and search for sustainable local solutions in several areas such CA technologies (Grabowski, 2013). The objectives of this paper are twofold: (i) to present the framework by which a mixed model of agricultural extension has been implemented in Mozambique and the results of the model being implemented; and (ii) to contribute to further discussion on appropriate models for agricultural extension in the region, especially where such systems are weak-poorly financed and under staffed.

Mixed Model Extension Methodology

The Aga Khan Foundation (M) works in the Cabo Delgado coast communities spreading different messages in different areas of development with the goal of improving the quality of life in the target communities (Dambiro at el. 2011). The agriculture component is involved in the dissemination of conservation agriculture techniques, the principles and practices of

[16] Cabo Delgado is located in the north of Mozambique.

Conservation Agriculture as defined by FAO (www.fao.org/ag/ca), in a community adapted to local conditions through a form of mixed model extension. The mixed model is in direct involvement in community leadership represented by members of VDO in the process of mobilizing of communities to participate in different village development projects. In short, the mixed model extension brings the methodologies: training and visit, FFS, Farmer to Farmer and community based extension.

Operation of mixed model

The process begins with the VDO training members. The training is carried out by civil society component. The training covers issues on governance, health, habitat and other including agriculture. In agriculture the VDO members are trained on sustainable operating benefits in the short, medium and long-term Conservation Agriculture systems and the impact of adherence of these practices in food security and quality of life in targeted communities. The VDO, with this tool, start with mobilizing communities through scheduled meetings and other sessions. The key message: Conservation *Agriculture is the way for sustainable production*. As a result of this work, farmers are organized in groups and through the FFS methodology are trained in Conservation Agriculture by community facilitators. The extension officers, periodically, visit groups to become aware of the problems and together with the group seek local solutions. The extension officers' role continuously train community facilitators so that they can have more skills on the technical process transmission. One of the fallout benefits is by training producers on CA principles community facilitators are able to gain from the additional labor by engaging the trainee producers to practice on their own (community facilitators) farms e.g. assisting at mulching, seeding, weeding, etc. In addition, during a project the Aga Khan Foundation provides to community facilitators a kit with tools and inputs.

Clubs Conservation Agriculture

Conservation Agriculture Clubs are formed by 4-6 farmers that are adopters of CA for over three years from the same or nearby village. They are volunteers in order to make this work. Aga Khan Foundation (Mozambique) organizes and pays travel. They meet monthly, in order to move in villages that have no extension services to give talks telling their stories.[17] In these workshop, whose purpose is to diffuse Conservation Agriculture practice, the CA club members, explain how the training process works in the groups as well the VDO role in the process.

Conservation Agriculture Forum

The CA Forum is composed of all stakeholders in the agricultural sector (farmers, extension workers from government and private sector, researchers, buyers and others). This forum has the largest participation producers CA practitioners, so the leadership is from the producers. This

[17] From 2014 Clubs of Conservation Agriculture will now display videos with practices on Conservation Agriculture. These videos are being produced by a project funded by the Ford Foundation.

forum creates a space for the sharing of different experiences throughout the province of Cabo Delgado. In the forum are also announced innovations and decisions to scaling up the new innovations as well as recommendations for research institutions.

Results and Discussion

In Table 1, we see that with the introduction of community facilitators significantly increased the number of groups trained in the same year, directly influenced total number of trained farmers in agricultural season 2013-14 (Table 2).

Costs for transportation (motorbike , fuel and maintenance costs) are more critical to have extension agents work efficiently , especially when they have to cover between 5-6 villages (distance between villages 8-25 km). The mixed model extension has economic advantage because of community facilitators do the training in their own fields, not needing to travel great distances from their village, which exempts motorized means. The incentives given by the project are seasonal (tools and inputs) and has no stipulated remunerations. Another advantage is related to the assisted groups. The VDO of each village can prepare the community promoters which needs, while the recruitment of state extension officers depends on the annual financial availability. The budget for extension services depends mainly on the donor (MINAG, 2003), which takes in some years no admission of new staff even if it is necessary.

Table 1: Trained groups

Trainers	Number of trainers	Trained groups		Total
		2010-12	2013-14	
Extension officers	21	216	92	308
Community facilitators	302	0	302	302
Total		216	394	610

The increase of farmers practicing conservation agriculture provides benefits in the medium and long-term quality of life of communities. The Conservation agriculture systems practiced by producers of Cabo Delgado communities allow them to work longer in the same farm, *forcing* them to settle down. Thus, reducing the traditional practices as an itinerant agriculture, deforestation and slash and burning, which has implications for the increase in the uptake of rainwater into the soil and reducing loss of soil by erosion.

Table 2: Trained producers

Trainers	Trained producers						Total
	2010-12			2013-14			
	Male	Female	Sub Total	Male	Female	Sub total	
Extension officers	3500	1900	5400	1450	850	2300	7721

Community facilitators	0	0	3700	3850	7550	7852
Total	3500	5400	5150	4700	9850	15573

The majority of communities receive extension from outside (who lives in another village), a lot of times producers, especially women, take time to gain confidence and interact with the extension officers. The mixed extension model allows for a gender balance. Table 2 shows a trend of having more women to participate in training when they are facilitated by community facilitators, although the data cannot be considered conclusive, because it is an approach that is being experienced in some time.

Conclusion

Members of the community participate in the process of training their own communities, which drastically reduces the costs of this process. The mixed extension method allows extension service to reach more producers. Communities adhere more messages when the diffusion process is led by VDO.

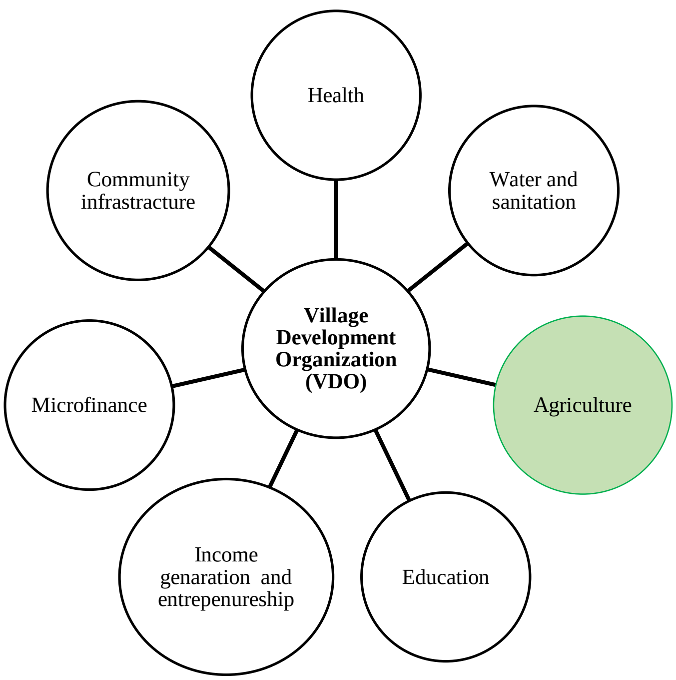

Figure 1: VDO stracture

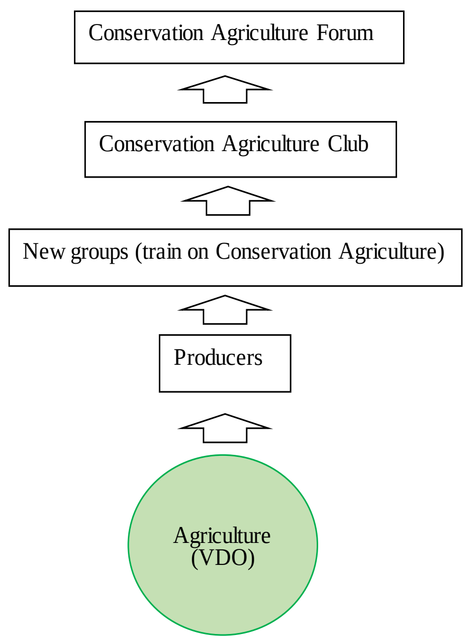

Figure 2: Mixed extension frame

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[iv] Some authors, such as Bationo in Bationo A (2012) *Lessons Learned from Long-term Soil Fertility Management Experiments in Africa,* Springer, Dordrecht, The Netherlands, maintain that tropical soils will inevitably deteriorate during 10 to 20 years of continuous cropping, but the experience of many farmers, best documented by Triomphe in Triomphe B (1996) *Seasonal Nitrogen Dynamics and Long-term Changes in Soil properties under the Mucuna/Maize Cropping System on the Hillsides of Northern Honduras*, Dissertation for PhD, Cornell University, Ithaca, New York, contradict that statement by increasing and then maintaining crop yields, without any use of chemical fertilizer, for the same periods of time. The crucial difference is probably that none of the trials reported by Bationo, produced 20 t/ha or more of leguminous biomass/year. In fact, if one consults Bationo's original sources, the one system he included in his book that does produce this amount of biomass—an alley-cropping system using leucaena and mother of cacao—did improve and then maintain yields when applied to a degraded soil.
[v] Triomphe, *op. cit.,* pp. 110-122.
[vi] Monegat C. (1991) *Plantas de Cobertura del Suelo, Caracteristicas y Manejo en Pequenas Propiedades,* Claudino Monegat, Chapeco, Brazil, pp. 140-141.
[vii] Bunch, *op. cit.*
[viii] Personal communication from Joseph Mureithi, Kenyan Agricultural Research Institute (KARI).

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