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Session 10: Conservation Agriculture: Key to Intensifying Crop Production

ORAL ABSTRACTS

Mobilizing Greater Crop and Land Potentials with Conservation Agriculture

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Background

In the coming decades, crop yields must increase substantially to cope with the growing demand for food driven by continued population growth and increasing incomes resulting in rising consumption of livestock products, but also due to the expansion of biofuel production. All this will dramatically increase the pressure on global agriculture and require boosting production per unit of land cropped, unless farming is expanded considerably into forest areas and natural habitats with the well-known consequences on wildlife biodiversity and carbon sequestration capacity. Thus, to produce more from the land already under cultivation means the intensification of crop production and narrowing the yield gaps between potential yields (Yp) or water-limited yields under rainfed conditions (Yw) and the actual average farm yields (Ya) (Ittersum et al., 2013). The question is how best to reduce this exploitable yield gap.

Current rates of improvement in both potential (Yp) and water-limited yields (Yw) in many of the world's important cereal producing regions appear to be well below the 1.16-1.31% per year rates necessary to meet the projected demand in 2050 (Hall and Richards, 2013), which calls for a 70% increase in global food production. According to Ray et al. (2013), the projected need is even to double global production by 2050, which would require a 2.4% increase per year. In any case, this is far beyond the current growth rates of 1.6%, 1.0%, 0.9% and 1.3% of the production of maize, rice, wheat and soybean, respectively. For many regions worldwide there are reports and concerns on yield stagnation or even declines (Lin and Huybers, 2012, Ray et al., 2012, Finger, 2010, Brisson et al., 2010, Hafner, 2003). Also, the dominant production methods based on intensive tillage and excessive agro-chemicals is now generally considered to be environmentally and economically unsustainable, particularly in the face of widespread degradation of agricultural lands, rising costs of energy and production inputs and climate change.

Exploring and improving the genetic yield potential of major staple crops is widely recognized as an important contribution to guaranteeing food security over the coming decades. Unexploited opportunities for further genetic improvement following several novel approaches could enhance current relative yield growth rates. However, the time-scales necessary between progress and widespread adoption are known to be considerable (Hall and Richards, 2013).

The role of Conservation Agriculture in harnessing the fuller potentials of crops and land

Given that the rate of increase in yield potential is much less than the rate of increase in expected demand and that the exploitable gap between genetic yield potential and average farm yields is becoming smaller, additional efforts have to be undertaken to find improved production system solutions towards global food security without further putting at risk the main natural resource base, the soil and its agronomic crop and land potential. Soil degradation in tillage-based production systems, in fact, is the major threat to future food security that must be addressed as an integral part of the task of coping with the need to maintain the yield gains already made and further improve actual crop yields in many of the important cropping areas worldwide. To halt and reverse this tendency of stagnating yield growth and increasing degradation, the principal resource base, the soil, has to be sustained and its productivity improved through its sustainable management.

According Lal (2013), strategies aiming to close crop yield gaps must comprise soil-based management approaches for site/crop-specific situations optimizing soil conditions for enhanced crop growth and yields. Thus soil quality management plays a key role in harnessing the full potential of crops and land. It is not by chance that despite the adoption of improved varieties, crop yields especially in Sub-Saharan

Africa showed very small increases over the last decades. Soil degradation and nutrient depletion are the most likely cause for the tremendous yield gap there. On the contrary, in countries like Brazil, where the grain cropping area between 1991 and 2004 increased approximately by 10%, total grain yields more than doubled (Cooplantio/Conab 2005, cited by Derpsch, 2005). In the same period the area under Conservation Agriculture (CA) raised from 1 million to over 20 million hectares. In addition, the crop yield increases observed in many situations of long-term CA practice are accompanied by reduced inputs, especially the amount of mineral fertilizers, fuel and labour (Derpsch 2005, Carvalho et al., 2012).

Concluding remarks

Based on worldwide empirical and scientific evidence, it appears generally evident that CA can play a major role in accelerating production output growth to meet future global food needs. The evidence also suggests that it can do so while arresting soil degradation and improving factor productivity (efficiency of input use) and profit margins, as well as add the much needed resilience to cropping systems and ecosystem services. There is growing evidence to show that CA through improved soil quality enables better phenotypic performance from any adapted genotype, traditional or improved. This is because CA enables agricultural soil and landscape to be treated as living biological entities in which soil biota and their symbiotic relationships with root systems are encouraged while maintaining improved and efficient soil-plant-moisture-nutrient relationships (Jat et al., 2014).

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Comparative Evaluation of Conservation Agriculture Practices on Productivity and Sustainability of Pigeonpea (*Cajanus cajan* L.)-Wheat (*Triticum aestivum* L.) Cropping Systems Under the Indo-Gangetic Plains of India

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Keywords: legume, bed planting, sustainability

The Indo-Gangetic Plains (IGP) occupies ~13% of total geographical area of India, and it produces about 50% of the total food grains to feed 40% population of the country. The rice-wheat is prominent rotation in IGP, where crop residue burning and intensive tillage is the most common farmers' practice. It is reported that residue burning has led to a loss of 8.2 t/ha soil organic carbon (SOC), and this led to considerable deterioration in SOC of IGP, although it was considered as one of the most fertile region of the country. Further, this system encountered a host of problems like higher nutrient depletion including micro-nutrients deficiency, water scarcity, pest and diseases, weed infestation, particularly *Phalaris minor.* So, this necessities the replacement of rice with legumes viz. pigeonpea or equally remunerative crops like cotton and maize. The pigeonpea (*Cajanus cajan* L)-wheat (*Triticum aestivum* L. emend Fiori & Paol) cropping system is a viable option, covering 3.58 m ha area in India. Again adoption of conventional system for growing these crops may not be that much productive and sustainable. Through adoption of Conservation agriculture (CA), resource use efficiency, productivity and soil health is improved by build-up of SOC pool over the conventional practices. Globally, CA occupies 124.8 m ha, but in India, area under zero tillage is approximately 2.2 m ha, which is mostly confined to the rice-wheat system. Keeping this in view, a long term field experiment was conducted to assess the effects of different tillage and crop residue management practices on system productivity and sustainability of pigeonpea-wheat cropping system in the IGP tracts of India.

Materials and methods

The field experiment was conducted during 2008-09 to 2011-12 at the research farm of Indian Agricultural Research Institute, New Delhi. The experimental area was semi-arid, sub-tropical region and mean annual rainfall during the experiment was 309, 542, 985 and 670 mm during 2008-09, 2009-10, 2010-11 and 2011-12, respectively. The soil was sandy loam (15.6% clay, 18.2% silt, 66.2% sand) in texture havingh pH 7.9 (1:2.5 soil to water). The soil contained 0.36 % organic C, 164 kg/ha available N, 10.2 kg/ha 0.5 *M* $NaHCO_3$ extractable available P and 270 kg/ha NH_4OAc extractable available K (Prasad *et al*. 2006). The treatments (16) comprised of combinations of 4 tillage and crop establishment techniques (conventional tillage – raised bed (CT-B); conventional tillage - flat bed (CT-F); zero tillage – raised bed (ZT-B) and zero tillage - flat bed (ZT-F)) in main plots and 4 residue management practices (no residue; sole wheat residue @ 3 t/ha; sole pigeonpea residue @ 3 t/ha and combined pigeonpea and wheat residue (50:50) @ 3 t/ha) in subplots, allocated randomly in a split plot design and replicated thrice. Pigeopea (cv Pusa 991) was sown in rows at 70 cm apart so as to get one row in the centre of each bed (70 cm centre to centre spacing), while three rows of wheat (cv HD 2895) were accommodated on the respective beds. Fertilizer dose of 20:26:33 kg N, P and K/ha was applied as basal to pigeonpea, while a dose of 120:26:33 kg N, P and K/ha was applied to wheat (50% of N and full P and K as basal and rest 50% N at first irrigation). Pigeonpea was sown during first week of June and manually harvested about 10 cm above the ground level during third week of November. Wheat was sown in fourth week of November and harvested in third week of April across the years. Productivity of the system was worked out by adding wheat yield and wheat equivalent yield for respective years. Afterwards, system productivity was pooled across four years and analysis of variance was performed to draw some logical conclusions. Also, sustainable yield index (SYI) of the system was calculated by using following formula.

$$SYI = (y - \sigma_{n-1}) / y_m$$

Where y is mean yield of respective treatment, σ_{n-1} is the standard deviation (SD) and y_m is the maximum yield of the treatment during a year. A two-factor analysis of variance (ANOVA) was carried out to test the significance of treatments. Critical difference (CD at P=0.05) was used to determine whether means differed significantly or not. Microsoft excel (Microsoft Corporation, USA) was used for statistical analysis of data.

Result and discussion

System Productivity, Net Returns and Sustainability

There was no significant ($P< 0.05$) variation in grain yield of pigeonpea, wheat, and system productivity over the years. The tillage and crop establishment techniques significantly influenced pigeonpea yield, wheat yield and system productivity (Table 1). Averaged over four years, the grain yield of pigeonpea and wheat varied from 1.6 to 1.8 and 3.8 to 4.4 t/ha, respectively. Under zero tillage (ZT), the average yield of pigeonpea and wheat was 1.8 and 4.1 t/ha, respectively. Likewise, corresponding grain yield for conventional till (CT) was 1.7 and 4.0 t/ha, respectively. Hence, the grain yield of pigeonpea and wheat in ZT was 5.4 and 2.5% ($P >0.05$) higher over CT, respectively. Similarly, the average system productivity across the years ranged from 7.5 to 9.0 t/ha. The highest system productivity was recorded in the 4th year (2011-12), which was 20, 15.4 and 4.5% higher over the 1st (2008-09), 2nd (2009-10) and 3rd years (2010- 11), respectively (Data not reported). Zero tillage on an average gave 8.2% increased system productivity over the CT. Further, plots under zero tillage - raised bed (ZT-B) and zero tillage - flat bed (ZT-F) were found comparable to each other, but both showed significantly better results over the plots with conventional tillage – flat bed (CT-F) and conventional tillage - raised bed (CT-B). ZT-F plots had an upper edge over the others, with respect to system productivity, sustainable yield index (SYI) and net returns. The system productivity in ZT-F was obtained 6.52, 4.60 and 2.76% higher over CT-B, CT-F and ZT-B, respectively. The highest value of SYI was recorded in ZT-F, which was significantly higher than CT-B, CT-F and ZT-B. Furthermore, net returns were also obtained highest with ZT-F, being 16.6, 9.9 and 6.9 % higher over CT-B, CT-F and ZT-B, respectively. In the case of pigeonpea and wheat grain yield, application of crop residues was found superior to no residue during all years. Application of crop residue gave 14.4 and 28.2% higher pigeonpea and wheat grain yield over no residue. Additionally, among the crop residue treatments, combined application of pigeonpea+wheat residue was found comparable with pigeonpea residue, but remained significantly higher over wheat residue. However, wheat residue was found superior over no residue plots. In ZT-B and CT-B plots, combined application of pigeonpea+wheat residue resulted in significantly higher system productivity than pigeonpea residue and other residue management practices. However, there was no significant difference in pigeonpea residue and combined application of pigeonpea+wheat residue in CT-F and ZT-F. Further, wheat residue gave highest system productivity under ZT-F, which was significantly higher compared with other tillage practices, but pigeonpea residue had similar system productivity at ZT-B and ZT-F. Similarly, in no residue plots, ZT-F gave significantly higher system productivity than the other tillage practices. Almost equal net returns were obtained with pigeonpea + wheat residue @ 3 t/ha (INR 84,500) and sole pigeonpea residue @ 3 t/ha (INR 84,200) application. Combined application of pigeonpea + wheat residue @ 3 t/ha gave significantly higher system productivity and SYI than all other residue management practices. Correlation analysis showed a positive and significant ($P\leq0.01$) linear relationship ($R^2 = 0.999$) between system productivity and sustainable yield index as influenced by crop residues (Fig. 1). The combined use of pigeonpea and wheat residue applied @ 3 t/ha may have enhanced the biodiversity of soil organisms, which may led to increased mineralization and recycling of nutrients (Sepat *et al*., 2014).

Conclusions

From present study of investigation it can be concluded that zero-tillage with either raised bed or flat bed, combined with application of pigeonpea + wheat residue at 3 t/ha is a suitable option to enhance the pigeonpea-wheat system productivity over along run in the western Indo-Gangetic Plains of India.

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Table 1 Yield, system productivity (in wheat equivalent yield) and net returns of pigeonpea- wheat system as influenced by tillage, crop establishment, and residue management practices (Mean of four years).

Treatment	Grain yield (t/ha)		Wheat equivalent yield (t/ha)	System productivity (t/ha)	SYI of the system	Net returns of the system (x 10^3 INR/ha)
	Pigeonpea	Wheat				
Tillage and crop establishment						
CT-B	1.72	3.84	4.18	8.02	0.80	71.8
CT-F	1.63	4.26	3.95	8.20	0.84	76.1
ZT-B	1.80	3.92	4.39	8.31	0.82	78.3
ZT-F	1.73	4.38	4.21	8.58	0.87	83.7
SEm±	0.03	0.01	0.04	0.04	0.003	-
LSD(P=0.05)	0.05	0.03	0.13	0.14	0.01	-
Residue management						
No residue	1.55	3.39	3.76	7.14	0.71	65.6
Wheat residue	1.73	4.12	4.20	8.32	0.84	75.5
Pigeonpea residue	1.80	4.35	4.40	8.75	0.88	84.2
Pigeonpea + wheat residue	1.79	4.54	4.36	8.89	0.90	84.5
SEm±	0.02	0.01	0.04	0.04	0.004	-
LSD (P=0.05)	0.04	0.02	0.11	0.12	0.01	-

CT-B: Conventional tillage-raised bed; CT-F: Conventional tillage-flat bed; ZT-B: Zero tillage-raised bed; ZT-F: Zero tillage-flat bed; System productivity: wheat equivalent yield of pigeonpea + wheat yield; SYI: Sustainability yield index; MSP of pigeonpea for 2008-09, 2009-10, 2010-11 and 2011-12 was 2000, 2300, 3000 and 3200 INR/q, respectively. MSP of wheat for 2008-09, 2009-10, 2010-11 and 2011-12 was 1000, 1080, 1100 and 1120 INR/q, respectively.

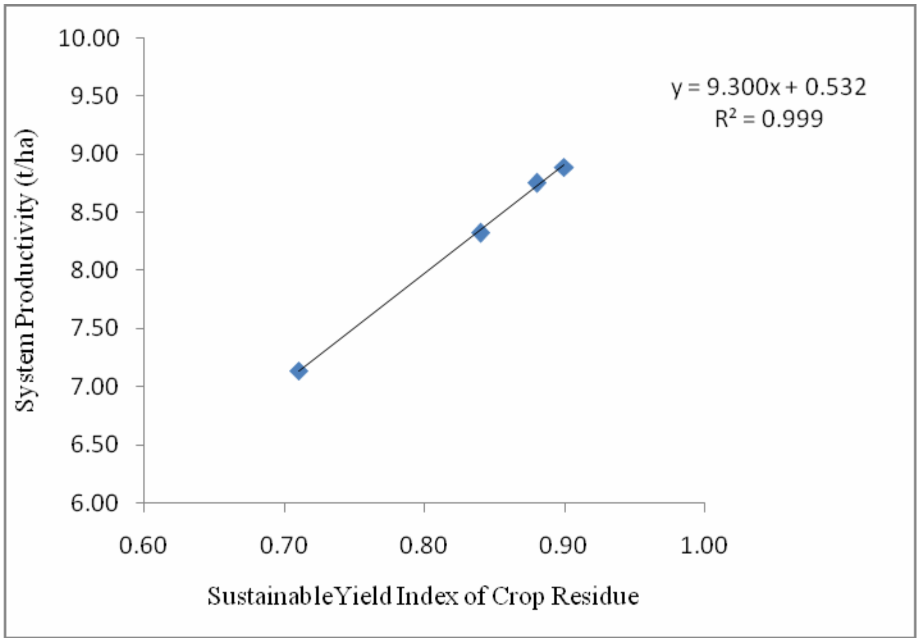

Fig. 1. Linear relationship between crop residue application and system productivity of pigeonpea-wheat cropping system

Implications for Adoption of Zero Tillage (ZT) on Productive Efficiency: A Syrian Case

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Background

Conservation agriculture (CA) is currently seen as a way to improve productivity and sustainable farming practices, especially in North and South America and Australia where it is widely practices relative to other regions of the world. Zero tillage (ZT) is one of the components of CA that has been found to conserve soils moisture, reduce wind and water erosion, and increase yields besides reducing farming production costs through use of lower input levels.

In recognition of the potential benefits of ZT, the governments of Syria and Iraq have made efforts to introduce those technologies to its farmers using local funding and in collaboration with international funding agencies. In particular, the ACIAR-AusAID[1] funded project has been in the forefront in promoting the adoption of ZT technology in Syria and Iraq. Empirical evidence indicates that adoption is taking place rapidly in Syria (Piggin et al. 2011). However, adoption is sometimes hampered by lack of empirical evidence of the benefits of ZT technology relative to conventional tillage (CT), especially among the doubtful farmers.

Review of a number of studies on the economics of ZT indicates benefits of adoption in terms of cost savings and increased yields (Erenstein and Laxmi 2008). However, empirical studies that analyse the differential in production efficiency between farm households that practice CT and ZT in the drylands areas of the Middle East are still rare.

This purpose of this study is to investigate the differential in technical efficiency between farms that have adopted ZT and those that continue to use CT among the resource-poor farmers of Syria. Technical inefficiency is an important factor that contributes to low productivity.

Data

Data for this study came from two main sources: a survey of 500 farmers that were randomly selected and a sample of 320 elite farmers that were purposively selected to participate in the CT project in Syria. The survey was conducted in 2011 in 28 villages distributed across 17 districts and 7 governorates. Since majority of Syrian farmers have not adopted the ZT technology, the elite farmers were selected and included in the project to avoid the risk of not having adequate numbers of adopters. The elite farmers had at least tried the ZT technology once.

Research Methods

Since our sample of 820 farmers do not randomly fall into two groups of adopters of ZT and non-adopters but was ordered by self-selection, this implies that our data is subject to sample selection bias. Therefore, our method of estimating productive efficiency takes into consideration the possibility that farmers may be facing differences production technologies and estimating a common frontier for both adopters and non-adopters may not represent the true frontier. Our analysis is in two parts: first we use the Heckman selection procedure to identify major determinants of adoption of ZT technology and the land area that

[1] Australian Centre for International Agricultural Research

will be committed to zero tillage (ZT). Second, we use the stochastic frontier approach to estimate the 'best practice frontier' and determinants of technical inefficiency while controlling for sample selection bias and other factors that contribute to heterogeneity across farms.

Results and Discussion

Our results show that participation in field days and hosting on-farm demonstration trials are among the most important promotion activities that increase adoption of ZT technology. On average, we find that CT farms are less efficient than ZT farms under the assumption that ZT technology is available to all farms.

However, the average efficiency scores are equal under assumption that the two technologies are different and ZT is not accessible to all farms (See table 1). Those results are quite robust to different production frontier model specifications. The density plot (Fig 1) shows that ZT farms tend to have higher efficiency scores. We also find that ZT farms have higher yields than CT farms and farm operator experience in farming is a key determinant of technical efficiency. Overall, we find use of more labor to be output reducing while use of more seeds to be output increasing.

Table 1. Technical efficiency under different technology assumptions

	Under Same Frontier			Under Different Frontiers	
	All Farms	**ZT Farms**	**CT Farms**	**ZT Farms**	**CT Farms**
Mean	74%	88%	65%	67%	67%
Median	79%	89%	71%	68%	72%
Maximum	95%	95%	89%	93%	98%
Minimum	28%	68%	28%	42%	17%

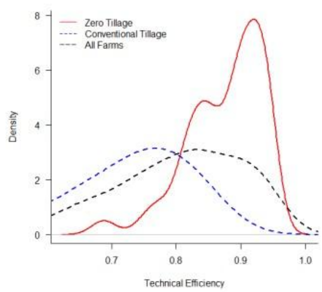

Figure 1. Densities of technical efficiency scores

Implication of Results for Conservation Agriculture

We find that, on average, CT farms are 23% less efficient than ZT farms. The implication of our results is that CT farmers could produce more output by using the same level of inputs if they adopt the ZT technology, all else held constant. Reduction of inefficiency in production is essential for achieving improved productivity in the dryland areas of the Middle East and lifting majority of the resource-poor farmers out of poverty and food insecurity.

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Impact of Nitrogen, Cover Cropping and Tillage on Population Sizes of Nitrogen- Cycling Bacteria under a Continuous No-till Cotton Experiment in West Tennessee.

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Abstract Background

Nitrogen (N) is the most limiting nutrient in crop production worldwide. Due to this limiting nature of N, its management poses certain challenges in crop production. In high input commercial systems, N fertilizer is often over applied therefore making N a potential pollutant in ground water through nitrate leaching while in low input subsistence systems N is underutilized, resulting in lower yields. These N fertilization management challenges mandate that alternative sources of N in crop production be sought. Biologically fixed N either through free living or symbiotic N-fixers may help to reduce the need for N fertilization in high input systems whereas in the low input systems it may help to augment the low yields without added costs. To this end, some agronomic practices have been developed including the no-till, cover crops and crop rotations. As these practices are being adopted by farmers worldwide, there has to be an understanding of how they interact together to effect the N transformation processes that will determine its use efficiency.

Experimental Approach

The current study was aimed at determining the effect of different agronomic practices including tillage (no-till and till), cover crops (no cover, hairy vetch and winter wheat) and different rates N fertilizer (0, 34 and 101 kg N/ha) on N transformation processes as measured by net N mineralization and nitrification rates and on the microbial biomass carbon (C) dynamics during cotton growing season. The experiment was set up as randomized complete block design with split-split plot. N fertilizer rate was set up as the whole plot, cover crops as split plot while tillage was the split-split plot.

Net N mineralization and nitrification rates were assessed through the use of intact *in situ* core incubation method (DiStefano and Gholz 1986). A 10-cm long polyvinylchloride (PVC) pipe containing a soil core of 7.5-cm fitted underneath with mixed ion (cation and anion) exchange resins in nylon mesh bag was used. Mixed ion resins were used to adsorb the inorganic N (NH4-N and NO3-N) that was released from the mineralization of the soil organic N or soil organic matter within the PVC pipe. Incubation was carried out twice during the cotton growing season. The first incubation lasted for 82 days (from crop emergence to cotton boll development) while the second incubation lasted for 46 days (from boll development to prior harvest). The net N mineralization rate was calculated as the total sum of NH4-N and NO3-N produced over the incubation period divided by incubation time in days. This sum total included both N from the soil within the PVC pipe and N that was adsorbed on mixed ion resins. Net nitrification rate was estimated as the sum of only nitrate from within the PVC pipe and from the mixed ion resins over the incubation time. For microbial biomass C, soil was sampled four times the during cotton growing season, at crop emergence, flowering, boll development and prior to harvest. Microbial biomass C was determined through chloroform slurry extraction (Ferier and Schimel 2002). Two replicates of the same sample are obtained, together with the extraction solution (KCl); one replicate is

treated with the chloroform. The difference of organic carbon C between the chloroform treated replicate and non-chloroform treated sample serves as a proxy for soil microbial biomass.

Results

N fertilizer rate affected both net N mineralization and net nitrification rate only for the first incubation period. The 101 kg N/ha fertilizer rate resulted with highest rate of mineralization (36.17 mg NH4-N and NO3-N m^{-2} d^{-1}) while the 0 kg N/ha rate had the lowest rate (23.00 mg NH4-N and NO3-N $m^{-2} d^{-1}$). Net nitrification rate resulted with the same observation as the net mineralization rate. Cover crops also had a significant effect on net mineralization and nitrification rate for both incubation periods. For the first incubation period, hairy vetch resulted with the highest net mineralization rate (35.98 mg NH4-N and NO3-N $m^{-2} d^{-1}$) while winter wheat resulted with the lowest (26.2142 mg NH4-N and NO3- N $m^{-2} d^{-1}$) which was not significantly different from that of no cover ($p<0.05$). Net nitrification was the same as the net mineralization rate. For the second incubation, N fertilizer rate had no effect on both these processes (mineralization and nitrification). The effect of the cover crop was similar to the first incubation period. None of the treatment factors had effect on microbial biomass C over the growing season; however tillage affected microbial biomass C at boll development with no-till resulting with almost 61 percent greater microbial biomass C than till.

Discussion and Implications

Due to the fast turnover rate of microbial biomass C, it is often referred to as a sink and source of nutrients. The gradual increase of microbial biomass C from crop emergence to boll development under no-till show the immobilized nutrients that are stored in biomass. When the biomass is itself mineralized, the immobilized nutrients will become available to crops and from this premise, the difference in microbial biomass C between till and no-till might be the depiction of no-till's potential in nutrient conservation. The higher mineralization rate under vetch cover crop shows that it can supply the N demand of subsequent crop. However a higher rate on mineralization at the beginning of the growing season may result with higher loss of N resulting in less N available when required in large amounts later in the season. Moreover, such a high rate of mineralization may result with the loss of sequestered C and soil organic N. The higher rate of nitrification as a result of higher N fertilizer rate together with leguminous cover crop could be understood as a threat to the environment. This could be so as the amount of N that was mineralized almost ended up being nitrified. To reduce the loss of N through high rate of nitrification, the amount of N applied to soil should be cut down especially when there is a use of leguminous crops in the cropping system.

Key words: Net N mineralization rate, nitrification rate and microbial biomass carbon.

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Can High Cereal Yields Be Attained and Sustained with Less Resource Use in the Rice-Wheat Cropping System of South Asia? A Case Study from Northwest India.

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Background:
The rice-wheat (R-W) cropping system of the Indo-Gangetic Plains provides the foundation for food security in the South Asian sub-continent, with productivty levels highest in Northwest (NW) India. In recent years, serious concerns have arisen in NW India for the long-term sustainability and viability of R-W cultivation with accelerating trends of resource scarcity (labour, water, and energy), rising costs of production, and a perceived increase in climate variability (Gathala et al. 2013). To address these issues and to determine if high cereal yields can be attained and sustained with less resource use while maintaining environmental quality, long-term field trials were established at Central Soil Salinity Research Institute, Karnal, India under the umbrella of Cereal Systems Initiative for South Asia (CSISA) project funded by the Bill and Malinda Gates Foundation and USAID.

Experimental Approach
The performance of following four cropping system scenarios (treatments), designed to adapt to current and future drivers of agricultural change were evaluated: S1) business as usual— conventional farmers' practices [conventional puddled transplanted rice (CT-TPR) followed by (fb) conventional till broadcast wheat]; S2) best management practices for yield maximization— partial conservation agriculture (CA) based [CT-TPR fb zero-till (ZT) wheat fb ZT mungbean]; S3) labor-, energy-, and water-saving drivers of change— CA based [ZT direct-seeded rice (ZT-DSR) fb ZT wheat fb ZT mungbean], and; S4) futuristic, intensified and/or diversified systems— CA based [ZT maize fb ZT wheat fb ZT mungbean]. Details of scenario treatments are given in Table 1. Crop and system yields, resource use (labor, water and energy) and economic data were collected from these cropping systems treatments. Data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedures of the Statistical Analysis System (SAS Institute, 2001). Scenario mean values were separated by Fisher's protected least significant difference test at $P < 0.05$.

Results
Based on 3-years of results, we recorded similar or higher system-level crop yields while using fewer resources (labour, water, tillage and crop establishment costs) through adopting CA and other best management practices. ZT-DSR (S3) yielded 8% higher than CT-TPR (S1) with 46% less irrigation water and 36% less energy use and higher profitability (US$ 178/ha). Optimally managed CT-TPR (S2) also resulted in higher rice yield than S1 (13%) with 27-31% less irrigation water and energy input use and higher profits. When maize was grown instead of rice (S4), the 'rice equivalent' maize yield was at par to S1but with 91% savings in irrigation water and 68% in energy use than S1 and with highest profitability among all scenarios. Wheat in full CA plots (S3-S4) yielded 15% higher than S1 and about 7% more than plots where partial CA was adopted (S2). On a system basis, rice equivalent system yield varied as follows: S2 (15.8 t/ha) > S3 (14.8 t/ha) = S4 (14.5 t/ha) > S1 (13.0 t/ha). Profitability varied as follows: S4 > S2=S3 > S1. Full CA-based rice-wheat-mungbean system (S3) resulted in substantial savings in

irrigation water (33%) and energy use (26%). Substitution of maize for rice cultivation in S4 resulted in much higher savings of irrigation water (71%) and energy use (46%) as compared to S1.

Application and Implication of Conservation Agriculture: These results suggest that CA in tandem with other best-bet agronomy have the potential to achieve high cereal yields without any yield penalty while using fewer resources including labor, water, energy and input costs than conventional practices. On-going research places these potenial gains in the context of overall challenges to the sustainability and viability of staple crop production in NW India.

Table: 1 Drivers of agricultural change, crop rotation, tillage, crop establishment method, and residue management of the four scenarios.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
	Business-as-usual	Integrated crop and resource management	Conservation agriculture (CA)-based systems	Futuristic and diversified systems based on principles of CA
Drivers of change	None	The need to increase cereal production and farmers' income	The need to increase cereal production and income in the face of increasing scarcity of water, labour, and energy, and soil degradation	The need to diversify and increase cereal production and income in the face of increasing scarcity of labour and energy, and soil degradation, and even greater water scarcity and food demand
Approach	Current farmers' practice	By intensification and best management practices	By intensification, best management practices, including zero tillage and residue retention	By intensification, best management practices, including zero tillage and residue retention, and diversifying by replacing rice with maize
Crop rotation	Rice-wheat	Rice-wheat-mungbean	Rice-wheat-mungbean	Maize-wheat-mungbean
Tillage	Conventional till Rice-puddling Wheat-conventional till	Conventional/zero till Rice-puddling Wheat-zero till Mungbean-zero till	Zero till Rice-zero till Wheat-zero till Mungbean-zero till	Zero till Maize-zero till Wheat-zero till Mungbean-zero till
Crop establishment method	Rice-transplanting Wheat-broadcasting	Rice-transplanting Wheat-drill seeding Mungbean-drill/relay broadcasting	Rice-drill seeding Wheat-drill seeding Mungbean-drill/relay broadcasting	Maize-drill seeding Wheat-drill seeding Mungbean-drill/relay broadcasting
Residue management	All residue removed	Partial rice residue (anchored) retained; partial wheat residue (anchored); full mungbean residues incorporated during puddling for rice	Full (100%) rice and mungbean; partial (anchored) wheat residue retained on soil surface	Full (100%) maize and mungbean; partial (anchored) wheat residue retained on soil surface

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