Compendium of deliverables of the conservation agriculture course 2012

NELE VERHULST, JUAN HERRERA, AMOR YAHYAOUI AND BRAM GOVAERTS (EDITORS)

CIMMYT
International Maize and Wheat Improvement Center

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Headquartered in Mexico, the International Maize and Wheat Improvement Center (known by its Spanish acronym, CIMMYT) is a not-for-profit agriculture research and training organization. The center works to reduce poverty and hunger by sustainably increasing the productivity of maize and wheat in the developing world. CIMMYT maintains the world's largest maize and wheat seed bank and is best known for initiating the Green Revolution, which saved millions of lives across Asia and for which CIMMYT's Dr. Norman Borlaug was awarded the Nobel Peace Prize. CIMMYT is a member of the CGIAR Consortium and receives support from national governments, foundations, development banks, and other public and private agencies.

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Foreword

This book is the result of the hard work of six CIMMYT trainees who work on sustainable practices in Argentina, India, Iran, Mexico and Nepal, and participated in the 2012 visiting scientist program "Conservation agriculture: Laying the groundwork for sustainable and productive cropping systems". Over 5 weeks the scientists received an intense training program that combined mentoring and problem solving approaches. They actively participated in the ongoing cropping systems management activities of the CIMMYT Mexico-based Conservation Agriculture Program, at the experimental stations located near Mexico City at El Batán and Toluca, and in nearby farmers' fields. Emphasis was given to conservation agriculture-based technologies, including conventional and reduced till permanent bed planting for both irrigated and rainfed conditions, and using alternative crop residue management strategies. Crops studied included wheat, maize, barley and dry beans.

Strong focus was given to interdisciplinary approaches. Breeders provided a better understanding of the nature of crop management by genotype interactions. Similarly, plant pathologists were involved in order to better understand disease interactions with the new tillage and crop residue management practices and an economist shed light on the complex system interactions and market chain developments related to conservation agriculture. These are just some of the numerous contributions we received from several CIMMYT scientists. Upon completion of the program, the participants presented their plans to initiate activities in their home countries. This included carrying out further research on what was learnt and the extension of the new technologies to farmers. They developed the necessary skills for trial management and plant and soil monitoring as influenced by management practices.

The main objectives of the program were:

- To enhance understanding of the use and application of conservation agriculture-based planting technologies and relevant agricultural implements (with emphasis on planters/planter modifications) for irrigated and rainfed wheat and maize production systems.
- To encourage and develop participants' ability to synthesize and use the information and knowledge related to conservation agriculture-based technologies (e.g., seeding methodologies in the different planting systems, irrigation water management, crop nutrient management, weed control strategies, and the importance of crop residue management).
- To increase participants' knowledge of (long-term) trial planning and management.
- To develop skills for monitoring soil and plant parameters as they relate to cropping management systems, as well as their influence on physical, chemical, and biological soil quality, their effect on climate change adaptation and mitigation, and their impact on water and nutrient use efficiency.
- To foster positive attitudinal changes such as improved confidence, increased motivation, and heightened appreciation of the benefits of team work and interdisciplinary research.
- To create a minimum level of proficiency in order to generate scientifically-sound hypotheses, determine data collection strategies, interpret data, and summarize them into scientifically-sound conclusions and recommendations.

To achieve the last objective, each participant chose a defined deliverable to work on during the 5 week course. Some scientists analyzed and summarized data they brought from their home country, others reviewed a specific theme of interest related to conservation agriculture. In this book, we present the deliverables of each participant.

We want to thank the participants of the course for the excellent work they delivered. Each of you really did an excellent job. Thanks for sharing your valuable knowledge with the group!

Congratulations,

Bram Govaerts
Head, Mexico based
Conservation Agriculture Program

This book is the result of a training course and has to be considered as a product of the course rather than a reference book. The views expressed in the chapters are those of the corresponding author and do not necesarily reflect the views of CIMMYT.

Chapter 1. Starter fertilizers of varying grades and rates for no-tillage maize in Argentina

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Keywords: liquid fertilizer mixtures, conservation agriculture, application rate

Abstract

In the northeast of Argentina where the soils are deficient in P and K, farmers often mix different fertilizers to apply the basal fertilization. However, these solid mixtures including nitrogen (N), known as 'starters', often increase soil acidity and can have phytotoxic effects on the seeds. The use of liquid formulations is proposed to increase nutrient absorption and reduce acidification and phytotoxic effects. The goal of this study was to compare the effect of different liquid mixtures of N, phosphorus (P), potassium (K), and sulfur (S). The experiment was conducted during the 2011-12 growing season in an experimental station of the Argentinean Federal Institute of Agricultural Technology (INTA) in Mercedes, Province of Corrientes in a site under long term conservation agriculture. Maize was grown after wheat during the summer season. In split-plot randomized blocks, three application rates (100, 125 and 150 kg ha^{-1}*) and two NPKS grades were applied. Preliminary results showed that lack of starter fertilization had a strong negative effect on crop development and growth. Additionally, there were significant effects of both application rate and NPKS grade. Higher rates of starter fertilization and higher proportions of PKS resulted in higher maize grain yields.*

Introduction

Fertilization of crops with an adequate concentration and formulation of nutrients is fundamental to achieve global food security (Raun and Johnson 1999; Shoji et al. 2001). Fertilizer consumption in Argentina has increased significantly in the last 20 years due to changes in crop management and rotations (Lavado and Taboada 2009). As a result, the demand for fertilizers has also increased (Viglizzo et al. 2011). Although the use of urea ammonium nitrate (UAN) and other nitrogen (N) and sulfur (S) solutions has had wide adoption for many years (Salvagiotti et al. 2009), fertilization with phosphorus (P) sources has had little adoption. Fertilizers containing P, especially in liquid form, may offer special and distinct challenges to all those along the value chain, from distributors to end users.

The application of liquid fertilizers is a practice that has already been undertaken for several years in many parts of the world (Havlin et al. 2004); however, it was initially developed in areas where soil temperature at sowing is less than 12ºC but high enough to allow roots to absorb N, P, K, and S. An additional advantage of applying liquid fertilizers in these areas is the faster and more efficient absorption by roots when soil moisture content is generally low. In a region like Corrientes, Argentina, where temperatures during maize sowing are generally above 12ºC and soil moisture content is relatively high, liquid starters may contribute to better nutrition for maize seedlings and may also avoid phytotoxicity and reduce soil acidification associated with the use of solid N sources. Hypothetically, two additional advantages are the supply of two nutrients which are usually low in these soils and the possibility to accelerate germination and emergence of maize. Time between sowing and emergence can be up to 20 days in this area and the longer this period the higher the chance that seeds or seedlings are severely damaged by pathogens or insects. Thus, management options that can accelerate germination and emergence such as the use of liquid fertilizers are considered very promising technologies. However, until now, liquid fertilizers have not been tested as starters for maize.

The application of NP or NPS/NPKS solutions as a starter fertilizer has to have distinctive advantages over the solid granular blends, as well as a lack of disadvantages, to be rapidly adopted by farmers. Among the major concerns of farmers using starters, solid or fluids, is the effect of toxicity on seeds (Colliver and Welch 1970), which has a lot to do with the N-ureic composition and the proximity of the fertilizer to the seeds.

The objectives of this study were to determine the suitability of liquid forms to be used as starters, to find out the optimum NPKS grades and rates as a starter and placement combinations along the row for grain production and related traits in a region of Argentina where the cultivation of row crops is expanding.

Materials and methods

Growing conditions

The field experiment was carried out during the 2011-12 growing season on an experimental station of the Argentinean Federal Institute of Agricultural Technology (INTA) located in Mercedes (29 °11'S – 58°02' W), Province of Corrientes. The experimental site was located in a field which had been under long term conservation agriculture with a sandy loam, Aquic Argiudoll. The soil of the experimental site at Mercedes is a sandy loam, Aquic Argiudoll, equally endowed with organic matter but much lower in available K (Table 1).

The properties of the soil and the methods used to analyze them (in parentheses) were the following: 5.6–5.9 pH (in water), 20–27 g kg^{-1} organic matter (Blake-Walkley), 2–7 mg kg^{-1} P (Bray), 0.1–0.8 cmol kg^{-1} assimilable K (NH4 acetate), 0.3–1.5 cmol kg^{-1} Mg, 4–6 cmol kg^{-1} Ca, and 2–12 mg kg^{-1} S-SO$_4$. A composite soil sample was collected at the site to characterize the initial fertility. The weather conditions of the experimental site were recorded on a daily basis including rainfall, solar radiation and temperatures.

Table 1. Starter fertilization treatments used in the experiment with the corresponding concentration of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S).

Treatments	Grade*	Rate	N	P	K	S
		kg ha^{-1}				
T1	0:0:0	0	0	0	0	0
T2	1:1:1	100	14	12	8	6
T3	1:1:1	125	18	15	10	7
T4	1:1:1	150	21	18	12	8
T5	1:2:1	100	19	9	6	4
T6	1:2:1	125	23	12	8	5
T7	1:2:1	150	28	14	9	6

* The grade specifies the proportion of ammonium phosphate (APP), urea ammonium nitrate (UAN) and potassium thiosulfate (TSK).

A maize hybrid, DK 390 HX RR (Dekalb, St. Louis, USA), was sown on December 23, 2011 at 6 plants m^{-1}. On the same day, the different treatments (Table 1) were applied on 15 m long plots containing four rows (2.80 m).

Fertilizers were applied with field machinery using 0.52 spaced row planters equipped with a fluid fertilizer applicator. Fertilizer application rates were regulated by an electric pump and a calibrated nozzle to deliver the differential rates to a manifold and tubes for each row, so that each row received a uniform flow. Maize emerged 8 days after sowing (December 31, 2011). Urea (46, 0, 0) was top-dress broadcast at a rate of 200 kg ha^{-1} on February 2, 2012 when maize was at the V5 growth stage (BBCH scale). To account for and avoid an N effect as the major factor on grain yield, enough N as urea (46% N) was applied between the V5 and V6 stage to standardize all treatments in 100 kg N ha^{-1}.

Using a central pivot irrigation system, 150 mm of irrigation was applied during the maize growing season. The crop was harvested on May 3, 2012 on an area of 31.2 m^2.

Experimental design and analysis

The experimental design was a split plot randomized block, with four replications. The main plots/treatments were the fertilizer rates and the NPKS grades were the secondary plots/treatments. Grain yield at physiological maturity was measured by collecting and counting ears in the center of the plot (four rows of 15 m length). A sample of the threshed grain was collected to evaluate thousand kernel weight (TKW) and thus estimate the number of grains per ear, and assess the effect of the various fertilizer combinations and placement methods.

Analysis of variance was used to analyze the data. Mean comparisons using a protected LSD test were made to separate treatments where F-tests indicated that there were significant differences ($P<0.05$).

Results and discussion

Figure 1 shows the effect of the treatments on the grain yield of maize. There were significant differences between the control (T1) and the treatments where starter fertilization was applied. There were differences up to 5 t ha^{-1} (between T1 and T4) even though both treatments received 100 kg ha^{-1} at V5. Therefore, the top-dress fertilization was not enough to compensate for the differences that resulted from the starter fertilization. This difference is attributed to low nutrient availability, especially P and K, in the soils where the experiment was conducted.

By comparing the nutrient concentrations of the different treatments, it is evident that T4 (1:2:1) had the highest grain yield, even though compared to T7 the differences were not statistically significant. The increases in grain yield in T4 and T7 are attributed to the increase in P concentration. No nutrient deficiencies were observed in T4 and T7. On average the treatments that had a relatively higher proportion of APP (i.e., T2, T3, and T4) had 16% higher grain yields than the treatments that had a relatively higher proportion of UAN (i.e., T5, T6, and T7). Therefore, the P concentration of starters was critical to achieve high yields while the increase in N supply from T2 to T3 or T5 to T6 did not result in increased grain yield probably due to the limitation of another nutrient.

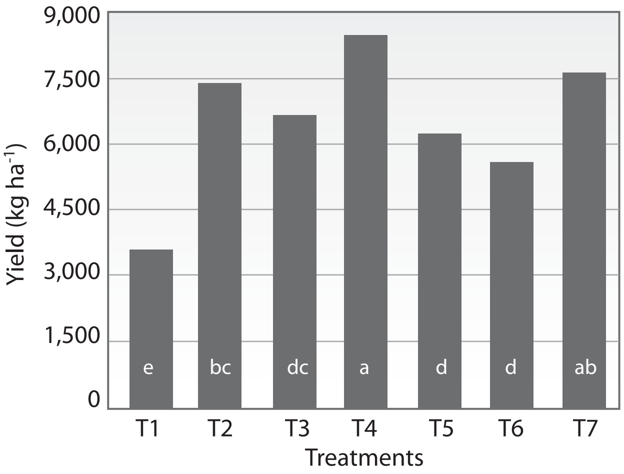

Figure 1. Effect of fertilizer treatments on grain yield of maize. Treatments with the same letters do not differ significantly (P > 0.005).

Sinaj et al. (2002) found similar effects of initial P fertilization in subtropical regions of West Africa. Similar effects of the starter formulations on grain yield were observed in yield components. For example, kernels per ear (data not shown) was significantly different in T1 compared to the other treatments. This is attributed to nutrient deficiencies during kernel set. The topdress N at V5 may have increased the deficiencies of P and K in T1. TKW was also significantly different in T1 compared to the other treatments (Table 2). The TKW obtained in the other treatments was more similar to the values for this parameter provided by the seed supplier.

Table 2. Effect of fertilizer treatments on thousand kernel weight (TKW), ear weight, and plant height.

Treatments	TKW (g)	Ear weight (g)	Plant height (cm)
T1	313 b	350 b	148
T2	360 a	577 a	177
T3	325 b	549 a	186
T4	326 b	570 a	188
T5	344 ba	572 a	193
T6	318 b	588 a	192
T7	326 b	608 a	197
CV	**4.1**	**7.4**	**9.12**

Treatments with the same letter within the column do not differ significantly (P > 0.005). CV = coefficient of variance.

Conclusions

The use of liquid formulations as starters proved to be effective in increasing maize grain yield in the area of Mercedes, Corrientes, Argentina. In contrast, the application of 100 kg N ha^{-1} at V5 was ineffective to increase grain yield with low basal fertilizations of P and K and even hastened deficiencies that resulted in lower grain yields.

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Chapter 2. Resource conserving techniques and nitrogen use efficiency in different cropping systems

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Keywords: conventional tillage, leaf color chart, nitrification inhibitors, nitrogen efficiencies, zero tillage

Abstract

Nitrogen (N) is the most important nutrient for cereal production. Although, the price of N fertilizers is increasing worldwide, N use efficiency is quite low. Fertilizer N recovery by the first crop in a rotation is 30–50% but the recovery by up to six consecutive crops is less than 7%. The use of resource conserving techniques for enhancing N efficiency is reviewed in this paper. No-tillage increases N losses through denitrification compared to other tillage systems. The rate of denitrification was higher in compacted areas, such as wheel tracks, compared to normal field conditions. Increasing fertilizer rate applications minimized potential yield reductions associated with implementing no-till corn production in a drier climate in silt loam soil and in a humid environment with fine textured soils, potential yield reductions minimized fertilizer N management, but tillage effect appears to be independent of N management. Deep banding N fertilizer (0.10–0.15 m deep) resulted in superior spring wheat yields compared to broadcast application under zero tillage (ZT) in semi-arid climates. The effectiveness of nitrification inhibitors (NIs) under conservation tillage depends on N placement and environmental conditions. Surface applied ammonical N treated with NIs was ineffective in reducing nitrification due to drier and warmer soil surfaces; these being ideal conditions for volatilization, whereas deep placement can reduce N losses and improve N use efficiency. N use efficiencies decreased with increasing critical values from ≤3 to 5, but it was always higher than recommended N management in rice–wheat cropping systems in different cultivars. A group of 107 farmers compared the leaf color chart (LCC) method with their own N management practices and found that the LCC reduced the N requirement from an average of 154 to 122 kg N ha^{-1}. A net saving of 32 kg ha^{-1} or 25% of applied N was recorded. The general trend showed that N uptake increased with strip tillage for all growth stages compared with the no-tillage across sites and years in corn.

Introduction

The atmosphere is full of nitrogen (N); however, more than 99 percent is not available to plants. Though some microorganisms and lightening make it reactive and available for human use, the proportion is too small to meet the food requirement of the burgeoning population. Thus, N is the nutrient that most often limits crop production despite its availability in our atmosphere. Its deficiency throughout the world is a serious issue and globally 105 million tons of fertilizer N is used to produce crops annually. This is more than 100 times greater than 100 years ago (FAOSTAT 2012). About 60% of the global N fertilizer is used for producing the world's three major cereals: rice, wheat, and maize. But at the same time, the nitrogen use efficiency (NUE) in cereal production is only 33% (Abrol et al. 2007) which is a serious concern in the context of increasing production costs and environmental pollution. Recovery by subsequent crops is very limited (less than 7% of applied N up to six consecutive crops), while the remaining N either remains in the soil or is lost from the soil–plant system, causing serious disruptions in ecosystem function. The N applied is not assimilated by the plant and is a potential source of environmental pollution such as groundwater contamination, eutrophication, acid rain, ammonia re-deposition, global warming, and stratospheric ozone depletion (Ladha et al. 2005).

Pressure is increasing for actions that will enhance fertilizer NUE, especially for the main cereals of the world, i.e., rice, wheat, and maize. Projections estimate that 50–70% more cereal grain will be required by 2050 to feed 9.3 billion people. This will require increased use of N to a similar magnitude if the efficiency with which N is used by crops is not improved. Globally, both cereal yields and fertilizer N consumption have increased in a linear fashion over the last 40 years (Dobermann and Cassman 2004). Much research has been conducted during the past decades to improve NUE by developing fertilizer management strategies based on better synchronization between the supply and requirement of N by the crop. Importantly, some of these techniques are being adopted on a large scale by farmers.

Resource conserving techniques (RCTs) are the practices that conserve resources and ensure their optimal utilization and enhance resource or input use efficiency. These techniques include zero or reduced tillage, direct seeding, permanent or semi-permanent residue cover, new varieties that use nitrogen more efficiently, laser land leveling, furrow irrigated raised beds (FIRBs), system of rice intensification (SRI), direct seeded rice (DSR), precision farming, use of leaf color charts (LCCs), and integrated crop management (ICM). In this paper, we review the potential of RCTs for enhancing NUE in crop production.

Nitrogen use efficiency terms and their calculation

Table 1 shows the equations to calculate the parameters that characterize NUE. These parameters vary greatly across regions and crops (Table 2). Usually, different parameters are used to estimate NUE (Dobermann 2005):

- *Agronomic efficiency (AE_N)*: May be defined as increase in grain yield (kg grain kg^{-1} N applied). Its value ranges from 18 to 24 kg grain kg^{-1} N applied and was the smallest in maize and largest in rice.
- *Apparent nitrogen recovery (ANR):* May be defined as the percentage increase in the uptake of N in fertilized crops compared to a control where no N was applied. Its value ranges from 10 to 70% across regions and crops.
- *Physiological efficiency (PE_N):* Is defined as the increase in grain yield (kg grain kg^{-1} N absorbed). Its value ranges from 20 to 52 kg grain kg^{-1} N absorbed across various regions and crops.
- *Partial factor productivity of N (PFP_N):* Is the increase in grain yield per kg N applied to the crop. Its value ranges between 39 and 72 kg grain kg^{-1} N applied, meaning that the application of 1 kg of N can result in a 39 to 72 kg increase in grain yield across various continents and crops.

The recovery efficiency of N of a few countries/regions was calculated from apparent N balance sheets taking into consideration major inputs and outputs (Table 3). The major inputs considered were mineral fertilizer, biological N fixation, atmospheric deposition, organic manure, residues, and irrigation water. This table shows that the largest N recovery was in the system with the lowest N input and the lowest crop N recovery was in the system with the highest N input. At the global level, Smil (1999) estimated that only 50% of all N input was recovered in the harvested crops. In the case of India, it is estimated that N recovery is 48% (Krupnik et al. 2004). It is very worrying that half of the applied N is lost and does not become a part of crop production. In this respect, use of RCTs for enhancing NUE is essential to increase NUE to at least 73%; the level observed in well managed farms.

Table 2. Descriptive statistics of various nitrogen use efficiency (NUE) terms for cereals in various continents.

Region/Crop	AE_N	RE_{N15}	PE_N	PFP_N
Africa	13.9	0.37	22.9	39.3
Australia	8.0	0.41	–	54.0
Europe	21.3	0.61	27.7	50.4
America	19.6	0.36	28.4	49.6
Asia	21.5	0.44	46.6	53.5
Average/ total	**19.6**	**0.44**	**40.6**	**51.6**
Maize	24.2	0.40	36.7	72.0
Rice	22.0	0.44	52.8	62.4
Wheat	18.1	0.45	28.9	44.5
Average/ total	**20.6**	**0.44**	**40.6**	**51.6**

AE_N = agronomic efficiency; RE_{N15} = recovery efficiency of the applied fertilizer determined by the ^{15}N isotope dilution method; PE_N = physiological efficiency; PFP_N = partial factor productivity of N.

Table 1. Nitrogen use efficiency terms and their calculation (Dobermann, 2005).

Efficiency ratio	Formula	Unit
Agronomic efficiency (AE_N)	Yt – Y0 / Nt	Increase in yield kg grain kg^{-1} N applied
Apparent nitrogen recovery (ANR)	Ut – U0 / Nt × 100	Percent
Physiological efficiency (PE_N)	Yt – Y0 / Ut - U0	Increase in yield kg grain kg^{-1} N absorbed
Nitrogen harvest index (NHI)	Ng / Nt × 100	Percent
Partial factor productivity (PFP_N)	Yt / Nt	kg grain kg^{-1} N applied
Physiological efficiency index of N (PE_N)	Grain yield / N absorbed by biomass	Ratio
Nitrogen efficiency ratio (NER)	DM yield / N accumulated at harvest	Ratio

Yt –Yield of fertilized crop (kg ha^{-1}); Y0 – Yield of non-fertilized crop (kg ha^{-1}); Nt – Total amount of N applied (kg ha^{-1}); Ut – Total N uptake in fertilized crop; U0 – Total N uptake in non-fertilized crop; Ng – Nitrogen content in grain (%); Nt – Nitrogen content in grain + straw (%); DM – dry matter.

Resource conserving techniques for enhancing N use efficiency

Among the various RCTs, conservation tillage, LCC, the method and source of fertilizer application, residue management, mulching, cropping systems, and application of nutrients in an integrated manner have potential to increase NUE. Some research carried out in these areas is discussed below.

Mulching

Mulching moderates the temperature and modifies the micro-environment for crop growth. It also increases the soil water content by reducing evaporation. The increased moisture favors mineralization of soil organic N and its further uptake by the plants which in turn improves NUE of the applied N. In a study conducted on a sandy loam soil in Punjab, Singh and Sandhu (1978) reported that straw mulching between corn rows during summer increased the dry forage yield by 13% and N uptake by 43%. Recently, Dendooven et al. (2012) observed that crop residue retention resulted in significantly lower NH_4^+ concentration in zero tillage (ZT) compared to conventional tillage (CT), but no effect was observed when it was removed. Crop residue removal increased the concentration of NH_4^+ compared to its retention in ZT, but not in CT. They observed that different processes contributed to this decrease, such as plant uptake, denitrification, NO_3^-, leaching and microbial N immobilization, especially when crop residue with a high C:N ratio, such as maize or wheat, is retained. So, crop residue mulch enhances the duration of availability of fertilizer N, matching it better with crop demand and, thus, minimizing the losses and helping to improve fertilizer NUE.

Tillage practices

Tillage practices influence the soil drying and heating/cooling processes (Ussiri and Lal 2009) as they disturb the soil surface and thus increase the loss of N from the soil by volatilization and therefore result in lower NUE. Compared to no-till, tillage of the soil can increase the emission of N_2O (Ussiri et al. 2009), have no effect at all (Jantalia et al. 2008) or decrease the emission of N_2O (Steinbach and Alvarez 2006). Crop residue retention increases emissions of N_2O (Singh et al. 2008) while its effect depends on the type of crop, biochemical quality of the residue, agricultural management, soil, and climatic conditions (Novoa and Tejeda 2006). An experiment in a rice–wheat cropping system with ZT had higher PFP_N compared to CT at all levels of fertilizer application. Application of nitrogen above 120 kg/ha gave a reduction in PFP_N, but yield was higher at subsequent levels under ZT treatment compared to CT. This indicates that ZT systems are more responsive to increases in N and give more PFP_N (Sharma et al. 2005).

Tillage and fertilizer application had significant effects on corn in a corn–oat rotation in a silty loam soil at South Dakota, USA. In this experiment, N was applied at 112 kg ha^{-1} as ammonium nitrate either injected (IN) or broadcasted (B). In ZT, N was applied by modified knives to apply anhydrous ammonia prior to planting as urea ammonia nitrate (UAN; 28% N). The data show that higher residue accumulation on the surface of the ZT plots provides greater carbon substrate for microbial activity. Residue is believed to increase moisture in the soil surface and increase the C source to microbes near the surface where high soil temperature favors denitrification. The zone of denitrifying activity was closer in the ZT treatment than in the other tillage treatments. Even with surface disturbance with plowing or disking, some residue remains on the surface when a chisel plough or moldboard plough is used. N losses in wheel track areas were 1.6 times higher than the non-wheel track areas and this is shown by the regression coefficient which was higher in non-wheel track areas compared to wheel track areas, due to anaerobic conditions after rainfall (Hilton et al. 1994). From this study, it may be concluded that ZT and non-wheel track areas decrease the nitrogen loss from the field area and thus increase NUE.

Table 3. Input, uptake and recovery efficiency of N at farm and regional scale (Adapted from Krupnik et al. 2004).

	Input					Recovery		
Farm / Region	Fertilizer	N_2 fixation	NOx deposition	Other	Total	Crop uptake	%	Reference
Farm (kg N ha^{-1})	219	5	9	58	285	179	73	Frissel 1978
Regional (Tg N ha^{-1})								
United States	11	5.9	1.4	–	18.5	10.5	56	Howarth et al. 2002
Canada	2.0	0.4	0.3	–	2.7	1.2	52	Janzen et al. 2003
World	78	33	20	38	169	85	50	Smil 1999
World	78	7.7	21.6	69	176	101	57	Sheldrick et al. 2002

N uptake was greater in soil plowed with a chisel plough than ZT and strip tillage systems at all stages of crop growth and finally the grain N uptake in corn in the loamy soils of the Iowa State University of USA. This may be attributed to the effect of N placement within the tilled zone where N becomes more available and increases mineralization due to soil disturbance (Licht and Kaisi 2005).

The increase in the soil nitrate N during fallow of various cropping systems was higher in ZT compared to the stubble mulch in wheat based cropping systems while the contrary occurred in sorghum based cropping systems. This is due to the application of stubble mulch year after year having more residual effects than the ZT soils. However, the final level of N was higher with stubble mulch in fallows of all the cropping systems (Eck and Jones 1992).

Tillage and fertilization

Howard and Essington (1998) conducted a corn experiment for 12 years in a silty loam soil with ZT. They applied N as UAN (46% N) at a rate of 168 kg ha^{-1} within 5 days after planting. This study showed that NUE as leaf N g kg^{-1} was low in all treatments with application of lime at 1.12 t ha^{-1} as compared to no application of lime. This may be due to the lime application causing N loss by both NH_3 volatilization and immobilization of N by surface mulch, while with no lime application there was a high degree of immobilization. Application of fertilizers by broadcasting causes more N loss and less N recovery compared to the incorporation of fertilizers. Thus, the application of lime and broadcasting of fertilizers should be avoided to increase NUE with ZT.

The five year average grain yield and N accumulation of corn was increased when N fertilizer was applied at two sites under all tillage and residue management practices. However, ZT with residue incorporation was best over all the treatments tested with or without N application. This might be due to the fact that ZT responds better to fertilizer N application (Sims et al. 1998).

There are two equations to predict a NUE increase due to the application of fertilizer N and soil N in semiarid regions on sandy loam soil. Placement of N was more important than timing of N application in influencing yields in this semiarid region. Deep banding of N fertilizer (0.1–0.15 m deep) resulted in a superior spring wheat yield compared to broadcast application. This indicated that each added amount of N is used less and less efficiently and the rate of yield increase with per unit increase in soil N is greater than the fertilizer N. It also shows that a NUE increment is directly related to water uptake and generally to soil N but inversely related to fertilizer N. NUE increases with year at less than 50 kg ha^{-1}, but the converse is true at a higher dose. This is due to an increase in the N mineralization capacity of the soil with an increase in years after cropping (Campbell et al. 1993).

Nitrification inhibitor and tillage

Controlled release N fertilizers offer a good option to reduce N losses from the system because their delayed N release pattern may match better with crop demand (Shoji et al. 1995). Jat (2010) also found that the zinc coated urea enhances NUE in rice–wheat cropping systems. Rao (1996) conducted an experiment at El Reno in the USA for 4 years during the wheat spring season and applied TSP on the surface of plots at 17 kg ha^{-1} P and urea at 60 kg N ha^{-1}. Nitrapyrin at 0.56 kg ha^{-1} and dicyandiamide (DCD) at 10% of N rate (6 kg ha^{-1}) was applied as nitrification inhibitors in ZT winter wheat. The results showed that the surface applied nitrification inhibitors were ineffective in reducing denitrification. There was no difference in DCD and Nitrapyrin due to severe volatilization loss making these products ineffective.

Cropping system and nutrient management

The inclusion of dual-purpose summer legumes in rice–wheat cropping systems has beneficial effects on the NUE of the system (Jat 2010). Chettri and Bandhopadhaya (2005) conducted an experiment at Kalyani (West Bengal) in clay loam soil with different sources of fertilizer application in different cropping sequences and found that the maximum grain yield can be obtained when either mungbean or lathyrus are incorporated in situ before rice transplanting in addition to 75% of the recommended dose of N plus 10 t farmyard manure ha^{-1}. A higher agronomic efficiency (AE) was observed in rice crops grown after mungbean or lathyrus as fodder crop with the recommended dose of N plus 10 t farmyard manure ha^{-1}. This may be due to the combined application of all these sources increasing the availability of the nutrients.

In-situ N management tools

Farmers have always used their eyes as a subjective indicator of the N stress of a crop. Leaf color charts, popularly known as LCCs, can now be used for a more accurate determination of leaf nitrogen content. It is based on chlorophyll content in the leaves at different growth stages. The critical LCC value for rice hybrids and high yielding varieties (HYVs) is 4 and for basmati rice is 3. These values should be taken from 7 to 10 days after sowing (DAS) or 20 to 25 days after transplanting (DAT) to heading. With the LCC and chlorophyll meter (SPAD), informed decisions can be made regarding the need for fertilizer N applications in the growing crops. The LCC depicts gradients of green hues that are based on the wavelength characteristics of rice leaves, from yellowish-green to dark-green. Shukla et al. (2006) established the agronomic efficiency, recovery efficiency and physiological efficiency in rice and wheat crops with two different varieties having a different fertilizer application method with the LCC at the Project Directorate of Cropping System Research, Merrut. NUE increases with application of N using the LCC compared to the recommended N and farmers' practices in sandy loam soil. But NUE decreases with increases in the critical value of the LCC from <3 to 5 but it was always higher than the other treatments. This may be due to the use of LCC, a RCT in rice and wheat that may help to restrict N leaching which may otherwise decrease NUE.

In several places in India, similar benefits from the use of LCCs were recorded compared to using farmers' practices. In wheat, applying 30 kg N ha^{-1} each time with an LCC score of 4, with a total application of 120 kg N ha^{-1} gave more PFP_N , N uptake and NUE than using a similar amount in three fixed time splits. The same thing was also reported in the case of rice (Ladha et al. 2005).

Tillage and irrigation

Gajri et al. (1997) observed that on a very low water retentive sand, NUE by wheat was enhanced by deep tillage, frequency of irrigation and their combination. Deep tillage with frequent light irrigations (25 mm) resulted in the highest NUE, while CT in combination with infrequent and heavy irrigations (75 mm) gave the lowest NUE. Other combinations of tillage and irrigation showed intermediate NUE.

The various tools and tactics with their limitations and relative benefits for enhancing the NUE in different cropping systems are summarized in Table 4.

Conclusions

RCTs are more effective in combination rather than when individually applied and among various RCTs, research work on tillage practices, mulching, and LCC are the most available. Although they seem to be potentially useful technologies, research on laser land leveling and rotary tillage is not readily available. LCCs reduced N requirement by approximately 25% of applied N and ZT is more responsive to applied N compared to CT in coarse textured soils, resulting in increases in NUE. At the same time, retention of residues increases N uptake and thereby increases NUE in different cropping systems.

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Table 4. Tools/ tactics of enhancing fertilizer N use-efficiency (Ladha et al. 2005).

Tools/ tactics	Benefit: cost	Limitations
Site-specific nutrient management	High	Infrastructure for every site
Chlorophyll meter	High	Initial high cost
Leaf color chart	Very high	None
Breeding strategy	Very high	Varieties yet to be developed
N-fixation in non-legumes	High	Technique yet to be developed for field scale
Precision farming technology	High	Technique needs to be fine tuned
Resource conserving techniques	High	Technique needs to be evaluated for long term impacts
Integrated crop management	High	Technique needs to be evaluated for long term impacts

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Chapter 3. Effect of tillage and crop establishment methods on yield, profitability, and soil physical properties under a rice–wheat rotation in the Indo–Gangetic Plains

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Abstract

Rice–wheat rotations (Oryza sativa L.–Triticum aestivum L.) are the major cropping systems in the Indo-Gangetic Plains of South Asia, occupying 13.5 million ha. The current conventional practices for growing rice (puddled transplanting) and wheat (conventional tillage) are deteriorating the soil and are input intensive, resulting in declining natural resources, increasing input costs, and reducing profitability. A field trial was conducted at the Sardar Vallabbhai Patel University of Agriculture and Technology (SVPUA&T), Meerut (UP), India for 2 years .The trial was carried out to study the effect of tillage and crop establishment methods on yield, profitability and soil physical properties in a rice–wheat rotation. The six tillage and crop establishment treatments included puddled transplanting (conventional, rotavator) and direct seeding of rice (DSR; with or without tillage) followed by wheat in (conventional tillage; CT and zero tillage; ZT). Tillage and crop establishment practices significantly influenced the physical properties of soil. Average infiltration was highest (0.10 cm hr^{-1}) in ZT DSR-ZT DSW and lowest in farmers' practice (FP) of puddling and CT (0.05 cm hr^{-1}). The bulk density of the16–20 cm soil layer was the highest in FP-FP (1.73 t m^{-3}) and lowest in the double no-till (ZT DSR-ZT HSW) treatment (1.70 t m^{-3}). Average rice yield was highest in RT TPR-ZT DSW (4.13 t ha^{-1}) and lowest in farmers' practice, FP-FP (3.70 t ha^{-1}). Direct seeded rice (ZT and CT) had a higher grain yield (5%) than FP of transplanted rice (CT-TPR).Wheat yield, on average, was 23% higher in zero till with residue (ZT DSR-ZT HSW) than FP of conventional tillage (FP-FP). Overall, ZT DSR-ZT HSW had the highest net returns (approximately US$2,017) and FP-FP had the lowest (approximately US$1,474) in the rice–wheat system. Our results from the 2 year study show that the conventional practice of transplanting and tillage could be successfully replaced by double no till (conservation agriculture) in a rice–wheat rotation. However, future work towards the fine tuning of ZT, particularly on rice and wheat varieties selected specifically under no till conditions, is important for the sustainability of the conservation agriculture system.

Introduction

The rice–wheat (RW) production system, which covers 13.5 million ha in the Indo-Gangetic Plains, is vital for food security, rural development and natural resource conservation in the region (Paroda et al. 1994; Gupta et al. 2003; Ladha et al. 2003). Both crops are fertility exhaustive and require large amounts of water, labor, time, nonrenewable energy and heavy farm machinery for their successful cultivation. The land preparation to grow transplanted rice is not only tedious, costly and time consuming but it also deteriorates the soil properties due to the formation of a compacted hard soil surface. The cost of tillage and crop establishment accounts for 25–30% of the total production cost of a rice–wheat cropping system (Saharawat et al. 2011; Pathak et al. 2011). Farmers undertake multiple tractor operations (both dry and wet tillage) with different implements like harrow cultivators and plankers etc. to prepare the field before sowing the crops. This results in higher energy consumption and costs of production compared to conservation tillage and thus lowers the benefit:cost ratio. Over decades, continued puddling has led to deterioration of soil physical properties through structural breakdown of soil aggregates and capillary pores, and clay dispersion. The rotavator is becoming popular among farmers as it is efficient and provides a clean seed bed and can also be used for puddling in transplanted rice. Rotary tillers prepare the seed bed differently to the conventional method of plowing. The soil is pulverized by the cutting and churning action of a number of blades that receive energy from the engine of the prime mover. The depth of the cut is up to 12–15 cm.

Farm mechanization saves labor and time but increases the energy bill for farmers. There will be a steep increase in the demand for energy for agriculture in the years ahead. Shrinking profit margins are of serious concern, not only for farmers but for researchers and planners as well. The productivity growth of crops is stagnant but the input costs are increasing. At present, the major challenge is to produce more quality food from the same land and water resources, in a sustainable manner. With the increasing cost of diesel and fertilizers, and gradual removal of subsidies for these items and other inputs, it is vital to decrease their use. Thus, the major challenge for the researcher is to develop an alternative system that produces a higher yield at a lower cost and improves farm profitability and sustainability (Gupta and Seth 2007; Jat et al. 2011; Gathala et al. 2011b).

This suggests that agricultural systems need a mixture of new technologies which focus more attention on issues of sustainability and conservation agriculture (CA) in intensive production systems. Conservation agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profit together with high and sustained production levels while concurrently conserving the environment (FAO 2007). Conservation agriculture is characterized by four principles that are linked to each other. They are (i) minimum mechanical soil disturbance for erosion control and fuel saving, (ii) maintenance of permanent organic soil cover, (iii) diversified crop rotation, and (iv) control of field traffic to reduce compaction. However, in practice, zero tillage (ZT) and residue retention have emerged as the two cardinal principles of CA. The main aim of CA is to achieve sustainable and profitable agriculture through application of the latest equipment. Encouraging results have been obtained indicating that wheat after rice can be successfully grown under minimum tillage or no tillage conditions, resulting in the efficient use of costly inputs in rice–wheat systems. In the Indo-Gangetic Plains, CA is adopted by farmers across about 3 million ha. However, in India its success is more in irrigated areas. Despite wider adoption of ZT in wheat, rice is still mainly grown conventionally by transplanting in puddled soil, and the benefits of ZT attained during the wheat phase are lost during the rice phase. To achieve the full benefits of ZT, both rice and wheat need to be grown under similar tillage conditions. In addition, rising labor and water shortages, escalating fuel prices, and soil fertility issues have increased the interest in a shift from puddled transplanting to dry direct-seeded rice (DSR) (Kumar and Ladha 2011).

Therefore, there is a need to minimize cost and energy use by improving tillage and crop establishment practices and developing efficient machines such as zero-till drill, roto-till drill, reduced tillage, happy seeder etc. that ensure efficient management of costly inputs such as diesel, nutrients and water. The objectives of our study were to assess the effects of different crop establishment and tillage techniques in rice–wheat systems on crop performance, yield, profitability and soil physical properties.

Materials and methods

Experimental site

A field experiment was established in the wet season of 2008 at the research farm of the Sardar Vallabhbhai Patel University of Agriculture and Technology, Uttar Pradesh, India (29°01′ N, 77°45′ E, 237 m.a.s.l.). The climate of the area is semi-arid, with an average annual rainfall of 800 mm (70–80% of which is received during July–September), minimum temperature of 0–4°C in January, maximum temperature of 41–45°C in June, and relative humidity of 67–83% throughout the year. Soil samples were collected at the start of the experiment (2008) from 0 to 45 cm depth at every 15 cm depth interval using an auger with a 5 cm diameter. Each sample was a composite of three samples from three locations. The soil samples were air-dried, crushed to pass through a 2 mm sieve, and stored in plastic jars for analysis. Soil samples were analyzed for organic C (Walkley and Black), total N (Kjeldahl digestion), Olsen P (0.5 M $NaHCO_3$ extractable), and 1 M neutral NH_4OAC-extractable K (by emission spectrophotometry) using the methods described by Olsen et al. (1954) and Page et al. (1982). Particle size distribution was determined using the hydrometer method (Bouyoucos 1962). Textural class was determined using the International Soil Science Society (ISSS) system. Based on the analysis done in 2008, the experimental soil (0–45 cm) was sandy loam in texture. The 0–15 cm soil layer had clay, silt, and sand at 19, 28, and 53 g kg^{-1} soil, respectively; pH 8.2; electrical conductivity (EC) 0.43 dS m^{-1}; total C 8.3 g kg^{-1}; total N 0.88 g kg^{-1}; Olsen P 26 mg kg^{-1}; and 1 M NH_4OAC-extractable K 125 mg kg^{-1}.

Experimental details and management

Six treatments (T1–T6) were replicated thrice in a randomized complete block design with a plot size of 20 m × 6 m. Details relating to treatments are described below and a summary is given in Table 1.

Treatment 1 (T1): Transplanted rice (line) after conventional puddling followed by wheat grown after conventional tillage (CT) seeded by inclined plate seed metering cum fertilizer planter (CT TPR-CT DSW).

After conventional puddling (3 dry harrowing + 2 wet cultivator + 1 planking), rice seedlings (21-days old) were transplanted in line manually (1–2 seedlings hill^{-1}) at 20 cm × 15 cm spacing; the plots were flooded (5 cm water submergence) initially for 2 weeks to establish the seedlings, and subsequent irrigations (5 cm depth of standing water) were applied on the appearance of hair-line cracks on the soil surface. Wheat was seeded in rows 20 cm apart using inclined plate seed metering system cum fertilizer planter following the conventional dry tillage (2 harrowing + 2 cultivator + 2 planking). Six irrigations (5 cm each) were applied at the crown root initiation (21 days after seeding, DAS), maximum tillering (35–50 DAS), jointing, flowering (50–70 DAS), dough (85–100 DAS), and late dough (115–125 DAS) stages of growth.

Treatment 2 (T2): DSR after dry tillage followed by ZT wheat using inclined plate seed metering cum fertilizer planter (CT DSR-ZT DSW)

Plots were prepared (2 dry harrowing + 1 cultivator + 1 planking) following direct seeding of rice at 20 cm row spacing by using an inclined plate seed metering system with fertilizer attachment planter. Light irrigation was given at 1 day after seeding for proper germination, and then at 3–4 day intervals for 3–4 weeks after germination. Thereafter, irrigation was applied at the appearance of hair-line cracks (5 cm depth of standing water) on the soil surface. Wheat was seeded in ZT plots at 20 cm row spacing using an inclined plate seed metering system with fertilizer attachment ZT planter. The irrigation schedule was the same as in T1.

Treatment 3 (T3): ZT DSR followed by ZT wheat with residue (happy seeder) - (ZT DSR-ZT HSW)

Direct seeding rice was done using ZT inclined plate seed metering with fertilizer attachment planter in ZT plots at 20 cm row spacing. Prior to seeding, annual weeds were controlled by applying glyphosate. Light irrigations were given at 1 DAS, and then at 3–4 day intervals for 3 weeks after germination, followed by subsequent irrigations (5 cm depth of standing water) at the appearance of hair-line cracks. Wheat was seeded in ZT retaining complete rice residue as mulch on the soil surface using the happy seeder planter which contained a seed and fertilizer mechanism which enables placement of both in a single operation. The irrigation schedule was the same as in T1.

Treatment 4 (T4): Transplanted rice after rotavator puddling followed by ZT wheat (RT TPR-ZT DSW)

Without any former dry tillage, plots were flooded with water. After that, cross puddling was done using a rotavator followed by one planking (2 wet tillage with rotavator + 1 planking). Rice seedlings (21 days old) were transplanted in the same way as in T1. The plots were flooded (5 cm water submergence) initially for 2 weeks to establish the seedlings, and subsequent irrigations were applied as was done in T1). For wheat, the same practices were followed as in T2.

Treatment 5 (T5): Transplanted rice after rotavator puddling followed by rotary till wheat (RT TPR-RT DSW)

Without any former dry tillage, plots were flooded with water. Then, cross puddling was done using a rotavator followed by one planking (2 wet tillage with rotavator + 1 planking). Rice seedlings (21 days old) were transplanted manually (1–2 seedlings hill^{-1})

Table 1. Description of the experimental treatments

Treatment No.	Abbreviation	Rice	Wheat
1	CT TPR-CT DSW	Transplanted rice (line) after conventional puddling	Conventional wheat after tillage sown with drill
2	CT DSR-ZT DSW	Direct seeded rice on flat after dry tillage	Zero till drill wheat
3	ZT DSR-ZT HSW	Zero till direct seeded rice	Zero till wheat with residue (happy seeder)
4	RT TPR-ZT DSW	Transplanted rice after rotavator puddling	Zero till drill wheat
5	RT TPR-RT DSW	Transplanted rice after rotavator puddling	Rotary till wheat
6	FP-FP	Farmers' practice	Farmers' practice

at 20 cm × 15 cm spacing; the plots were flooded (5 cm water submergence) initially for 2 weeks to establish the seedlings, and subsequent irrigations (5 cm depth of standing water) were applied on the appearance of hair-line cracks on the soil surface. Before sowing the wheat, plots were prepared by one pass of a rotavator. Wheat was sown as in T1. The irrigation schedule was also the same as in T1.

Treatment 6 (T6): Farmers' Practice (FP-FP)

Rice plots were prepared as in T1 (3 dry harrowing + 2 wet cultivator + 1 planking), rice seedlings (30 days old) were transplanted manually (2–3 seedlings hill^{-1}) and randomly, without maintaining plant spacing, similar as is done in farmers' fields. The plots were flooded continuously during the crop season. For wheat, plots were prepared by disc harrowing and cultivator (2 harrowing + 2 cultivator + 1 planking). Wheat seed was broadcasted and mixed using a cross pass of cultivators and planking (2 cultivator + 1 planking). The irrigation schedule was the same as in T1.

Residue management

Rice and wheat were harvested manually after leaving 15 cm anchored crop stubble in all plots, except T3. The observed dry biomass of crop stubble after each crop harvest was approximately 0.8 t ha^{-1} per treatment. The crop stubble was incorporated into the soil in conventional puddling/tillage plots whereas in ZT plots, the seeding was done in the standing stubble. In T3, around 8 t ha^{-1} crop residue was managed at the time of sowing through the happy seeder planter and retained as mulch on the soil surface.

Seeding and seed rate

The rice variety Pusa 1121 (Pusa Sugandha-4) was used in both years for all treatments. DSR was sown in the first week of June, as per treatments and the same day the nursery was raised for the transplanting treatments. However, transplanting was done manually from the last week of June to the first week of July, depending on treatments. The seeding rate for DSR was 25 kg ha^{-1} and in the nursery for transplanted rice it was 15 kg ha^{-1}. Wheat variety PBW 343 was sown in both years in the first week of November with a seeding rate of 100 kg ha^{-1} in treatments T1–T5 and 120 kg ha^{-1} in T6.

Fertilizer application

In rice, all plots received 100 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}, and 25 kg $ZnSO_4$ ha^{-1}. A full rate of P, K and one-third N were applied as band placement using a ZT seed with fertilizer planter at the time of seeding in DSR and these were broadcast manually at the time of transplanting in puddled transplanted rice (TPR). $ZnSO_4$ fertilizer was broadcasted 10 DAS in DSR plots before irrigation and 2 days after transplanting (DAT) in TPR plots. The remaining N was applied in two equal splits at 35–40 DAS in DSR plots and 20 DAT in TPR plots followed at the late tillering stage 50–55 DAS. In wheat, all treatments received 150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 60 kg K_2O ha^{-1}. The full dose of P, K and one-third dose of N were applied using a ZT seed with fertilizer drill at sowing (T1–T5) and broadcasting in T6. The remaining N was applied in two equal splits at just before first irrigation (CRI), and second irrigation (tillering).

Weed management

Weeds in ZT plots were killed before the seeding of rice and wheat by spraying glyphosate at 900 g a.i. ha^{-1}. In DSR, pendimethalin 1,000 g a.i. ha^{-1} was applied at 2 DAS, followed by one each post emergence spray of ethoxysulfuron 18 g a.i. ha^{-1} and fenoxaprop 56 g a.i. ha^{-1} at 21 DAS for broadleaf weeds and 30 DAS for grassy weeds, respectively. In TPR, butachlor 1,000 g a.i. ha^{-1} was applied 2 DAT. One hand spot weeding was also done in TPR and DSR to keep the plots weed free. For wheat, grassy and broad leaf weeds were controlled by spraying sulfosulfuron + metsulfuron methyl at 35 g a.i. + 4 g a.i. ha^{-1} at 25–30 DAS.

Measurement of soil physical parameters

Soil physical properties, such as bulk density and steady state infiltration were measured after the rice harvest in 2008 and 2009. Bulk density was determined by collecting soil cores at 0–5, 6–10, 11–15, and 16–20 cm depth, using 3 cm long and 5 cm diameter metal cores by placing the core in the middle of each soil layer. A double ring infiltrometer was used to determine the infiltration rate at the time of harvest of the rice crop. The infiltration rate was measured by recording the amount of water needed to maintain a constant level in the inner ring as a function of time. Two infiltrometers per plot were pushed into the ground to a depth of 10 cm. A constant water level (5 cm) was maintained in both the inner and outer rings of the infiltrometer. The measurements were continued until a steady state infiltration rate was achieved.

Measurment of yield and yield parameters

At maturity, rice and wheat growth and yield parameters i.e., plant height, total number of effective panicles, panicle or ear length, number of grains earhead^{-1} and thousand grain weight were measured. Total number of panicles was recorded at two places in each plot using a 1 m quadrat. Simultaneously, 10 plants were randomly selected from each quadrat for measurements of yield parameters. The crop was harvested manually at 15 cm above ground level. Grain and straw yields were determined from an area of 15 m × 4 m (60 m^{2}). The rice grains were threshed manually and wheat grains were threshed using a plot thresher, dried in a batch grain dryer and weighed. Grain moisture was determined immediately after weighing. Grain yields of rice and wheat were reported at 140 and 120 g kg^{-1} water content, respectively.

Economic analysis

The cost of all inputs (tractor use, seed, fertilizer, fuel, biocides, irrigation, and labor) and the returns for outputs were used for respective years in the study (Gathala et al. 2011a). These data were obtained from current market prices paid for inputs. The cost of human labor used for tillage, seeding, irrigation, fertilizer and pesticide application, weeding, and harvesting of rice and wheat crops was based on person-day ha^{-1} (Minimum Wages Act India, 1948). Time (h) required to complete a particular field operation in a given treatment was recorded and expressed as person-day ha^{-1}, with 8 h considered to be equivalent to 1 person-day. Similarly, time (h) required by a tractor-drawn machine to complete a field operation such as tillage, seeding, fertilizer application and harvesting was recorded, and expressed as h ha^{-1}. Time (h) required to irrigate a particular plot and consumption of diesel (l h^{-1}) by the pump was also recorded. Cost of irrigation was calculated by multiplying time (h) required to irrigate a particular plot, consumption of diesel by the pump (1 h^{-1}) and cost of diesel (varied 0.44–0.90 US\$l^{-1}). The cost of production was calculated by taking into account the cost of all the inputs and the hiring charges of human labor and machines for different purposes as stated above based on the current market rates (Minimum Wages Act India, 1948). Gross returns (GR) were calculated by multiplying grain yield of wheat by minimum support price offered by the Government of India (Economic Survey of India, 2009), and straw value of wheat was calculated using current market rates. Net returns (NR) were calculated as the difference between gross returns and total cost of cultivation (NR = GR – TCP). The benefit:cost ratio was calculated by dividing the gross returns (GR) by the total cost of production (TCP).

Data analysis

The data were subjected to ANOVA and analyzed using Cropstat. Treatment means were compared using the least significant difference (LSD) test. Unless stated otherwise, differences were considered significant only when $P < 0.05$.

Results and discussion

Rice yield and yield attributes

Average plant height, effective panicles m^{-2}, panicle length, grains panicle^{-1} and thousand kernel weight were recorded at the harvest stage during 2008 and 2009 (Table 2). The rotavator TPR (RT TPR-ZT DSW) had significantly higher plant height than conventional line transplanted rice (T1) followed by conventional till direct seeded rice (CT DSR-ZT DSW). Despite significantly higher panicles m^{-2}, slightly lower yields in DSR treatments (T2 and T3) compared to RT-TPR (T4) suggest that higher panicles m^{-2} could not compensate losses caused by lower number of grains panicles^{-1} and lower thousand kernel weights in T2 and T3. Similar results of higher panicles m^{-2} in DSR compared to TPR and higher spikelet sterility in DSR were observed by Choudhury et al. (2007) and Bhusan et al. (2008). Tillage and crop establishment techniques did not significantly affect other yield attributes (panicle length, grains panicle^{-1}and thousand kernel weight). However, the beneficial effects on soil health by CA were not reflected on the crop yield attributes. Lindstorm and Onstad (1984)

Table 2. Effect of tillage and crop establishment techniques on average rice yield attributes in a rice–wheat rotation

Treatments	Plant height (cm)	Effective panicles (m^{-2})	Panicle length (cm)	Grains panicle^{-1}	Thousand grain weight (g)
CT TPR-CT DSW	121^{b}	332^{b}	28.17^{a}	82.87^{a}	24.36^{a}
CT DSR-ZT DSW	121^{b}	416^{a}	27.37^{a}	81.13^{a}	23.8^{a}
ZT DSR-ZT HSW	126^{ab}	418^{a}	26.49^{a}	81.27^{a}	23.44^{a}
RT TPR-ZT DSW	131^{a}	336^{b}	28.93^{a}	86.73^{a}	24.66^{a}
RT TPR-RT DSW	126^{ab}	329^{b}	27.72^{a}	85.67^{a}	24.01^{a}
FP-FP	126^{ab}	312V^{c}	27.86^{a}	80.20^{a}	23.87^{a}

Within a column, means followed by the same superscript letter are not different at the 0.05 level of probability by Tukey's HST test.

concluded that although much research has shown various beneficial effects of no-till on soil properties, it cannot be expected to be effective in increasing yields under all situations. Ladha et al. (2009), while working on rice–wheat cropping systems in the Indo-Gangetic Plains, reported that under several alternate tillage and crop establishment strategies crop productivity may or may not have a positive response.

A combined ANOVA of 2 years showed no significant effect of treatments and treatment × year interaction on rice grain yield (Table 3). Rice yield was not significant but was consistently the highest in RT TPR-ZT DSW and lowest in farmers' practice (FP-FP) in both years. Rice grain yield was similar in all treatments. However, DSR treatments T2 and T3 yielded higher (5%) grain yield than farmers' practice of transplanted rice (T6). Other studies have also reported inconsistent results for DSR. A field study conducted by Jat et al. (2009) found similar grain yield under TPR and DSR. Based on large datasets, Kumar and Ladha (2011) reported 10% lower yields in ZT DSR compared to CT TPR in India. The yield benefit with the RT TPR treatment (T4) over DSR treatments (T2 and T3) was about 7% but DSR has other advantages such as reducing labor, time, water, energy, and thus the cost of production (Kumar and Ladha 2011). Direct seeded rice has another advantage, decreased growth duration, as DSR matures 7–10 days earlier than TPR which allows timely planting of the succeeding wheat crop (Balasubramanian and Hill 2002; Saharawat et al. 2010).

Table 3. Effect of tillage and crop establishment techniques on rice yield in a rice-wheat rotation

	Rice yield (t ha^{-1})		
Treatments	**2008**	**2009**	**Mean**
CT TPR-CT DSW	3.87	3.73	3.80
CT DSR-ZT DSW	4.01	3.88	3.95
ZT DSR-ZT HSW	4.03	3.67	3.85
RT TPR-ZT DSW	4.15	4.10	4.13
RT TPR-RT DSW	3.90	3.83	3.87
FP-FP	3.72	3.68	3.70

Wheat yield and yield attributes

The average results from 2 years reveal that tillage and crop establishment methods adopted during the rice crop had a significant effect on the succeeding wheat crop grain yield and yield attributes. These effects started showing in the first cropping cycle (Table 4). The plant height at harvest was the highest in ZT wheat, happy seeder (ZT DSR-ZT HSW) followed by ZT wheat (CT DSR-ZT DSW) and, lowest under farmers practice (FP-FP) in both years. Earhead length, number of grains earhead^{-1} and thousand grain weight was significantly higher in the ZT HSW (T3) system compared to the CT treatments (T6, T5 and T1) followed by ZT wheat with partial residue (T2 and T4). Similar results of effective tillers m^{-2} (approximately 15% higher) have also been reported in ZT planter seeded wheat compared to CT wheat (Saharawat et al. 2010; Gathala et al. 2011a).

Average wheat grain yield ranged from 3.71 to 4.84 t ha^{-1} (Table 5). Zero till wheat with residue, happy seeder (T3) had the highest wheat productivity (4.75 and 4.93 t ha^{-1} in 2008 and 2009, respectively) followed by ZT with partial residue (T2 and T4), rotary till wheat (T5), conventional line (T1). The lowest yield was obtained under farmers' practice of wheat cultivation, T6 (3.58 and 3.83 t ha^{-1} in 2008 and 2009, respectively). The poor performance of farmers' practice may be attributed to lower primary yield components i.e., earhead length, number of grains earhead^{-1} and thousand grain weight (Table 4). Gathala et al. (2009) conducted on-station and on-farm trials in which wheat grain yield of ZTW HST was 10% and 3% higher than CT wheat,

Table 4. Effect of tillage and crop establishment techniques on wheat yield attributes in a rice–wheat rotation.

	Plant height at harvest (cm)		Earhead length (cm)		Grains earhead^{-1}		Thousand grain weight (g)	
Treatments	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
CT TPR-CT DSW	91^{a}	90^{b}	10^{b}	10^{b}	40^{f}	46^{b}	42^{c}	43^{c}
CT DSR-ZT DSW	90^{a}	93^{a}	11^{a}	11^{b}	58^{b}	56^{a}	45^{a}	45^{ab}
ZT DSR-ZT HSW	92^{a}	96^{a}	11^{a}	13^{a}	53^{c}	60^{a}	45^{a}	46^{a}
RT TPR-ZT DSW	91^{a}	92^{b}	11^{a}	11^{b}	60^{a}	57^{a}	44^{b}	45^{ab}
RT TPR-RT DSW	91^{a}	91^{b}	10^{b}	10^{b}	48^{d}	50^{b}	45^{a}	44^{bc}
FP-FP	93^{a}	87^{bc}	9^{bc}	9^{bc}	43^{e}	44^{b}	42^{c}	41^{d}

Within a column, means followed by the same superscript letter are not different at the 0.05 level of probability by Tukey's HST test.

respectively. These results are also in agreement with earlier short-term studies (Kumar et al. 2008; Jat et al. 2009) in which wheat yield after direct DSR was higher than after TPR. Kumar et al. (2008) reported 8% higher wheat yield after DSR than after TPR. The other important benefit of the happy seeder technology is that it provides an alternative to burning for managing rice residues and allows direct drilling of wheat in standing as well as loose residues (Gathala et al. 2009).

Soil physical properties

Changes in soil physical properties are not readily noticeable over a short period of time. Infiltration rate is governed by the amount of pore space present in the soil. The steady state infiltration rate after rice harvest was not significantly different during the first year but significant differences were observed during the second year of the study (Table 6). Steady state infiltration was consistently highest in DSR treatments with an average of 0.10 cm h^{-1} in T2 (CT DSR-CT DSW) followed by T3 (ZT DSR-ZT HSW) and significantly lower in all other puddling treatments (T1, T5, T4 and T6). Infiltration rate was significantly lower in treatments where CT was conducted in both cropping cycles compared to treatments which included a no till cycle. Puddling decreased infiltration rate probably because of the progressive destruction of soil structure and increase in subsoil compaction. In fact, one of the objectives of puddling in rice is to lower infiltration to allow water stagnation in rice fields (Sharma and De Datta, 1986). Savabi et al. (2007) reported that ZT in medium texture soils (silty loam and silty clay loam) enhanced infiltration rate with time. These results also agree with Jat et al. (2009) who found higher steady state infiltration rates under DSR compared to conventional puddle rice.

Table 5. Effect of tillage and crop establishment techniques on wheat yield in a rice-wheat rotation

Treatments	Wheat yield (t ha^{-1})		
	2008	2009	Mean
CT TPR-CT DSW	3.97^{b}	4.17^{b}	4.07^{c}
CT DSR-ZT DSW	4.25^{a}	4.73^{a}	4.49^{b}
ZT DSR-ZT HSW	4.75^{a}	4.93^{a}	4.84^{a}
RT TPR-ZT DSW	4.40^{a}	4.63^{a}	4.52^{b}
RT TPR-RT DSW	4.50^{a}	4.54^{a}	4.52^{b}
FP-FP	3.58^{b}	3.83^{b}	3.71^{d}

Within a column, means followed by the same superscript letter are not different at the 0.05 level of probability by Tukey's HST test.

Table 6. Effect of tillage and crop establishment techniques on infiltration rate in a rice– wheat rotation.

Treatments	Infiltration rate (cm h^{-1})		
	2008	2009	Mean
CT TPR-CT DSW	0.08^{a}	0.06^{b}	0.07^{b}
CT DSR-ZT DSW	0.09^{a}	0.11^{a}	0.10^{a}
ZT DSR-ZT HSW	0.08^{a}	0.09^{a}	0.08^{a}
RT TPR-ZT DSW	0.06^{a}	0.05^{b}	0.05^{b}
RT TPR-RT DSW	0.07^{a}	0.05^{b}	0.06^{b}
FP-FP	0.05^{a}	0.05^{b}	0.05^{b}

Within a column, means followed by the same superscript letter are not different at the 0.05 level of probability by Tukey's HST test.

Based on this 2 year study, soil bulk density at all depths was not significantly affected by tillage and crop establishment methods (Figures 1 and 2). In general, bulk density increased with increase in depth in all treatments. Bulk density is inversely related to total porosity, which provides a measure of the porous space remaining in the soil for air and water movement (Min et al. 2003; Tester 1990). However, in all treatments there was not a significant or noticeable change in the short period of two years. In surface soil (0–5 cm), average bulk density was higher (1.52 t m^{-3}) in T3 where both crops are grown under ZT conditions and lowest (1.42 t m^{-3}) under farmers' practice (T6). This may be due to the tillage operations pulverizing surface soil which results in sub surface compaction. At a lower depth (16–20 cm) bulk density was higher in puddling treatments (T6 and T4) and lowest in the double no till treatment (T3). Lower bulk density implies greater pore space and improved

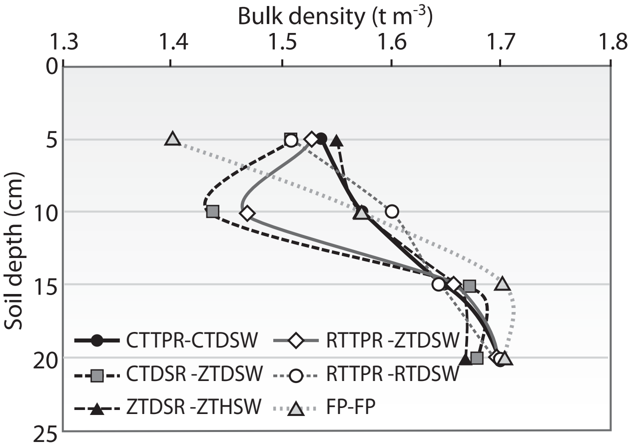

Figure 1. Effect of tillage and crop establishment methods on bulk density in a rice–wheat rotation in 2008.

aeration, developing a suitable environment for biological activity (Min et al. 2003). Sub surface (11–20 cm) bulk density was lower in ZTW HST compared to CT wheat because of compaction caused by trafficking of machines used during tillage operations (Gathala et al. 2011b).

Economic analysis

The average cost of rice and wheat production over the 2 years was highly affected by tillage and crop establishment methods (Table 7). The average cost of rice production was highest (US$779 ha^{-1}) under the conventional practice of puddling and transplanting rice (T1 and T6) followed by rotavator puddling (T4 and T5), CT DSR (T2) and lowest (US$720 ha^{-1}) in ZT DSR (T3). The cost of wheat production was highest for the farmers' practice treatment (T6) and lowest in ZT-DSW (T2 and T4). The difference between the highest and lowest cost of production was US$59 ha^{-1} and US$84 ha^{-1} in rice and wheat, respectively. The highest net income for the rice crop was from RT TPR (T4), followed by CT DSR (T2) and lowest in FP-FP (T6). Net income from wheat was highest in ZT HSW (T3), followed by RT DSW (T5) and lowest in FP-FP (T6). The highest benefit:cost ratio in rice was in CT DSR, T2 and RT TPR, T4 (2.4) and lowest in FP-FP, T6 (2.1). In wheat, the benefit:cost ratio was highest (3.0) in ZT HSW (T3) followed by ZT DSW (T4; 2.7) and lowest (2.0) in farmers' practice (T6). The results show that the no till method was most profitable in this rice–wheat cropping system. Similar results have been reported in rice–wheat cropping systems by Saharawat et al. (2010), Gathala et al. (2011a) and Jat et al. (2011).

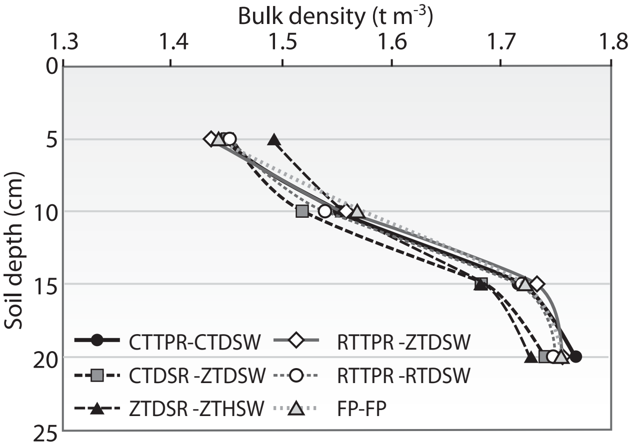

Figure 2. Effect of tillage and crop establishment methods on bulk density in a rice–wheat rotation in 2009.

Conclusions

The results from the 2 year study showed that rotavator TPR followed by ZT wheat (T4) gave the highest rice grain yield followed by CT and ZT DSR (T2 and T3), but the effect of tillage-seeding treatment on rice yield was not significant. A higher net income and benefit:cost ratio was found in both DSR treatments compared to the conventional system of TPR with continuous flooding (T6 and T1). On the other hand, ZT had a positive effect on the productivity of the wheat crop. The significantly highest wheat productivity (4.84 t ha^{-1}) was obtained with ZT under full residue, happy seeder (T3), followed by ZT with partial residue (T4). However, when evaluating the overall performance in the rice–wheat rotation, ZT DSR followed by ZT wheat with residue, happy seeder (T3) shows higher net returns and a higher benefit cost ratio than all other treatments. Also, ZT DSR and wheat had better soil physical conditions, namely soil bulk density and steady state infiltration compared to the conventional system of rice–wheat production. The results of the study indicate that resource conserving technologies (ZT DSR and ZT wheat with residue, happy seeder)

Table 7. Effect of tillage and crop establishment methods on average economics of rice and wheat crops in a rice–wheat rotation.

	Rice crop parameters			Wheat crop parameters		
Treatments	Cost of production US$ ha^{-1}	Net income US$ ha^{-1}	Benefit: cost ratio	Cost of production US$ ha^{-1}	Net income US$ ha^{-1}	Benefit: cost ratio
CT TPR-CT DSW	779	884	2.1	609	716	2.2
CT DSR-ZT DSW	748	1,040	2.4	538	877	2.6
ZT DSR-ZT HSW	720	918	2.3	541	1,099	3.0
RT TPR-ZT DSW	764	1,066	2.4	538	926	2.7
RT TPR-RT DSW	764	946	2.2	558	932	2.7
FP-FP	779	862	2.1	622	612	2.0

would be preferred by the farmers because of the low production cost, higher benefit:cost ratio, less dependency on labor, and gradual improvement in soil quality i.e., physical parameters.

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Chapter 4. Yield potential of durum wheat elite genotypes in Darab

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Abstract

Although durum wheat occupies more than 20% of the total wheat cultivating area in southern Iran, only two varieties are widely adopted by farmers. This experiment was conducted to evaluate the yield potential of 18 CIMMYT originated durum wheat elite genotypes with local checks in years 2008-09 and 2009-10 in a semi-arid climate at the Darab agriculture research station (sea level elevation 1,098 m, 28°:47´N, 54°:17E´). The experimental design was a randomized complete block design (RCBD) with three replicates. Experimental management aimed to avoid any non-environmental stresses. Measured plant traits included days to heading, days to maturity, plant height, thousand kernel weights and grain yield. The sowing date was mid-November and the harvesting date was late April. Seeds were planted in three rows on the top of beds with 60 cm width under conventional tillage practices. Results of the experiment showed that days to heading between two years was not different and days to maturity, plant height, thousand kernel weight and grain yield in the second year were higher than the first year, mainly due to less later season heat stress and also the absence of plant lodging in the first year. There was no difference between the days to heading and maturity of genotypes for the first year, second year and mean of the two years. Days to heading, plant height, thousand kernel weight and grain yield of the genotypes showed some differences within both years and the mean of the two years. Differences for these plant traits within genotypes were not considerable, probably due to high genetic uniformity within the genotypes. Correlation between all plant traits and grain yield was very low when the mean of the two years was used. The new genotypes did not out-yield the local checks, indicating that optimizing the number of crosses and introduction of new genetic diversity in durum wheat breeding programs is recommended to maximize the probability of increasing yield potential in the new released durum wheat varieties.

Introduction

On a global scale, durum wheat (*Triticum turgidum* var. *durum* Desf.) comprises 10% of the wheat area and more than one-half the area sown to durum wheat in developing countries is located in North Africa and West Asia, with the remainder distributed throughout north central Asia, central India, Ethiopia, and Latin America. Production of durum wheat is limited by the crop's greater susceptibility to soil-borne diseases, its greater sensitivity to soil micronutrient imbalances, and its lack of cold tolerance (Trethowan et al. 2005). CIMMYT's spring durum wheat breeding program continues to have an enormous impact. During the period 1988–2002, 88% of the spring durum wheat varieties released in the developing world had some degree of CIMMYT ancestry. Direct use of CIMMYT-bred germplasm has been extensive so that over 60% of all spring durum wheat varieties released were CIMMYT-crossed materials. The total global grain production of durum wheat, cultivated area and yield per hectare in 2009 was 31.9 million tons, 13.3 million hectares and 2,380 kg/ha, respectively (USDA 2009).

Before the epidemic of Karnal bunt disease in 1996 and the high susceptibility of the most widespread bread wheat commercial varieties, mainly Seri 82 derived varieties such as Falat, cultivation of durum wheat was negligible in the Darab and other southern parts of Iran. Promotion of durum wheat varieties, derived from CIMMYT germplasm, at first began in order to control Karnal bunt disease. However, the good adaptability, high yield and higher price for durum wheat caused an increase in its cultivated area to more than 20% of the total wheat growing area in warm, and to a lesser extent in moderate, climates of Iran with the dominant variety being Yavaros 79. Although some new durum wheat varieties, such as Behrang

(Zhng zou/2*Green-3), were released in the Darab, Yavaros 79 is still the most accepted durum wheat by farmers in southern Iran. This may be due to the high yearly fluctuation of climatic conditions and high genotype × environment interactions, low stability of the new durum wheat genotypes, or low yield differences between new and old varieties.

A two year study on stability zones in Iran, showed that among 18 genotypes studied, 5 genotypes had more general and grain yield stability and two of those genotypes were identified as suitable and adapted genotypes with grain yield stability for the southern warm and dry agro-climatic zone of Iran (Haji Mohammad et al. 2011). A study on five superior durum wheat cultivars, Cocorit 71, Mexicali 75, Yavaros 79, Altar 84 and Aconchi 89, at Ciudad Obregon, Mexico showed that changes in grain yield were due to increased grains m^{-2}, via more grains/spike, but for thousand kernel weight the effect was negative (Pfeiffer et al. 2001). An assessment of durum wheat yield potential in Mega-environment 1 showed that the annual rate of increase in grain yield for the time period 1967–1990 has been 1.4% and from 1971 to 1990, it has been 0.6% per year and there was no out yielding by new varieties of Mexicali 75 (Sayre 1992). Although these results indicate that remarkable progress has been made over the past 40 years in increasing genetic yield potential of durum wheat in Mega-environment 1 conditions, the apparent leveling-off in the rate of increasing genetic yield potential for durum wheat as well as bread wheat is troubling (Sayre 1992). Iran is considered a Mega-environment 1 environment according to the CIMMYT global climatic classification, and most Iranian durum wheat germplasm is imported from CIMMYT. Therefore, the expectation is that the yield potential of Iran's durum wheat genotypes, which originate from CIMMYT, may also be leveling-off. In this study, some durum wheat elite genotypes were studied under normal conditions to evaluate the grain yield potential, along with some other plant traits, in order to recommend those lines that out-yield local check genotypes to the southern Iran durum growers.

Materials and methods

This experiment was conducted in the Darab agriculture research station (Sea level elevation 1,098 m , 28°:47′ E, 54°:17′N) in two cycles during 2008-09 and 2009-10 to study the yield potential of 18 elite durum genotypes originating from CIMMYT along with local checks. Soil texture was a clay loam, without salinity, with low organic carbon and high pH (Table 1). The climatic parameters of both years were recorded in a synoptic meteorological station inside the Darab agriculture station (Table 2). Long term yearly rainfall was low (average 270 mm) with low relative humidity and hot spring and summer seasons. Air relative humidity is not high at most times of the year and air temperature is high in June and July (Table 2). Twenty genotypes were planted in both years (Table 3). The experimental design was a randomized complete block design (RCBD) with three replicates. Phosphorous and potassium fertilizers were applied according to the recommendation from soil sample analysis and the application of nitrogen fertilizer was split three times; 50 kg/ha urea (46% N) as starter, 100 kg/ha urea at tillering and 100 kg/ha at stem elongation. Sowing date for both years was mid-November, harvesting date was late April and the seeding rate was 400 seeds/m^2.

Parameters measured included grain yield, date of maturity, date of heading, plant height, thousand kernel weight, and percent lodging. Land was prepared as conventional tillage; previous season was weed free fallow, seeding rate was 500 seed/m^2 and seeds were planted in three rows on top of beds with 60 cm width. Row spacing was 20 cm and plot size was 1.2 m × 6 m. Plots were irrigated normally without exposing the plants to water stress, taking into consideration the rainfall values. Data were analyzed via ANOVA and then means were compared using Duncan's Multiple Range Test.

Table 1. Soil properties in the Darab Agriculture Research Station during the two year experiment.

Year	PWP	FC	Texture	K	P	OC	pH	EC	BD
2009	12.5	22.5	CL	179	7	0.50	7.9	0.72	1.46
2010	12.5	22.5	CL	174	7	0.50	8.0	0.75	1.48

BD = bulk density, PWP = permanent wilting point, FC = field capacity, CL = Clay loam, OC = organic carbon, EC = electrical conductivity, P = phosphorus, K = potassium.

Results and discussion

Year effects on plant traits

In both years, total rainfall was less than the long term rainfall (272 mm), and rainfall in the first year (188 mm) was less than the second year (215 mm). Mean yearly temperature in the first year (21°C) was less than the long term mean yearly temperature (22°C) and the second year mean yearly temperature (23°C) was greater than the long term mean yearly temperature. Mean wind speed in the second year and long term were equal (12 m/s) and greater than the first year (9.5 m/s) (Table 2).

Days to heading was not significantly different between the two years of the experiment, mainly due to the low difference in the mean temperatures of the two years until heading (mid-November to early April) (Table 2). Despite days to heading being the same in each year, cooler days during the later

Table 2. Monthly mean temperature (°C), relative humidity (%), wind speed (m/s) and rainfall (mm) for 2008-09, 2009-10 and long term average at the Darab Agriculture Research Station.

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
2008-09												
Mean temperature	24.9	18.5	12.0	10.2	11.3	16.9	16.8	25.4	30.2	33.3	33.6	29.7
Relative humidity	31	44	45	48	47	45	60	33	21	24	29	32
Wind speed	8.0	14.0	8.0	5.0	6.0	9.0	12.0	10.0	9.0	11.0	12.0	10.0
Rainfall	0.0	0.7	2.2	6.6	2.5	39.4	133.4	0.0	0.0	0.4	2.5	0.4
2009-10												
Mean temperature	24.0	19.2	11.8	11.5	12.6	17.3	20.8	25.5	31.9	34.3	33.5	29.7
Relative humidity	32	42	64	43	60	51	40	34	22	26	19	27
Wind speed	7.0	7.0	8.0	10.0	8.0	17	16	13	16	10	12	18
Rainfall	0.0	28.0	108.9	12.2	37.3	12.5	10.7	0.8	0.0	0.0	0.0	4.7
Long term												
Mean temperature	24.4	18.9	14.1	11.9	12.5	15.7	19.2	24.7	29.1	32.1	32.2	29.3
Relative humidity	33	41	52	56	59	53	47	25	36	27	29	30
Wind speed	11	8	8	9	10	11	14	15	15	15	16	11
Rainfall	8.7	4.2	46.0	69.3	57.0	35.4	35.0	7.0	2.0	2,0	4.0	3.0

Table 3. Pedigree of genotypes planted in the experiment.

Genotype no.	Pedigree
1	Shwa/mauld (Check1)
2	Bread wheat (Chamran Check 2)
3	AVILLO_1/SNITAN
4	GUANAY/SNITAN
5	SULA/AAZ_5//CHEN/ALTAR84/3/AJAIA_12/F3L…
6	DIPPER_2/BUSHEN_3//SNITAN
7	URA/4/CHEN_1/TEZ/3/GUIL//CIT71/CII/5/CHEN/A…
8	SNITAN/3/STOT//ALTAR 84/ALD
9	TRN//21563/AA/3/BD2080/4/KHIAR/5/SKEST//HUI/TU…
10	SRN_2/BISU/4/KHP/D31708//KHP/3/CORM/5/SNITAN…
11	SOMO/CROC_4//LOTUS_1/3/KITTI/4/STOT//ALTAR 84…
12	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/2*RASC…
13	BCRIS/BICUM//LLARETA INIA/3/DUKEM_12/2*RA…
14	GUAYACAN INIA/YEBAS_8/3/TOPDY_18/FOCHA_1…
15	DUKEM_12/2*RASCON_21//SNITAN
16	HAI-OU_17//PLATA_2//LIRO_3
17	LABUD_1/SHAG_23//SNITAN/3/CNDO/VEE//7*SILVER_2
18	MALMUK_1//LOTUS_5/F3LOCAL(SEL.ETHIO.135.85)
19	PLATA_6/GREEN_17//SNITAN
20	RASCON_21/3/MQUE/ALO//FOJA

growing season in 2009-10 caused a longer period to maturity compared to 2008-09. Plant height in 2008-09 was more than 2009-10, most probably due to better temperature conditions, less wind and consequently less plant stress, resulting in better crop growing during the stem elongation period and taller plant height in the first year of the experiment.

Plant lodging was 0% in the first year of the experiment and 75% in the second year. Although plant lodging is strongly dependent on genetic characteristics of the plant stem, roots and management practices (Foulkes et al. 2011) it is also dependent on uncontrollable physical forces such as wind. In 2008-09, wind speed was considerably lower than 2009-10, so speed of wind was not enough to cause the lodging of plants in this year, while high-speed winds in the second year of the experiment could have caused the high amount of plant lodging. Lodging is a persistent phenomenon in wheat that reduces harvestable yield by up to 80% as well as reducing grain quality (Berry et al. 2003a, 2003b, 2007).

Table 4. Days to heading, days to maturity, plant height (cm), lodging (%), thousand kernel weight (mg) and yield (t/ha) of genotypes.

Year	DHE	DMA	PLH	LODG	TKW	GY
1	113.8 A	160.1 A	102.4 A	0.0 B	46.8 A	8.294 A
2	113.3 A	154.1 B	94 B	75.0 A	40.3 B	6.849 B

DHE = days to heading, DMA = days to maturity, PLH = plant height, LODG = plant lodging, TKW = thousand kernel weight, GY = grain yield. Mean values with the same letters in each column do not differ according to Duncan's Multiple Range Test at 0.05 level of probability.

Thousand kernel weight was different among the two years. The larger thousand kernel weight in 2008-09 could be attributed to the lack of plant lodging, better partitioning of assimilates, less plant abiotic stress, and a longer time for grain maturity in this year. Grain yield was also different among the years of the experiment. The increased grain yield in 2008-09 is most probably due to the above-mentioned traits, as well as thousand kernel weight. Higher kernel weight and grain yield has been reported by other cereal researchers (e.g., Getinet et al. 1980).

Table 5. Days to heading, days to maturity, plant height (cm), lodging (%), thousand kernel weight (mg) and grain yield (t/ha) of genotypes in 2008-09.

Genotype	DHE	DMA	PLH	LODG	TKW	GY
1	113.7 A	161.0 A	104 ABCD	0 A	51 AB	8.592 ABC
2	115.7 A	161.3 A	98 EFG	0 A	43 BC	8.430 ABC
3	113.0 A	161.0 A	101CDEF	0 A	53 A	8.151 ABC
4	114.3 A	160.7 A	106 ABCD	0 A	51 AB	8.423 ABC
5	113.3 A	160.7 A	106 ABCD	0 A	48 ABC	8.536 ABC
6	113.0 A	160.7 A	105 ABCD	0 A	49 ABC	7.860 ABC
7	114.3 A	161.3 A	100 DEFG	0 A	44 BC	8.669 ABC
8	112.0 A	160.0 A	101 CDEF	0 A	48 ABC	8.257 ABC
9	112.7 A	161.0 A	107 AB	0 A	43 BC	7.761 ABC
10	114.7 A	161.0 A	108 A	0 A	45 BC	8.342 ABC
11	113.0 A	160.0 A	109 A	0 A	48 ABC	8.876 AB
12	114.7 A	161.0 A	97 FGH	0 A	44 BC	7.339 BC
13	113.0 A	161.0 A	95 GH	0 A	46 BC	8.307 ABC
14	115.0 A	158.7 A	103 BCDE	0 A	47 ABC	9.530 A
15	113.3 A	161.0 A	102 B…F	0 A	46 ABC	7.806 ABC
16	115.0 A	160.7 A	104 A…E	0 A	43 C	8.572 ABC
17	113.7 A	161.0 A	104 A…E	0 A	47 ABC	7.041 C
18	113.0 A	160.7 A	101 C…G	0 A	47 ABC	8.018 ABC
19	113.0 A	160.7 A	104 C…E	0 A	46 ABC	9.032 AB
20	114.7 A	159.3 A	93 H	0 A	46 ABC	8.424 ABC

DHE = days to heading, DMA = days to maturity, PLH = plant height, LODG = plant lodging, TKW = thousand kernel weight, GY = grain yield. Mean values with the same letters in each column do not differ according to Duncan's Multiple Range Test at 0.05 level of probability.

Genotype traits

Days to heading and maturity were not different among the twenty genotypes in both years of the experiment (Tables 4 and 5). The high genetic uniformity of some phenological traits, such as days to heading and maturity, is mainly due to avoidance of selecting the late maturing genotypes in preliminary experiments to escape from the late season drought and heat stress under warm and dry conditions in southern Iran.

Plant height of the genotypes showed some variation in both years and also genotype × year interaction. Plant height of genotypes 1, 4, 6, 8, 9, 11 and 19 had more stability, the plant height of genotypes 10, 14, 15, and 16 had the most variation, and the remainder showed moderate year-to-year variability. The strategy of plant breeding programs in southern Iran is to select the genotypes which have a plant height range of 90–110 cm in normal years, so the height of most genotypes in this experiment was close to 1 m. Genotypes 4, 6, 10, 11, 16 and 19 were taller and genotypes 2, 7, 8, 12, 13, 15 and 20 were shorter averaged over the two years. Some of the plant height variation could be related to the genetic inheritance and the environmental effects. Kahrizi et al. (2010) found that plant height heritability estimates of durum varieties were more than 60%.

Thousand kernel weights showed some significant differences among the genotypes in both years (Table 4 and 5). In 2008-09, genotypes 2, 7, 9, 10, 12 and 16 had low kernel weight and the kernel weight of the other genotypes having negligible differences was high. In 2009-10, the kernel weight of genotypes 1, 3, 4, 10, 11, 15, 16, 17, 18, 19, and 20 was high while that for other genotypes was somewhat less. On average, over the two years, genotypes 2, 7, 12 and 13 had lower kernel weight than the other genotypes (Table 7). Between years, thousand kernel weight was affected by year as an environmental factor, however, in 2008-09, plant traits such as days to heading and maturity and plant lodging within genotypes were not different; therefore, significant variation of thousand kernel weight cannot be related to these plant traits and it can have a genetic basis. In this experiment the interaction of year × thousand kernel weight was not significant.

Table 6. Days to heading, days to maturity, plant height (cm), lodging (%), thousand kernel weight (mg) and yield (t/ha) of genotypes in 2009-10.

Genotype	DHE	DMA	PLH	LODG	TKW	GY
1	110.7 A	154.3 A	94 BCDE	68 EF	42.3 A…E	7.260 AB
2	113.7 A	154.3 A	91 CDE	45 I	34.7 G	5.699 C
3	114.7 A	153.3 A	95 ABC	52 GHI	42.7 A…D	7.340 AB
4	110.7 A	154.3 A	95 ABC	77 BCDE	44.0 ABC	6.048 BC
5	109.0 A	153.7 A	93 BCDE	60 FGH	37.0 C…G	6.822 BC
6	112.3 A	154.7. A	96 ABC	96 A	37.3 C…G	6.496ABC
7	112.3 A	154.3 A	91 CDE	85 ABCD	39.3 B…G	6.728 BC
8	115.0 A	154.3 A	92 BCDE	95 A	38.0 C…G	6.982 ABC
9	114.0 A	154.0 A	97 ABC	97 A	35.0 FG	7.163 AB
10	112,0 A	153.3 A	93 BCDE	87 ABC	40.3 A…G	7.581 AB
11	114.3 A	154.3 A	98 AB	73 CDEF	43.0 A…D	7.481 AB
12	114.7 A	154.7 A	89 DE	72 DEF	35.3 EFG	6.761 BC
13	114.7 A	154.7 A	94 BCDE	87 ABC	36.0 DEFG	6.907 ABC
14	112.0 A	154.0 A	96 ABC	90 AB	36.0 D…G	6.819 ABC
15	112.3 A	153.3 A	88 E	90 AB	42.0 A…F	6.579 ABC
16	113.7 A	153.3 A	100 A	63 EFGH	42.7 A…D	5.682 C
17	115.3 A	156.0 A	94 BCD	62 EFGH	45.3 AB	6.687 ABC
18	115.0 A	153.7 A	94 BCD	70 EF	42.3 A…E	6.914 ABC
19	115,0 A	154.0 A	97 ABC	48 HI	42.0 A…F	7.667 A
20	114 A	154.3 A	94 BCDE	96 A	47.3 A	7.371 AB

DHE = days to heading, DMA = days to maturity, PLH = plant height, LODG = plant lodging, TKW = thousand kernel weight, GY = grain yield. Mean values with the same letters in each column do not differ according to Duncan's Multiple Range Test at 0.05 level of probability.

There were no large differences among the grain yield of genotypes in both years (Tables 4 and 5). In the first year of the experiment, genotype 14 had significantly more grain yield than genotypes 12 and 17 and the grain yield of genotype 19 was significantly more than genotype 17. The other grain yields of the genotypes were not significantly different. Results of the present experiment showed that there was not a high correlation between grain yields and other plant traits including days to heading ($r^2 = 0.048$; Figure 1); days to maturity ($r^2 = 0.028$; Figure 2); plant height ($r^2 = 0.054$; Figure 3); plant lodging ($r^2 = 0.03$; Figure 4) and thousand kernel weight ($r^2 = 0.046$; Figure 5).

Table 7. Mean days to heading, days to maturity, plant height (cm), lodging (%), thousand kernel weight (mg) and yield (t/ha) of genotypes over the two years of the experiment.

Genotype	DHE	DMA	PLH	LODG	TKW	GY
1	114.3 A	157.8 A	99.0 A…F	34.2 EF	46.8 ABC	7.926 ABC
2	113.2 A	157.8 A	94.7 FGH	22.5 I	39.0 F	7.064 BC
3	113.3 A	157.2 A	97.8 B…G	25.8 GHI	48.0 A	7.701 ABC
4	114.2 A	157.5 A	100.3 A…D	38.3 BCGE	47.7 AB	7.235 BC
5	112.0 A	157.2 A	99.7 A…E	30.0 FGH	42.5 B…F	7.679 ABC
6	111.0 A	157.7 A	100.5 ABC	48.0 A	43.0 A…F	7.178 BC
7	113.3 A	157.8 A	97.7 D…H	42.5 A…D	41.8 C…F	7.698 ABC
8	112.2 A	157.2 A	96.5 C…H	47.3 A	43.0 A…F	7.619 ABC
9	113.8 A	157.5 A	102.2 AB	48.5 A	39.0 F	7.462 ABC
10	114.3 A	157.2 A	100.7 ABC	43.3 ABC	42.5 B…F	7.962 ABC
11	112.5 A	157.2 A	103.2 A	36.7 C…F	45.5 A…D	8.178 AB
12	114.5 A	157.8 A	92.7 H	35.8 DEF	39.7 EF	7.050 BC
13	114.2 A	157.8 A	94.7 FGH	43.3 ABC	41.0 DEF	7.607 ABC
14	114.8 A	156.3 A	99.3 A…F	45.0 AB	42.5 B…F	8.175 AB
15	112.7 A	157.2 A	95.2 E…H	45.0 AB	44.1 A…F	7.192 BC
16	113.7 A	157.2 A	102.2 AB	31.7 EFG	42.7 A…F	7.127 BC
17	113.7 A	153.2 A	99.2 A…F	30.8 FGH	46.3 A…D	6.864 C
18	114.2 A	157.2 A	97.3 B…H	35.0 EF	44.5 A…E	7.466 ABC
19	114.0 A	153.3 A	100.2 A…D	24.2 HI	44.0 A…F	8.349 A
20	114.8 A	156.2 A	93.5 GH	48.0 A	46.5 ABC	7.898 ABC

DHE = days to heading, DMA = days to maturity, PLH = plant height, LODG = plant lodging, TKW = thousand kernel weight, GY = grain yield. Mean values with the same letters in each column do not differ according to Duncan's Multiple Range Test at 0.05 level of probability.

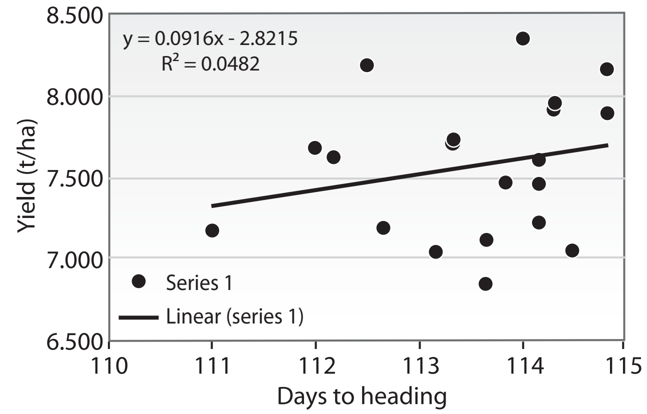

Figure 1. Linear correlation between mean grain yield and days to heading.

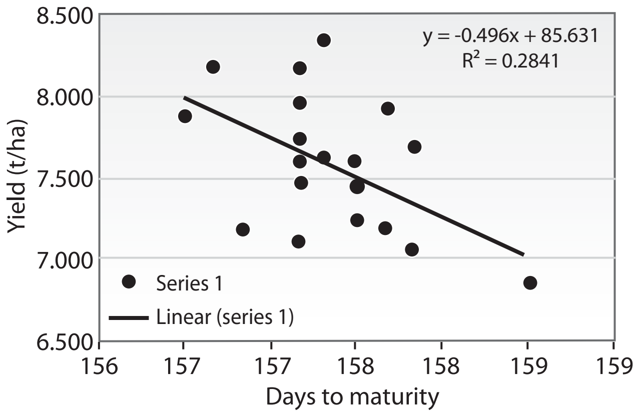

Figure 2. Linear correlation between mean grain yield and days to maturity.

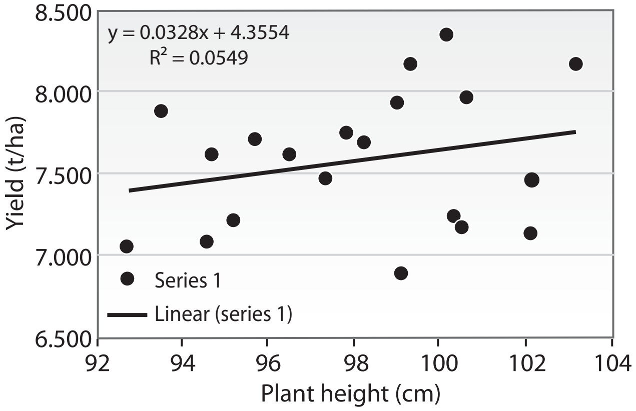

Figure 3. Linear correlation between mean yield and plant height.

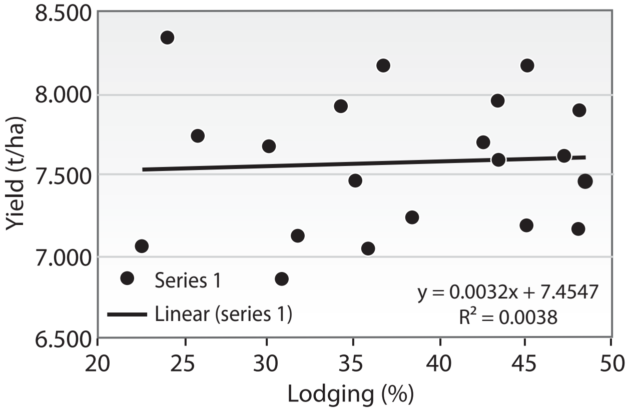

Figure 4. Linear correlation between mean grain yield and plant lodging.

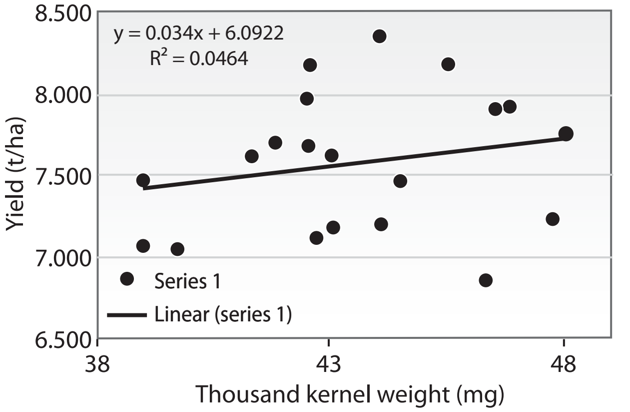

Figure 5. Linear correlation between mean grain yield and thousand kernel weight.

The high level of similarity between the grain yield of durum wheat elite genotypes indicates that in breeding programs, selection of genotypes has been more focused on grain yield, resulting in genetic homogeneity and the identification of superior genotypes that are commercially viable will be a major challenge in the next years.

Conclusions

In general, grain yield of most of the durum wheat elite genotypes was high, particularly in the second year due to better climatic conditions. However, the absence of any genotype out-yielding the local check genotypes could be a concern, as there may be a leveling-off of grain yield potential for the durum wheat elite genotypes. Low correlation between plant traits and grain yield indicated that grain yield variations could be attributed to other grain yield related traits such as spikes/m^2, grains/spike, grains/m^2, biomass, and harvest index. Thus, more detailed physiological studies are needed to better understand the variation in grain yield among durum wheat elite genotypes. Optimizing the number of crosses and population sizes and introducing new genetic diversity is recommended to decrease the genetic uniformity and maximize the probability of releasing high yield potential durum wheat genotypes.

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Chapter 5. Participatory evaluation of intercropping systems for the rainfed hill side environments of Nepal

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Keywords: gross income, inter-crop, maize equivalent yield, participatory on-farm trial, socio-economic class

Abstract

Farmer participatory trials were conducted during 2011 to identify suitable intercropping systems for the rainfed hill environment of Nepal. In addition to this, a survey was conducted to assess the performance of various intercropping systems among farmers from diverse socio-economic groups (gender, caste/ethnicity and food self-sufficiency). A total of 225 households from nine locations representing different food self-sufficiency classes (A: more than 12 months, B: 6–12 months, C: less than 6 months), castes/ethnicity (Dalit, Janajati, and Bramhins and others) and gender (male and female) conducted on-farm trials and participated in the survey. Results of the analysis of Maize Equivalent Yield (MEY) showed 149% MEY gains from maize–vegetable intercropping was achieved. Based on MEY for the system and gross income, maize + ginger was the most profitable intercropping system followed by maize + tomato, maize + bean, maize + cowpea, and maize + soybean. Data from the survey showed that there were no significant differences in the performance of various intercropping systems for gender, caste and food self-sufficiency groups. This indicated that the targeted participatory approach plays a vital role in mainstreaming women, marginalized and poor farmers in agricultural research and development.

Introduction

Maize (*Zea mays* L.) is the most important food crop in the hills of Nepal. The strategic importance of the crop in food security is summarized in the hill's common proverb: "If there is no maize, there is nothing to eat". Maize in Nepal is currently cultivated on approximately 0.875 million ha with an average yield of 2.2 t/ha (MoAC 2011).

Traditionally, maize sole and maize–millet systems dominated production systems in the hills of Nepal. Repetitions of the same cropping system for generations have caused the depletion of soil fertility in maize–millet and maize sole systems (Upreti et al. 2002). Diversification of the crop rotation by developing intercropping technologies is essential to maintain the soil fertility (Upreti et al. 2002). Other studies have shown that intercropping of vegetable crops in maize-based systems in the hills of Nepal has the potential to improve food security and income (Tiwari et al. 2002; Ferrara et al. 2010; Chand 1997; Prasad and Brook 2005). Intercropping experiments conducted in the hills over the last 10 years have shown that farmers can obtain significant net profits by intercropping other cash crops with maize (HMRP/CIMMYT 2010).

Willey (1979) reported that intercropping is more productive and efficient due to higher combined yield than that of sole cropping. Rao and Willey (1980) reported that the yield of intercropping is more stable than in sole cropping because of better disease and insect control and compensation by the companion crop if the other fails or grows poorly. These benefits are more pronounced in wider spaced crops. Furthermore, Chand (1997) stressed that intercropping increases the productivity of land as measured by yield per unit area. Intercropping plays a role of food insurance for the subsistence level farmers in the areas of continual risk of natural calamities (KC 1989). Sowing two maize plants per hill was found to be better for vegetable intercropping (HMRP/CIMMYT 2010). According to Prasad and Brook (2005), soybean could be better grown under maize by increasing between-row spacing of maize from 0.75 to 1.0 m to improve light transmission to the understory, resulting in higher overall productivity of the intercropping system. The double planting of maize at a spacing of 1.0 × 0.5 m was found appropriate for intercropping of tomato (*Lycopersicon esculentum*) and French bean (*Phaseolus vulgaris* L.) without reducing the maize yield (Gautam et al. 2006). The intercropping of tomato and French bean with maize has been found most profitable in road accessible areas for increasing high economic return and sustainable maize production (Gautam et al. 2006).

Nepal is a nation of incredible diversity. Nestled between China and India, Nepal is home to nearly 27.1 million people and over 100 ethnic groups that combined speak nearly 80 different recognized languages. Within these diversities, there are various types of social exclusion in Nepal such as those based on social class, gender and caste, and landlord–tenant relationships. Because of these exclusions, the poor and marginal, as well as those with small farms, have been deprived of the benefits of research and development efforts (Tiwari et al. 2010). An understanding of the interaction between new technologies and different socio-economic classes, mainly gender, caste/ethnicity and food self-sufficiency levels is still lacking.

Therefore, this study was designed to evaluate the performance of different intercropping systems in farmers' fields and assess whether the new technologies developed and promoted through participatory approaches can benefit the rural poor and marginalized people.

Materials and methods

Study location

The study was conducted in the mid hill districts of Nepal in nine different locations (Khotang, Kavre, Dhading, Gulmi, Baglung, Surkhet, Dailekh, Jajarkot, and Kalikot; 1,000–1,800 m.a.s.l. altitude) during 2011. From each district, one location (village) was selected to conduct participatory intercropping trials and surveys. These sites typically represented the mid hill environment of Nepal in terms of agro-ecological and socio-economic conditions (Figure 1). Location selection was based on the relative importance of maize as food, presence of farmers from various castes/ethnic groups and the level of partnership with the farmers in conducting maize Participatory Variety Selection (PVS) and Community Based Seed Production (CBSP) by the Hill Maize Research Project (HMRP) partners. From each site, 25–30 farmers were randomly selected from the list of farmers who had participated in one or more of the HMRP-supported activities and had continued to use seed of new varieties.

The nine locations across the mid-hills were: Narayansthan VDC-6 of Baglung; Baraha VDC-5 of Dailekh; Maidi-3 of Dhading; Simchaur-3 of Gulmi; Karkigaun 1 of Jajarkot; Kotbada 6 of Kalikot; Baluwapati-5 of Kavre; Khalde 2 of Khotang, and Rakam 5 of Surkhet. The HMRP has been working with farmers in these locations and distributing seed of new maize varieties for the past 4–5 years or more.

Selection of intercropping systems

The HMRP in the past two phases (1999–2007) has developed several recommendations for promising intercropping technologies for the hills of Nepal based on the results of on-station experiments. From these recommendations, five intercropping systems were identified for further evaluation in farmers' fields in consultation with the farmers'

Figure 1. Map of Nepal showing the nine districts and locations used in the study.

representatives of the respective locations. The intercropping systems identified jointly by farmers and researchers were: maize (*Zea mays* L.) + cowpea (*Vigna unguiculata* L.); maize + soybean (*Glycine max* L.); maize + ginger (*Zingiber officinalis*); maize + beans (*Phaseolus vulgaris* L.) and maize + tomato (*Lycopersicon esculentum* M.). The maize and vegetable varieties used were those validated by PVS conducted in the past two years.

Farmers' participatory trials

Twenty four to twenty seven farmers in each location conducted on-farm intercropping experiments in 2011. These farmers were selected from the total list of the famers in the village. The composition, in terms of gender, caste/ethnicity and food self-sufficiency level is summarized in Table 1. Five selected intercropping systems were randomly assigned to a total of eight different categories of farmer (Tables 1 and 2). In this way the number of farmer replicates for each intercropping system was about 45. The sole maize crop planted by a selected farmer in his/her remaining land was considered the control plot. The size of the plot ranged from 60 to 100 square meters depending on the availability of land.

Maize was planted at 1.0 m row/row and 0.5 m plant/plant distance by planting two plants per hill in the second week of May to the second week of June. Tomato, French bean, cowpea, ginger and soybean were planted between two rows of maize. Varieties of maize and vegetables were selected based on the results of the PVS conducted in each of the locations from 2006 to 2009. The maize varieties used were Deuti, Manakaman-3, Posili Makai-1 and the vegetable varieties were trishuli and four season bean (bean), Akash and Prakash (cowpea), BL-410 and Snow Crown (Tomato) and local (ginger). Fertilizer and compost was applied at 60:30:20 kg N:P:K kg/ha and 15 t/ha, respectively. All phosphorus and potash and half of the nitrogen was applied as a basal dose and the remaining half of the nitrogen was applied at 45 days after planting in the case of maize and just before flowering stage for vegetables in all the locations.

Survey

In addition to the on-farm experimentation, a survey was conducted during November 2011 to February 2012 to assess the performance and impacts of intercropping systems for various categories of famers. A simple one-page household-level questionnaire was used in the survey. A total of 225 farmers who conducted the on-farm trials were interviewed (Table 1). Questions were asked about the benefits of intercropping in terms of yield and profitability. The yields of maize and intercrops were recorded in local units (Pathi = 3.2 kg) and converted into metric units (t ha^{-1}) for the analysis.

Table 1. Number of participating farmers in on-farm experiment.

District/ Locations	VDC and Wards	Participating farmers								Total farmers
		Gender [c]		Food self-sufficiency level [a]			Caste/Ethnicity [b]			
		F	M	A	B	C	J	D	B^+	
Baglung	Narayansthan-6	14	11	2	12	12	8	6	10	24
Dailekh	Barah-5	14	11	2	12	10	8	6	10	24
Dhading	Maidi-3	14	11	2	12	10	8	5	12	25
Gulmi	Simichaur-3	14	11	2	12	10	10	5	12	27
Jajarkot	Karkigaun-1	14	11	2	13	10	8	5	10	23
Kalikot	Kotwada- 6	14	11	3	13	10	9	5	12	26
Kavre	Balupati-5	14	12	3	13	10	8	6	11	25
Khotang	Khalde-2	14	11	2	13	10	8	6	12	26
Surkhet	Rakam-5	13	11	2	13	10	8	6	11	25
Total		125	100	20	113	92	75	50	100	225

[a] A = households with food self-sufficiency for more than 12 months in a year; B = households with food self-sufficiency from 6 to 12 months in a year; C = households with food self-sufficiency for less than 6 months in a year.

[b] J = Janajati (ethnic community with medium position in traditional caste hierarchical system); D = Dalit (general caste group with lowest position in traditional caste hierarchical system); B^+ = Bramhins and others (general caste group with highest positions in the traditional caste hierarchical system)

[c] F = Female; M = Male

VDC = Village Development Committee (lowest level of administrative division)

Results

Evaluation of intercropping systems through farmers' participation

Five intercropping systems were assessed and compared on the basis of mean yield, gross income and Maize Equivalent Yield (MEY) of the system (Table 3). In intercropped plots maize yield varied from 1.9 to 2.6 t ha^{-1} (Table 4) whereas in sole crops the yield of maize ranged from 2.0 to 3.0 t ha^{-1}. The analysis of variance for mean yield of maize and intercrop and the MEY of the system revealed that the differences between various intercropping systems were significant.

Interaction of intercropping systems with socio-economic classes

Interaction of intercropping systems with gender (i.e., male/female), caste/ethnicity (Dalit, Jajati and Bramhins and others) and food self-sufficiency level (more than 12 months–A; 6 to 12 months–B and less than 6 months–C) were all non-significant (Table 4). Among the three categories of farmers for food self-sufficiency, the average yield of maize was highest for category B (3.0 t ha^{-1}) followed by A (2.7 t ha^{-1}) and C (2.0 t ha^{-1}). For the same farmers, intercrop yield was highest with farmers from category C (3.5 t ha^{-1}), followed by B (3.0 t ha^{-1}) and A (2.0 t ha^{-1}). The interaction of intercropping with caste/ethnicity showed that Bramhins and other upper caste groups (B^{+} = 2.9 t ha^{-1}) had the highest maize yield compared to Dalits (D = 2.6 t ha^{-1}) and Janajatis (J = 2.3 t ha^{-1}). However, the yield from intercropping was just the opposite. Janajatis produced the highest intercrop yield (J = 3.6 t ha^{-1}) followed by Bramhins and other upper caste groups (B^{+} = 3.1 t ha^{-1}) and Dalits (D = 1.4 t ha^{-1}).

Farmers' preference ranking

Ranking of five maize-based intercropping systems evaluated based on the economic criteria and mathematical calculations in on-station and on-farm experiments were different than the ranking by

Table 2. Types of trials and categories of farmers.

Intercropping systems[a]	Food self-sufficiency level [b]			Ethnicity [c]			Gender [d]	
	A	B	C	J	D	B^{+}	M	F
MT	MT*A	MT*B	MT*C	MT*J	MT*D	MT*B^{+}	MT*M	MT*F
MB	MB*A	MB*B	MB*C	MB*J	MB*D	MB*B^{+}	MB*M	MB*F
MC	MC*A	MC*B	MC*C	MC*J	MC*D	MC*B^{+}	MC*M	MC*F
MG	MG*A	MG*B	MG*C	MG*J	MG*D	MG*B^{+}	MG*M	MG*F
MS	MS*A	MS*B	MS*C	MS*J	MS*D	MS*B^{+}	MS*M	MS*F

[a] MT = Maize + Tomato; MB = Maize + Bean; MC = Maize + Cowpea; MG = Maize + Ginger; MS = Maize + Soybean.

[b] A = households with food self-sufficiency for more than 12 months in a year; B = households with food self-sufficiency from 6 to 12 months in a year; C = households with food self-sufficiency for less than 6 months in a year.

[c] J = Janajati (ethnic community with medium position in traditional caste hierarchical system); D = Dalit (general caste group with lowest position in traditional caste hierarchical system); B^{+} = Bramhins and others (general caste group with highest positions in the traditional caste hierarchical system).

[d] F = Female; M = Male.

Table 3. Yield and income from various intercropping systems, 2011 (1 US$ = NRs. 75).

Treatments (intercropping)	Mean maize yield (t ha^{-1})	Mean intercrop yield (t ha^{-1})	Gross income[a] from maize (US$)	Gross income from intercrop (US$)	Total gross income (US$)	MEY of intercrop (t ha^{-1})	MEY of system (t ha^{-1})
Maize + Tomato	2.0	5.1	873	2,021	2,893	7.0	9.6
Maize + Bean	2.6	2.8	842	1,293	2,136	3.8	6.4
Maize + Cowpea	2.2	1.5	739	806	1,546	2.0	4.1
Maize + Ginger	2.1	8.2	579	6,006	6,585	11.1	13.2
Maize + Soybean	2.2	1.2	740	806	1,545	1.7	3.9
Mean	2,638		785	1,908	2,693	3.9	6.6
P-value	0.0004						0.0001
Significance	***						***

[a] Gross income was calculated based on the farm-gate price and gross income doesn't include the by-product. MEY = Maize Equivalent Yield, *** = Highly significant.

farmers during the focus group discussion. Across all of the locations, the majority of farmers preferred maize + bean followed by maize + soybean, maize + ginger, maize + cowpea, and maize + tomato.

Discussion

Participatory evaluation of intercropping systems and farmers' perceptions

Initial recommendations for intercropping technologies and systems based on the results of on-station experiments was important for identifying promising systems in consultation with the farmers for further testing and validation by farmers. On-farm experiments allowed evaluation of different intercropping technologies jointly by farmers and researchers in their own field conditions. Through the participatory research, farmers could identify and then adopt intercropping systems that suited their conditions. This also enhanced the dissemination rate which is a major advantage of participatory approaches (Tiwari et al. 2010).

Five intercropping systems were assessed and compared on the basis of mean yield, gross income and MEY of the system. The average yield of maize in intercropping systems was almost equal to the sole maize system. The main reason for this was that the double plant per hill system with the spacing of 100 cm × 50 cm to plant intercrops between the rows of maize could maintain 40,000 plants ha^{-1}.

From the analysis of variance there were significant differences in the mean yield of maize and intercrop and the MEY of the system. This shows that location specific evaluation of intercropping systems is very important. Analysis of the MEY of the system and the gross income showed that the maize + ginger ranked first, followed by maize + tomato, maize + bean, maize + cowpea, and maize + soybean.

Intercropping systems verses gender, caste/ ethnicity and the level of food self-sufficiency

The analysis of variance for mean yield of maize and intercrop and the gross income in the maize-based intercropping system showed non-significant differences for gender, caste and social class. This means that the poor and marginalized farmers could also gain equally from the new technologies. This is one of the most important advantages that participatory research has in mainstreaming gender, poor and marginalized farmers in agricultural

Table 4. Mean maize and intercrop yield (t ha^{-1}) in maize–vegetable intercropping systems for different categories of farmers.

	Category	Mean maize yield (t ha^{-1})	Mean intercrop yield (t ha^{-1})	Total gross income (US$)
1. Gender	M (n = 102)	2.8	2.6	2,490
	F (n = 127)	3.0	2.3	2,322
	Mean	2.9		2,406
	P-value	0.48		0.24
	Significance	NS	NS	NS
2. Food self-sufficiency (FSS) level	A (n = 22)	2.7	2.9	2,643
	B (n = 105)	3.0	3.0	2,783
	C (n = 92)	2.0	6.0	4,271
	Mean	2.6		3,232
	P-value	<0.0001		0.89
	Significance	S	NS	NS
3. Caste/ Ethnicity	J (n = 76)	2.3	3.6	2,933
	D (n = 48)	2.6	1.4	1,672
	B^{+} (n = 105)	2.9	3.1	2,778
	Mean	2.6		2,461
	P-value	0.07		0.27
	Significance	NS	NS	NS

NS = not significant, M = male, F = female, A = households with food self-sufficiency for more than 12 months in a year, B = households with food self-sufficiency from 6 to 12 months in a year, C = households with food self-sufficiency for less than 6 months in a year, J = Janajati (ethnic community with medium position in traditional caste hierarchical system), D = Dalit (general caste group with lowest position in traditional caste hierarchical system), B^{+} = Bramhins and others (general caste group with highest positions in the traditional caste hierarchical system).

research. Among the three categories of farmers for food self-sufficiency, the average yield of the intercrop was highest with farmers from category C followed by B and A. This may be due to the fact that small land holdings of farmers in category C allowed them to take care of their crop in a better manner than the other two categories of farmers. Interaction of intercropping with caste/ethnicity showed Dalits farmers could have the lowest gains from intercropping technologies. This shows that more training and other support may be needed for these categories of farmers.

Farmers' preference ranking

Ranking of five maize-based intercropping systems by farmers during the focus group discussion was different than the ranking by mathematical calculation based on the results of the on-farm experiments. Across all the locations, the majority of the farmers preferred maize + bean, followed by maize + soybean, maize + ginger, maize + cowpea, and maize + tomato. Farmers ranked bean and soybean as their first preference due to the role of these crops in household food security, cultural values, availability of local markets and high storability. Farmers considered ginger and tomato as less important due to insecure markets, high cost of production, incidence of insects and diseases and their lesser role in food security.

Conclusion

Intercropping technology is appropriate especially for small farmers who possess small pieces of land. Maize Equivalent Yield (MEY) for the system showed almost 149% additional gains in main yield. The study also revealed that the participatory approach plays a significant role in mainstreaming women, marginalized and poor farmers and empowering them to get greater benefits from the new technologies. This has helped to reverse our assumption that new technological interventions have only been benefiting the richer farmers. As improvement of food security is a global concern, managers and policy makers from agricultural research and development organizations should seriously consider a wider adoption of focused and participatory approaches.

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Chapter 6. Conventional tilled-beds – a brief description and a furrow opener to apply this technology

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Abstract

Wheat production in rainfed areas faces many biotic and abiotic constraints for optimal grain yields. A suitable alternative for growers to cope with these is the application of innovative technologies such as the planting system on conventional tilled beds (CTB). Research and practical application of this technology has shown that this system takes advantage of natural resources to produce greater grain yield compared to the conventional planting system on the flat. Additionally, production costs are relatively reduced. The application of this technology requires the modification of the conventional drills with one–three furrow openers specifically designed for the most common planting equipment in the highlands of Mexico.

Introduction

Wheat growers in the highlands of Mexico plant their crop following conventional means of plowing and disking operations, in addition to the use of excessive seed and fertilizer rates. One of the side effects of the intensive tillage operations for soil preparation is soil erosion which in Mexico accounts for about 533 million t lost annually (Etchevers et al. 2006). Most of the wheat from rainfed areas is produced in the states of Mexico and Tlaxcala. Grain yield in these states has shown a high degree of variation. For example, grain yield in the state of Mexico varied from 1,900 to 2,700 kg ha^{-1} in 2001 and 2010, respectively (SIACON 2010).

These grain yield variations can be attributed to several factors including increased production costs due to intensive tillage and high seed and fertilizer inputs. Similarly, climate change is another issue that appears to be already affecting crop production. For example, the onset of the rainy season in recent years has been delayed. This change has also included frost events at critical growth stages affecting crops. According to St Clair and Linch (2010), developing countries will be most affected by climatic issues that are characterized by relatively long drought periods followed by short but intensive rains (Easterling et al. 2000).

One of the alternatives for assisting growers in facing these constraints is through the application of new technologies developed for crop production. A suitable alternative is a planting system on beds that uses conventional till methods. The study of this technology in Mexico was initiated in the early 1960's for the irrigated areas of the northwest (Sayre and Moreno 1997). However, research in the rainfed areas of the highlands of Mexico has shown that the technology is also suitable for this area (Rivera Ramírez 2002).

Unfortunately, the application of this technology to wheat requires specific planting equipment that is not commercially available in the area. Therefore, growers in the highlands of Mexico that adopted the CTB modified their conventional drills with a furrow opener developed by the Instituto Nacional de Investigaciones Agricolas Forestales y Pecuarias (INIFAP). A detailed description of this implement can be found in Limón-Ortega et al. (2009).

The purpose of this document is to review the CTB for rainfed wheat production and a prototype of furrow opener to modify a conventional drill to plant on beds.

Innovative planting systems for wheat

It has been documented that an alternate planting system on beds was applied in the southeast of Tlaxcala, Mexico, about 300 years BC (Crews and Gliessman 1991). Clearly, this production system was applied to other crops like maize, pumpkin and beans in areas with a high water table and concurrent water logging events. Nowadays, the CTB is extensively applied in the irrigated areas of the northwest of Mexico and by a few farmers in the rainfed areas of the Mexican highlands. The earliest field research to apply this system for wheat production was initiated in Mexico in the 1960's (Wang et al. 2009). Even though this technology is currently applied following the protocols of intensive tillage for soil preparation, it is considered that the efficiency is higher than conventional planting methods as soil erosion is substantially reduced and greater grain yield can be obtained.

Even though the application of the CTB is the main concern of this document, it is important to mention that the planting system on permanent beds is an alternative option that can further improve the resource use efficiency of crop production (Hobbs et al. 2008).

Application of conventional till beds

The application of CTB requires the modification of conventional drills as the equipment for beds is not easily available in the market. This modification consists of attaching between one and three furrowers to the planter. For each furrow attached, a seed dropper is removed and its corresponding seed and fertilizer gates are blocked with tape. When the decision to modify a conventional drill is made with only one furrower, the latter is attached to the center of the drill. If the decision is to install two furrowers, these are attached in line with the tractor wheels. In the case of three furrow openers, the one is attached to the center and the other two in line with the tractor wheels. An example of how a conventional drill looks after the modification during the planting operation is shown in Figure 1.

Land preparation

One of the most common agricultural practices is related to soil preparation. However, it is important that growers reconsider this practice as soil erosion and oxidation are greatly increased (Etchevers et al. 2006), among other disadvantages. In general, the objective of soil preparation is to fractionate large clods into smaller ones. This is easily achieved when disking is conducted at the appropriate soil moisture content. Otherwise, when the soil is disked at the wrong time the optimal fractionation is not achieved and excessive passes are required. Consequently, aggregates are pulverized and crop emergence is impeded as the soil tends to crust under this physical condition. Thus, applying the operations for soil preparation at the optimal time and planting on beds reduces the crusting problem (Eghbal et al. 1996; Wang et al. 2009).

Planting

Recommended planting dates for the CTB are the same as for conventional planting. However, it is important to consider the earliness of the variety as the onset of the rainy season has recently been shortened. For the specific case of the state of Mexico, the traditional recommended dates for rainfed wheat range from May 15 to Jun 20 (Villaseñor et al. 2011).

Figure 1. Conventional drill modified with three furrow openers to plant on conventional tilled beds. This equipment was modified attaching three furrow openers in such a way that the planting and raising beds operations are performed simultaneously. Depending upon the number of furrow openers installed, bed width and number of seed rows on the bed is set. It should be noted that the furrow openers behind the tractor wheel have the dual function of opening the furrow and loosening the compaction of the wheels.

Appropriate wheat varieties

Generally, the process of developing a wheat variety is conducted under conventional planting conditions on the flat. Therefore, released varieties should be tested for their suitability under beds prior to adoption. For instance, in one of the earliest studies on CTB in the highlands of Mexico, only two varieties (Nahuatl F2000 and Tlaxcala F2000) out of eight available were identified as appropriate for this planting system (Limón-Ortega et al. 2008). However, considering the year these varieties were released (2000) and the life-span of a variety (4–6 years) (http://oregonstate.edu/instruct/css/330/four/index.htm), they may no longer be adequate for planting due to disease susceptibility. However, there were two varieties recently released; Nana F2007 and Altiplano F2007 (Villaseñor et al. 2011) and field work is underway to estimate their suitability for planting on beds.

On the other hand, optimal seeding rates to obtain adequate grain yields range from 80 to 120 kg seed ha^{-1}. In this regard, the goal is to obtain an average of 350 spikes m^{-2} (Limón-Ortega et al. 2008; Limón-Ortega, 2011).

Weed control

Weed control in CTB can be achieved by chemical means using the same herbicides, rates and growth stages that are used in conventional planting fields. However, CTB offers two additional options; mechanical and chemical control applied in the furrows. The latter also offers the additional opportunity to spray at later growth stages without causing any damage to the crop.

Advantages of planting on beds

Previous research has shown that wheat grain yield from CTB is similar to grain yield from conventional planting (Freeman et al. 2007). However, wheat growers in the state of Mexico that have adopted this system indicate that grain yield can be even higher on CTB. Some of the possible reasons for a higher grain yield from beds are indicated in the following paragraphs.

Rainfall water use efficiency can be improved in moderate rainfall environments by means of furrow diking CTB. This practice is necessary considering climatic issues, overall rainfall amount, and distribution (Villaseñor et al. 2002). However, caution must be taken with furrow diking as in heavy rainfall environments this practice may result in waterlogged areas and lower yields (Jones and Clark 1987). Thus, the decision to furrow-dike will depend on reaching an equilibrium between improving the superficial drainage in high rainfall environments and retaining water in low rainfall environments.

A common constraint after planting in rainfed areas is the formation of superficial soil crusting. Generally, this crust results from the poor soil aggregate stability due to the intensive tillage for soil preparation (Diaz-Zorita et al. 2004). The superficial crust formation normally occurs when the seed is germinating and after a heavy rain. This crust impedes rapid crop emergence, exposing seedlings to soil borne diseases. Even though growers resolve this problem by breaking the crust by mechanical means, seedlings still lose vigor. Research has shown that this constraint is greatly reduced when CTB are applied as the crusts tend to be thinner and weaker compared to a soil crust formed in conventional planting systems (Eghbal et al. 1996). This advantage allows a more rapid crop emergence in CTB compared to a conventional planting system (Fahong et al. 2004).

The open space between beds in CTB creates a microclimate environment that has several advantages. Presumably, this space is exposed to periodic warming and drying processes where pathogens may not progress (Cook et al. 2000). For instance, some reports indicate that the incidence of some diseases in wheat such as *Pseudocercosporella herpotrichoides* and *Erysiphe graminis* are considerably reduced under the planting system on beds (Fahong et al. 2004).

Another advantage to CTB is related to the improvement of the N use efficiency (Limón-Ortega 2004), and is partly due to the split applications that can be made at any growth stage to match the crop's needs. Additionally, as the plant size is relatively reduced, lodging tends to decrease (Fahong et al. 2004).

A prototype of a furrow opener to modify conventional planters

A suitable alternative for growers to apply CTB is through the modification of conventional planters. This modification is simple and cheap. Figure 2 shows the proposed prototype that was designed by INIFAP. A detailed description of this prototype can be found in Limón-Ortega et al. (2009). Once this furrow opener is attached to the planter, the equipment can simultaneously plant and raise beds. The materials employed to assemble a furrow opener weigh approximately 16 kg. Thus, the mass that is added to the planter is not substantial considering that for each furrow opener attached a seed dropper is removed.

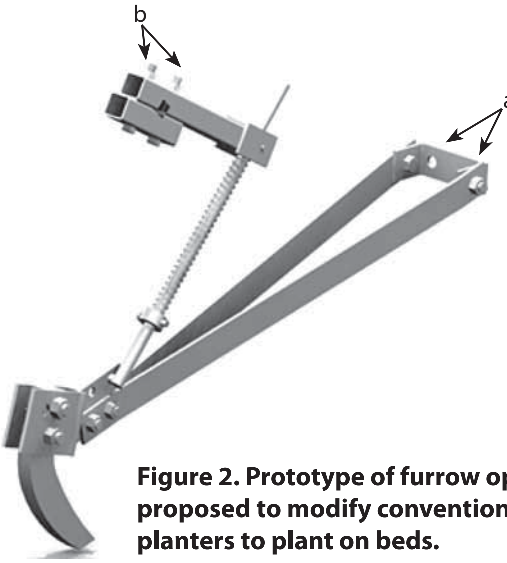

Figure 2. Prototype of furrow opener proposed to modify conventional planters to plant on beds.

This furrow opener was designed based upon the frame of one of the most common planters in the highlands of Mexico. Thus, to modify a different planter the furrower will need additional changes. This furrow opener has two structures in its frame that match two parts of the planter (Figure 2); one goes in the front bar (a) and the other in the raising bar (b). The geometry of the latter has a square hole with an angle that allows the furrow opener to reach a similar height as the seed droppers. It is also important to note that the configuration of the furrow opener is very similar to the seed droppers, except that the length of the former is larger. The purpose of this difference is to avoid the interference of one structure over the other during the planting operation. This condition is reinforced with the attachment of the right shovel (pata de mula) to the furrow opener.

Modification of conventional planters

Growers have three options when modifying their planting equipment for CTB; install one, two or three furrow openers. According to this, one opener should be installed in the center of the equipment and one behind each wheel of the tractor. For every furrow opener to be installed, a seed dropper should be removed from the planter. This change is made following this procedure:

1) The seed and fertilizer gates of the corresponding seed planters to be removed should be blocked with tape,
2) The four screws that hold the seed droppers in the planter should be removed, and
3) Once the seed dropper is taken off the planter, this space should be replaced with a furrow opener including the screws previously removed.

Once these three steps are completed, the planter is ready to plant on CTB. Depending on the number of furrow openers installed, the bed width and number of seed rows per bed will be established.

For seed rate purposes, it is recommended to keep the seed and fertilizer dispenser in the same notch as it was before the modification. In this way, a conventional planter with 13 seed droppers modified with three furrow openers, the previous seed and fertilizer rate is reduced by 23% without any negative effects on plant establishment and final grain yield. This relative reduction represents important economic and ecological savings.

Cost of the furrow opener

Considering that the required labor to manufacture this furrow opener is not highly specialized in agricultural machinery, the price of each piece is not expensive. According to the prices in 2011 and depending on the workshop, the cost of each furrow opener is equivalent to less than half a ton of wheat. However, it is important to consider that this investment is needed only once.

Conclusions

An efficient alternative in agricultural procedures is the application of CTB. Even though field research on this system was initially to be applied for wheat production in the irrigated areas, recent results have shown that this innovative technology can be applied to produce rainfed wheat. Improved economy is one of the factors that encourages the adoption of this system as seed and fertilizer rates are relatively reduced. Consequently, the adoption of this system implies an important reduction in ecological costs, overall through the reduction in N and P application. In addition, the manufacture of the furrow openers is not expensive and is a once only investment.

Given the advantages of the CTB and the acceptance by farmers, the next step in this process is to design an eccentric wheel to be attached to the furrow opener to dike the bottom of the furrow. This possibility will enhance the current water rainfall efficiency.

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