Compendium of deliverables of the **conservation agriculture course** 2011

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Marie-Soleil Turmel, and Juan Herrera

CIMMYT
International Maize and Wheat Improvement Center

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Foreword

This book is the result of the hard work of 11 CIMMYT trainees who work on sustainable practices in India, Pakistan, Afghanistan, Ethiopia, China, Tunisia, Morocco, Turkey, and Bangladesh, and participated in the 2011 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 conservation agriculture-based 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 and resource conserving 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 the importance of 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 planting technologies and relevant agriculture 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 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.

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 necessarily reflect the views of CIMMYT.

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, and others developed a project proposal to be used in their home country activities. 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

Chapter 1. Reduced tillage systems and water productivity in irrigated environments: Towards data synthesis

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Keywords: meta-analysis, raised bed, reduced tillage, residue, water saving, zero tillage

Abstract

Both physical and economic water scarcity threaten the future productivity of irrigated agriculture. Reduced tillage (RT) cropping systems have typically focused on the conservation of soil resources, although when combined with conservation agriculture (CA) based practices, such as residue retention and crop rotation, an important ancillary benefit of RT could be improved input water productivity (WP) at the field level. While the efficiency of rainwater use has been widely studied in RT systems, very little is known about the effect of these practices, especially when combined with residue retention and crop rotations, on WP in irrigated environments. This paper describes the first steps taken towards the development of a database prepared for meta-analysis of paired experiments comparing yield, water savings and WP in RT and conventionally tilled (CT) crop management systems. We describe the process used to identify and select studies, the construction of the database, and the preliminary results. The initial results are inconclusive, and mainly indicate that more data collection and analysis is necessary. To date, studies of WP in irrigated RT systems are relatively rare, therefore a more thorough literature review will be necessary for proper meta-analysis. In our future research efforts, we are likely to include data from reports from reputable research institutes, in addition to the peer-reviewed literature. Another important constraint of several of the studies currently in the database is that researchers purposely irrigated RT and CT plots with the same volume of water, to control against water as a limiting or confounding factor, to examine the effect of tillage alone. While this approach is understandable, it obscures the potential benefit of RT systems in saving water, especially where residue is retained. We conclude by outlining plans for future data acquisition, including rainfed experimental comparisons and other cereal crops, and advanced statistical analysis. A major conclusion of this preliminary analysis is that there are relatively few published studies examining the potential for increased WP in RT and CA based cropping systems under irrigation, signifying that more research should be conducted in this important area.

Introduction

Despite comprising just 20% of the global cropped surface area, irrigated agriculture contributes about 40% of the world's food output (Turral et al. 2011). Irrigation, however, also accounts for approximately 70% and 90% of the fresh water withdrawn globally and in developing nations, respectively (Cai and Rosegrant 2003). While irrigation is undeniably productive, the future viability of freshwater resources for agriculture – especially in developing nations – is threatened by climate change, water quality degradation, and increased competition from urban consumers and industry (Rijsberman 2006).

The most serious water over use occurs in the Mediterranean region, the Middle East, United States, Mexico, India and China (Cook et al. 2006). In the latter case, pumping from the Yellow River is so severe that the river frequently dries before reaching its Delta (Postel 1997). About 60% of the globe's irrigated area is in South Asia (Barker et al. 1988), where water scarcity is also having dramatic impacts (Rijsberman 2006). Water withdrawn in India, for example, now exceeds the potential for aquifer recharge by a factor of two or greater. An estimated 25% of India's grain harvests are now threatened by unreliable water supply (Cook et al. 2006). In the South Asian Punjab and China's Northern Plains, groundwater tables are falling by 0.5–3 m per year, dramatically increasing the fuel and economic resources required to pump water to the surface (Seckler et al. 1999).

The world's three most important cereals are wheat (*Triticum aestivum*), maize (*Zea mays* L.) and rice (*Oryza sativa* L.) and measured values for 1 kg of grain produced per unit of water evapotranspired by these crops are approximately 1.09, 1.80 and 1.09 m^{-3}, respectively (Zwart and Bastiaanssen 2004). Holding other factors constant, yields of these cereals are usually highest under full or supplemental irrigation, though agronomic management – and thus total water requirements – differ dramatically among crops. When non-productive field water losses such as deep percolation or field seepage are accounted for, total water requirements can be higher. When wheat is irrigated, for example, about 1.3 m^{-3} of water is required to produce 1 kg of grain. In irrigated rice, floodwaters serve multiple purposes including weed suppression, thermal regulation of the crop, and provision of habitat nitrogen fixing cyanobacteria, among others. Consequently, flooded rice usually requires at least double the water required by wheat to produce 1 kg of grain (Bouman et al. 2007). Irrigated maize, on the other hand, requires somewhat less water than rice. Clearly, crop management strategies that improve crop output while reducing water requirements – thereby improving water productivity (WP) – are urgently needed.

Water productivity means different things to different people. The importance and definition of WP will vary if one is a hydrologist, crop physiologist, ecologist, economist, or an agronomist (Ali and Talukder 2008), as well as upon the degree and type of water scarcity (Zoebl 2006). In this paper, we employ the agronomic term, defining WP as the ratio of economic (grain) yield per unit of irrigation and/or rainwater necessary to prepare land for, and to grow, a cereal crop. But saving water alone will not result in improved WP if yield is compromised (Barker et al. 1988). The goal, therefore, is to attain high WP by maintaining and/or increasing yield, while concurrently making more efficient and wise use of water resources.

Conservation agriculture (CA) and reduced tillage systems have been proposed as a means to conserve soil, water and energy resources, while assuring high crop output (Gupta and Seth 2007; Hobbs et al. 2008; Kassam et al. 2009). Gaining "more crop per drop" depends not just on efficient irrigation delivery, but also upon water retention in the field, reduced evaporative and percolation losses, and thus improved supply to the crop itself. With respect to WP, a key goal of reduced tillage in CA is improved soil quality, defined here as sustained and/or increased soil organic matter, improved pore and aggregate structure, and thus water holding capacity. However, the impact of these practices on these parameters may vary by soil type and texture, crop, irrigation management, and/or climate. Other approaches commonly used in RT and CA systems include raised beds, which facilitate furrow rather than flood irrigation. The principles of CA based management approaches are as follows:

Minimal soil disturbance: Avoidance of soil inversion through use of the plow. This is perhaps the most basic, and primarily important, principle of RT and CA management systems. In practice, no more than 25% of the soil surface should be moved for tillage (Govaerts et al. 2009). Direct seeding techniques that avoid tillage and soil disturbance are used for crop establishment, theoretically avoiding the degradation of soil physical qualities that could compromise water holding capacity. To achieve this goal in mechanized systems, CA is frequently coupled with strip or zero tillage, and/or permanent raised bed planting. When correctly implemented, raised beds in particular permit furrow irrigation, and should reduce water requirements compared to flooding flatly planted field surfaces. CA equipment has also been adapted to suit non-mechanized conditions, through the use of basin planting, jab planters, or modified reduced-till implements coupled with animal traction.

Maintenance of soil cover: This is achieved by retaining crop residues and stubble. The rationale is to protect the soil from erosion, to enhance soil chemical, physical and biological properties, and to reduce evaporative water losses. Full residue retention may not always be necessary. Baker et al. (2006), for example, suggest a minimum of 30% retention for most annual cropping systems, meaning that farmers may still remove a portion of their crop residues for fuel, feed, construction material or other purposes. However, numerous literature examples exist where RT is employed without deliberate crop residue retention, either for experimental purposes or in environments where residues are used for other purposes. The removal of residues therefore presents a trade-off in RT systems. Complete residue removal is likely to reduce WP by increasing evaporation, by potentially lowering yields, or some combination of both. In practice, the amount of residue that should be retained depends on numerous factors, for example the socioeconomic system in which the crop is managed, the quality of the residue, underlying soil and residue quality, climate, etc.

Crop rotations: Crop rotations are recommended to break potential pest and disease cycles, to facilitate improved weed control, and to enhance nutrient cycling. Ideally, rotations would include cover crops, though this is not always economically viable, thereby necessitating rotation with alternative cereal or horticultural crops. While rotations may have limited direct effects on water conservation, they could have indirect effects by helping to maintain stable and high yields, and by improving soil quality by contributing varied types of biomass to the soil.

An additional principle, *short-term economic benefits*, is increasingly proposed as a fourth component of CA based crop management systems. This is especially important in encouraging the adoption of CA systems. While yield benefits may not always be immediately obtainable, reductions in fuel or other input costs may still be attractive for farmers. Where irrigation costs are high or increasing, and especially where farmers irrigate by pump rather than by gravity, improved WP through CA based crop management systems could help to offer additional economic advantages.

The advantages and disadvantages of CA and reduced tillage for improved precipitation use efficiency in rainfed systems has been discussed elsewhere (Kassam et al. 2009; Lal 1989, 1994; Rockstrom et al. 2009; Thierfelder and Wall 2010). Less understood is the impact of RT and CA management practices on WP in irrigated cropping systems. While RT should theoretically help to improve the efficiency of water use – especially when coupled with residue retention and crop rotations – there are numerous confounding management factors and environmental trade-offs that could complicate attempts to save irrigation water. For example, improved WP may not always be observed in semi-arid or relatively humid climates with low evaporative demand, where water tables are excessively deep, where poorly adapted cultivars are used, or where soils already have high water holding capacities. The potential benefits of these techniques may also be reduced in locations were farmers remove residues above an environmentally-specific threshold. Due to CA maintaining soil structure and avoiding the development of a plow pan, benefits may also be limited compared to flooded rice systems where farmers puddle their soils, reducing deep percolation losses.

In this paper, we discuss the development of a database that will be used to analyze RT land management options and their effect on WP irrigated wheat, maize and rice. While full farm, community, and catchment level water conservation analyses are important (Cook et al. 2006), we focus primarily on field-scale assessment using data from paired CT verses RT or CA experiments to better elucidate the complexities and trade-offs between water savings, yield and WP in each management system. We describe the criteria used to select literature for meta-analysis, present preliminary exploratory results, and discuss limitations of the current database. Wherever possible, we sought to access studies building on RT by including residue retention and crop rotations, thereby signifying a full CA system, although this was not always possible due to a lack of available peer-reviewed studies. We conclude by describing plans for additional data collection, and discuss potential statistical analyses to better assess WP in RT and CA based crop management systems.

Towards a synthesis of the data

The meta-analysis of results from multiple studies can be a powerful tool for summarizing scientific information and looking for patterns in data (Borenstein et al. 2009). Meta-analysis considers the measurement of response variables across locations, times and/or environments, and is especially useful when large analytical scales are considered, and where the scientific literature is vast. In agricultural development, meta-analysis is beginning to be used to guide broad agricultural and environmental policies, especially as they pertain to the endorsement of improved or "best" crop management practices (Doré et al. 2011). To this end, this paper describes the initial steps taken to assemble a comprehensive database for meta-analysis of studies assessing WP in RT and CA based cropping systems.

We used the ISI Web of Science database provided by Thompson Reuters to explore the scientific literature from 1982 to the present. The ISI database was queried using keywords relevant to water savings and WP, looking for studies with paired RT-CT comparisons. We further restricted our search to experiments in rice, wheat and maize based cropping systems. Twelve search terms were crossed with WP specific terms (Table 1), yielding well over 1,000 papers which were individually checked before selection. Only peer-reviewed, paired experiments comparing RT with CT with standard research methodologies were selected.

Although reduced tillage remained the constant CA criteria for our search, we also included treatments using less than all three CA principles. For example, studies using zero tillage and crop rotation, but no residue retention were included, as were those with reduced tillage, even if no residue was retained. Conversely, studies using crop rotation and/or mulching, but with full inversion tillage, were not considered to be RT. Using these criteria, a total of 11 papers was identified (Appendix 1 and 2)[1]. Six of the eleven papers (Bhattacharyya et al. 2003; Parihar et al. 2003; Qin et al. 2010; Saharawat et al. 2010; Singh

[1] The remaining papers will be entered when time is more permitting. The results presented in this paper are therefore extremely preliminary and should by no means be taken as conclusive.

et al. 2010K; Singh et al. 2010L; See Appendix 1) did not always include residue retention in RT systems. One paper (He et al. 2003) did not use crop rotation, although residues were retained in the RT system.

In each study we obtained mean values for the WP of irrigation (WP_{IR}) as follows:

$$WP_{IR} = Y / \sum(I, R) \qquad \text{Eq. 1}$$

where Y is grain yield (kg ha^{-1}), and I and R are irrigation and rainfall (m^3) summed for the period for crop preparation and field growth.

Meta-analysis is best conducted using studies that provide measures of statistical dispersion such as the standard deviation, error, or coefficient of variation for the treatment mean. These variables allow assessment of the statistical reliability and variability of reported means (Borenstein et al. 2009). For this reason, we attempted to collect measures of error in addition to other continuous and categorical variables (see Table 2).

However, very few of the studies meeting our selection criteria report these measures. Some provided Least Significant Difference (LSD) values, which can be used to back-calculate sample variance (see Ngugi et al. 2011), although these studies comprised a small fraction of the papers searched. For these reasons, this paper provides only preliminary descriptive results of the database as it is comprised thus far. Descriptive statistical and linear regression analyses were carried out using JMP 8.0.2 (SAS Institute Inc., San Francisco). Presentation of summary statistics and simple correlation coefficients is useful to indicate problems with the database, so that further research efforts can be adjusted to correct identified problem areas.

Table 1. Search terms used to query the ISI Web of Science database.

Variable search term†	Crossed search term†
Permanent raised bed*	Water productivity
Raised bed*	Water saving*
Bed planting	Water use efficiency
Conservation tillage	Irrigation productivity
Zero till*	Irrigation use efficiency
No till*	
Tillage option*	
Strip till*	
Residue retention	
Residue management	
Mulch	

† Future searches will include terms like "controlled traffic", "precipitation use efficiency", "rainwater use efficiency", "precipitation productivity", "rainwater productivity", "water storage", and others.

Use of the asterisk (*) in ISI Web of Science searches will return papers that relate to the entered term, but which could vary slightly. For example, "permanent raised bed*" may also return studies that use "permanent raised beds" as a keyword. Asterisks therefore allow broader and more inclusive database searches.

Table 2. Information currently collected in the database[a].

Background information
Paper reviewer name, paper first author, year of publication, journal name, peer-review status, environment (arid, semi-arid or humid), country, latitude and longitude, on-station or on-farm status, number of experimental seasons, number of replicates, experimental years, plot size (m^2), plastic lining of plot (yes/no), soil taxonomy, soil texture (sand, silt and clay %), fertilizer NPK dose (kg ha^{-1}).
Water management information
Irrigation and precipitation inputs (mm), capilary rise (if measured, mm), change in soil moisture (if measured, mm), deep percolation losses (if measured, mm), evapotranspiration (if measured, mm).
Categorical variables listed in papers or grouped when entering data
Land leveling status (laser or traditional), crop management system (CA or CT), tillage treatment (zero tillage, reduced tillage, sub-soiling, fresh beds, permanent raised beds, conventional inversion tillage), residue retention (%), residue placement (incorporation, mulch, stubble mulch), land configuration (flat, narrow or wide beds), bed or zero tillage age (years), crop (rice, wheat or maize), crop establishment (direct seeding or transplanting), irrigation type (flood, alternate wetting and drying, furrow, mid-season drainage, sprinkler, drip, furrow alternate wetting and drying), rotation code (for example, rice wheat = RW), N fertilizer method (banding or broadcasting), water table depth (deep or shallow).
Continous response variables and measures of statistical dispursion
Yield, standard deviation, standard error, LSD, SED (Mg ha^{-1}), statistical significance of yield (mean separations), water productivity of irrigation and rain water, standard deviation, standard error, LSD, SED (kg m^{-3}), statistical significance of water productivity (mean separations), water use efficiency of evapotranspiration, standard deviation, standard error, LSD, SED (kg m^{-3}), statistical significance of water use efficiency (mean separations).

[a] Not all data may be of use in later analyses. At this point we are taking a wide approach towards data collection, and including parameters which may be useful for more detailed analysis and/or modeling.

Preliminary results and discussion

Crop performance in CT verses RT is synthesized for rice, wheat, and maize (Figure 1). Preliminary results for average rice grain yield in RT (6.08 Mg ha^{-1}) tended to be lower than CT (7.24 Mg ha^{-1}), though the insufficient number of data points means that these results should be treated with caution. In wheat, RT produced 4% higher yield than CT; while in maize, data is clearly lacking at this point to be able to identify data trends, especially for CT.

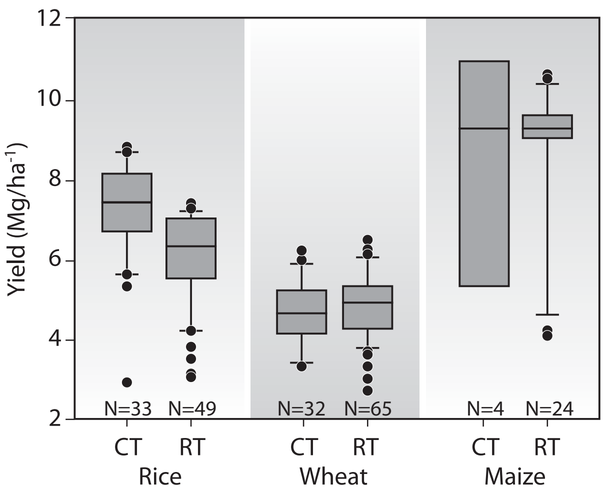

Figure 1. Box and whisker plots of grain yield (Mg ha^{-1}) for rice, wheat and maize under conventional tillage (CT) and reduced tillage (RT). The center line in the box represents the mean, the outer horizontal lines of the boxes are the upper and lower 25th quartiles, the ends of the error bars are the 95% confidence intervals, while dots are outliers.

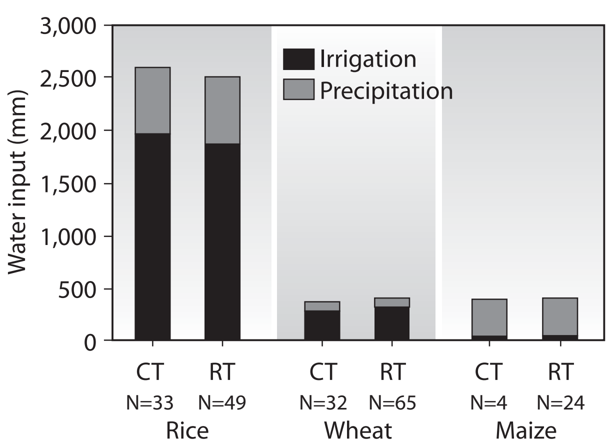

Figure 2. Total water inputs (irrigaton and precipitation; mm) for rice, wheat and maize under conventional tillage (CT) and reduced tillage (RT) for the studies currently included in the database.

Considering measured inflows of irrigation and precipitation, we found that most of the studies currently included in the database show little difference between CT and RT treatments (Figure 2). Only Jat et al. (2009), Jin et al. (2009), Gathala et al. (2010), He et al. (2010), Saharawat et al. (2010), Singh et al. (2010L) and Singh et al. (2010K) varied irrigation inputs between treatments to examine the potential for water savings in RT and CA systems, although even in these studies, water savings were frequently marginal. In the remaining four studies, researchers kept water inflows constant to avoid potential water stress, and to examine the response of treatments to simplified factors such as tillage alone. This is a serious problem for meta-analysis of WP in irrigated CA and RT systems. Our preliminary search of the literature yielded results indicating that many researchers are not yet challenging their methodologies by varying irrigation inputs to examine the potential for water savings. We suggest that comparative CT-RT experiments could easily consider water savings without risking water stress and thus confounded results, simply by utilising gravimetric water content measures or tensiometers to show soil water potential dropping below a pre-defined threshold.

Examining WP, we found only marginally different trends among the mean values for rice and wheat. Maize will again require more data collection before even slight trends can be identified (Figure 3).

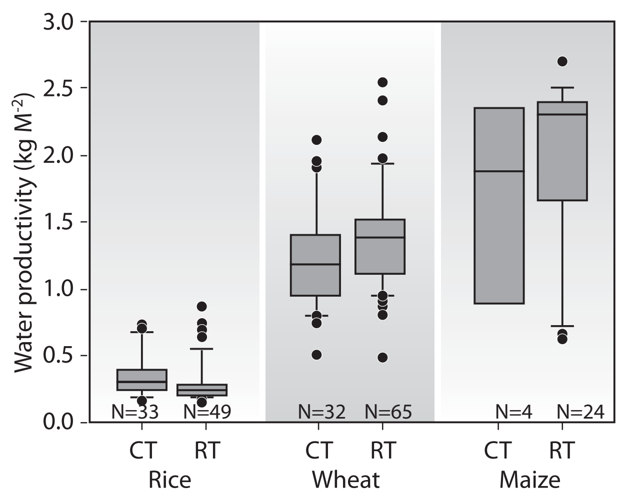

Figure 3. Box and whisker plots of agronomic water productivity (kg grain m^{-3} irrigation + precipitation) for rice, wheat and maize under conventional tillage (CT) and reduced tillage (RT). The center line in the box represents the mean, the outer horizontal lines of the boxes are the upper and lower 25th quartiles, the ends of the error bars are the 95% confidence intervals, while dots are outliers.

This is partly due to the confounding effect of the four papers that had no differences in irrigation and precipitation water inflows to experimental plots: because agronomic WP_{IR} is the ratio of grain yield to total water inflows, only the yield affected WP_{IR} in these studies.

The effect of the percent residue retention on WP in CT and RT is assessed in Table 3, although we again stress the current limitations of the dataset and therefore that these results should be treated as preliminary, and thus with the utmost caution. For the data currently available, there are slight but significant positive correlations between WP and the percent of residue retained as stubble and/or as mulch.

In contrast to Figure 3, which includes studies with and without residue, disentangling the data by applying linear regression shows that there is a tendency that increased residue retention benefits WP, although model results do not currently show a difference between CT and RT systems. The latter issue is again likely to be the result of the four studies in which water inputs were not varied. The key message from this preliminary result is that once we have built a more comprehensive database, it will be useful to separate and individually compare WP in studies with and without residue retention to see if this management factor has a broadly significant and beneficial effect on the efficiency of water use.

Outlook for database improvement and improved analyses

Far from presenting definitive results, this paper represents the first steps we have taken in a larger research project to examine yield and WP trends in conventional versus reduced tillage systems. The preliminary results indicate clear meta-analytical limitations given the papers currently included in the database. In the coming months, we plan to expand our search to include additional papers with paired systems comparisons. Other cereal crops may also be included when they are rotated with wheat, rice and/or maize as the dominant crop. Unfortunately, we may have already located the majority of the available ISI papers examining WP in CA or RT systems. For this reason, we will likely expand our search using other resources such as Google Scholar, students' theses, or reports from reputable research institutes. Additional search terms (see the footnote included with Table 1) will be included when using each of these resources.

Table 3. Correlation coefficients between grain yield, water productivity of irrigation + rainwater, and the percentage of residue retained/incorporation in conventional versus reduced tillage systems.

	Rice	Wheat	Maize
Yield			
Conventional tillage	ns	ns	Insufficient observations
Reduced tillage	ns	ns	Insufficient observations
Water productivity			
Conventional tillage	0.32**	0.26**	Insufficient observations
Reduced tillage	0.39***	0.51***	Insufficient observations

* = significant at *P*<0.05, ** = significant at *P*<0.01, *** = significant at *P*<0.001, ns = not significant.

It would also be interesting to compare irrigated with rainfed RT and CA cropping systems. The impact of residue rentention on water conservation is likely to be far greater in the former as opposed to the latter, although we expect considerable variability depending on the environment, soil texture, and so on. To this end, we plan to expand our search to include rainfed environments, using additional search terms such as "rainwater use efficiency", "precipitation use efficiency", etc. Given the data collected through the inclusion of additional papers, it may also be possible to look at different parameters relevant to the sustainability of production systems, for example by examining long-term or multi-site yield stability, production risk (by examining within-treatment coefficient of variation trends), or by applying other agronomic sustainability indices, especially where studies are broken into groups and examined by environment and/or soil texture, etc. If we are able to develop a comprehensive database considering WP in both rainfed and irrigated environments, we hope to submit a meta-analytical review paper to a high-impact journal such as *Agricultural Water Management* or *Field Crops Research*.

Finally, a key problem with the current database relates to unequal sample sizes, as evidenced by the N values presented in Figures 1 and 3. Many papers compare one or two CT treatments as a control to many more RT or CA treatments as an alternative. We plan to overcome this issue by examining yield and WP response ratios, which are calculated by taking the natural logarithm of the response ratio (log RR) for the means of all possible paired combinations of crop system treatments weighted by replicate number using Equation 2,

$$\log \mathrm{RR} = \log\left(A_{CA} / A_{CT}\right) \qquad \text{Eq. 2}$$

where *A* and *B* are either mean weighted yields or WP for CA and CT, respectively. For example, calculation of response ratios given the 11 papers in the current database would result in 108, 84 and 6 paired observations for rice, wheat, and maize, respectively. The latter crop therefore requires significant additional efforts to search the literature for more data points. After comparing response ratios, we are considering using stepwise multiple linear regression models using the continuous biophysical (for example soil texure) and management (e.g., NPK inputs, total irrigation volume applied, etc.) variables contained in the database to help explain the expected variability in yield and WP trends between systems. Our work is therefore far from complete, although this preliminary data collection and exploratory analysis has been useful in helping to identify and rectify problems with data collection for meta-analysis, thereby ameliorating future analytical problems in the present.

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Appendix 1. Select summary information of the studies currently included in the database that will be used for later response ratio comparisons.

Study	Environment	Country	N[b]	Years[c]	Treatment descriptions[d]	Crop establishment[e]	Residue retention (%)	Residue mgt.[f]	Irrigation mgt.[g]	Rotation code[h]
Bhattacharyya	Humid	India	1	Mean	RT Rice, ZT, Flat, Trad	DS	0	Removed	Flood	R-W
et al.				4	CT Rice, CT, Flat, Trad	DS	0	Removed	Flood	R-W
(2003)			1	Mean	RT Wheat, ZT, Flat, Trad	DS	0	Removed	Flood	W-R
				4	CT Wheat, CT, Flat, Trad	DS	0	Removed	Flood	W-R
Casa	Semi-	Italy	6	3	CT Maize, CT, Flat, Trad	DS	0	Removed	Sprinkler	M-S
et al.	arid				RT Maize, RT, Flat, Trad	DS	100	Incorp-mulch	Sprinkler	M-S
(2008)					RT Maize, ZT, PRB, Trad	DS	100	Stubble-mulch	Sprinkler	M-S
Gathala	Semi-	India	35	7	CT Rice, CT, Flat, Trad	TP	15	Incorporated	Flood	R-W
et al.	arid				CT Rice, CT, Flat, Trad	TP	15	Incorporated	AWD	R-W
(2003)			35	7	RT Rice, ZT, PRB, Trad	DS	15	Stubble-mulch	Furrow	R-W
					RT Rice, ZT, PRB, Trad	TP	15	Stubble-mulch	Furrow	R-W
					RT Rice, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
					RT Rice, ZT, Flat, Trad	TP	15	Stubble-mulch	Flood	R-W
					CT Wheat, CT, Flat, Trad	DS	15	Incorporated	Flood	R-W
					RT Wheat, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
					RT Wheat, ZT, PRB, Trad	DS	15	Stubble-mulch	Furrow	R-W
					RT Wheat, ZT, PRB, Trad	DS	15	Stubble-mulch	Furrow	R-W
					RT Wheat, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
					RT Wheat, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
He et al.	Arid	China	6	3	CT Wheat, CT, Flat, Trad	DS	20	Incorporated	Flood	W-W
(2003)					RT Wheat, ZT, Flat, Trad	DS	40	Stubble-mulch	Flood	W-W
					RT Wheat, ZT, PRB, Trad	DS	40	Stubble-mulch	Furrow	W-W
Jat et al.	Semi-	India	12	2	CT Rice, CT, Flat, Trad	TP	15	Incorporated	Flood	R-W
(2003)	arid				CT Rice, CT, Flat, Trad	DS	15	Incorporated	Flood	R-W
					RT Rice, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
					RT Rice, ZT, PRB, Trad	DS	15	Stubble-mulch	Furrow	R-W
			12	2	CT Rice, CT, Flat, Laser	TP	15	Incorporated	Flood	R-W
					CT Rice, CT, Flat, Laser	DS	15	Incorporated	Flood	R-W
					RT Rice, ZT, Flat, Laser	DS	15	Stubble-mulch	Flood	R-W
					RT Rice, ZT, PRB, Laser	DS	15	Stubble-mulch	Furrow	R-W
					CT Wheat, CT, Flat, Trad	DS	15	Incorporated	Flood	R-W
					RT Wheat, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
					RT Wheat, ZT, Flat, Trad	DS	15	Stubble-mulch	Flood	R-W
					RT Wheat, ZT, PRB, Trad	DS	15	Stubble-mulch	Furrow	R-W
					CT Wheat, CT, Flat, Laser	DS	15	Incorporated	Flood	R-W
					RT Wheat, ZT, Flat, Laser	DS	15	Stubble-mulch	Flood	R-W
					RT Wheat, ZT, Flat, Laser	DS	15	Stubble-mulch	Flood	R-W
					RT Wheat, ZT, PRB, Laser	DS	15	Stubble-mulch	Furrow	R-W
Jin et al.	Semi-	China	12	3	CT Maize, CT, Flat, Trad	DS	0	Removed	Flood	M-W
(2003)	arid				RT Maize, ZT, Flat, Trad	DS	50	Stubble-mulch	Flood	M-W
					RT Maize, SS, Flat, Trad[i]	DS	100	Stubble-mulch	Flood	M-W
					RT Maize, SS, Flat, Trad[j]	DS	100	Stubble-mulch	Flood	M-W
					RT Maize, ZT, Flat, Trad[j]	DS	100	Stubble-mulch	Flood	M-W
			16	Mean	CT Wheat, CT, Flat, Trad[i]	DS	0	Removed	Flood	W-M
				2	CT Wheat, CT, Flat, Trad[j]	DS	0	Removed	Flood	W-M
					CT Wheat, CT, Flat, Trad[i]	DS	100	Incorporated	Flood	W-M
					CT Wheat, CT, Flat, Trad[j]	DS	100	Incorporated	Flood	W-M
					RT Wheat, ZT, Flat, Trad	DS	0	Removed	Flood	W-M
					RT Wheat, ZT, Flat, Trad	DS	50	Stubble-mulch	Flood	W-M
					RT Wheat, SS, Flat, Trad[k]	DS	100	Stubble-mulch	Flood	W-M
					RT Wheat, SS, Flat, Trad[k]	DS	100	Stubble-mulch	Flood	W-M

Appendix 1. Select summary information cont'd....

Study	Environ-ment	Country	N[b]	Years[c]	Treatment descriptions[d]	Crop establish-ment[e]	Residue retention (%)	Residue mgt.[f]	Irrigation mgt.[g]	Rotation code[h]
Parihar et al. (2003)	Semi-arid	India	4	Mean 3	CT Wheat, CT, Flat, Trad[i]	DS	0	Removed	Flood	R-W
					CT Wheat, CT, Flat, Trad[i]	DS	0	Removed	Flood	R-W
					RT Wheat, RT, Flat, Trad	DS	0	Removed	Flood	R-W
					RT Wheat, ZT, Flat, Trad[i]	DS	0	Removed	Flood	R-W
Qin et al. (2010)	Humid	China	36	Mean 3	CT Rice, CT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					CT Rice, CT, Flat, Trad[i]	TP	100	Mulch	Flood	R-R
					CT Rice, CT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					CT Rice, CT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					CT Rice, CT, Flat, Trad[i]	TP	100	Mulch	Flood	R-R
					CT Rice, CT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					RT Rice, ZT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					RT Rice, ZT, Flat, Trad[i]	TP	100	Stubble-mulch	Flood	R-R
					RT Rice, ZT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					RT Rice, ZT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
					RT Rice, ZT, Flat, Trad[i]	TP	100	Stubble-mulch	Flood	R-R
					RT Rice, ZT, Flat, Trad[i]	TP	0	Removed	Flood	R-R
Saharawat et al. (2010)	Semi-arid	India	12	2	CT Rice, CT, Flat, Trad	TP	0	Removed	Flood	R-W
					CT Rice, CT, Flat, Trad	DRUM	0	Removed	Flood	R-W
					RT Rice, RT, Flat, Trad	TP	0	Removed	Flood	R-W
					RT Rice, ZT, Flat, Trad	TP	0	Removed	Flood	R-W
					RT Rice, ZT, Flat, Trad	DS	0	Removed	Flood	R-W
			8	2	CT Wheat, CT, Flat, Tradi	DS	0	Removed	Flood	R-W
					RT Wheat, CT, Flat, Tradi	DS	0	Removed	Flood	R-W
					RT Wheat, CT, Flat, Tradi	DS	0	Removed	Flood	R-W
					RT Wheat, CT, Flat, Tradi	DS	0	Removed	Flood	R-W
					RT Wheat, RT, Flat, Trad	DS	0	Removed	Flood	R-W
Singh et al. (2010)[k]	Semi-arid	India	1	1	CT Wheat, CT, Flat, Trad	DS	0	Removed	Flood	R-W
					RT Wheat, ZT, Flat, Trad	DS	0	Removed	Flood	R-W
Singh et al. (2010)[l]	Semi-arid	India	1	Mean 3	CT Wheat, CT, Flat, Trad	DS	0	Removed	Flood	P-W
					RT Wheat, ZT, PRB, Trad	DS	0	Removed	Furrow	P-W

[a] Arid <500 mm precipitation year^{-1}; Semi-arid = 500–1,000 mm precipitation year^{-1}; Humid <1,000 mm precipitation year^{-1}.
[b] Number of paired CA vs. CT observations available which will later be used to calculate response ratios.
[c] Number of consecutive years during which the experiment was conducted. Studies which provide mean response variables for multi-year experiments are listed as "mean" for the number of years counted.
[d] CT = Conventional Tillage; RT = Reduced Tillage; ZT = Zero Tillage; Flat = planting on flat fields; PRB = Permanent raised beds; Trad = Traditional land leveling; Laser = Land leveling by laser.
[e] DS = Direct seeding; TP = Transplanting; DRUM = Drum seeder.
[f] Management and placement of crop residues, if retained.
[g] AWD = Alternate wetting and drying.
[h] R-W = Rice-Wheat; W-R = Wheat-Rice; M-S = Maize-Soy; W-W = Wheat-Wheat; W-M = Wheat-Maize; R-R = Rice-Rice; P-W = Pigeon pea-Wheat.
[i] Interim rotation or minor experimental treatments differed, but CA treatments did not. We therefore counted them as separate treatments.
[j] Age of ZT treatment differed, and was therefore counted as two independent observations.
[k] On-farm trials; Outlook on Agriculture.
[l] On-station trials; Field Crops Research.

Appendix 2: Papers used in analysis of irrigated water productivity to date[2]

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Casa, R., and B. Lo Cascio. 2008. Soil conservation tillage effects on yield and water use efficiency on irrigated crops in Central Italy. *Journal of Agronomy and Crop Science* 194: 310–319.

Gathala, M.K., J.K. Ladha, V. Kumar, Y.S. Saharawat, V. Kumar, P. Kumar Sharma, S.K. Sharma, and H. Pathak. 2011. Tillage and crop establishment affects sustainability of South Asian rice–wheat system. *Agronomy Journal* 103: 1–11.

He, J., H.W. Li, A.D. McHugh, Z.M. Ma, X.H. Cao, Q.J. Wang, X.M. Zhang, and X.R. Zhang. 2008. Spring wheat performance and water use efficiency on permanent raised beds in arid northwest China. *Australian Journal of Soil Research* 46: 659–666.

Jat, M.L., M.K. Gathala, J.K. Ladha, Y.S. Saharawat, A.S. Jat, V. Kumar, S.K. Sharma, V. Kumar, and R. Gupta. 2009. Evaluation of precision land leveling and double zero-till systems in the rice-wheat rotation: Water use, productivity, profitability and soil physical properties. *Soil and Tillage Research* 105: 112–121.

[2] These papers comprise a preliminary list only. More data will be collected when time is more permitting.

Jin, H., W. Qingjie, L. Hogwen, L. Lijin, and G. Huanwen. 2009. Effect of alternative tillage and residue cover on yield and water use efficiency in annual double cropping system in North China Plain. *Soil and Tillage Research* 104: 198–205.

Parihar, S.S. 2004. Effect of crop-establishment method, tillage, irrigation and nitrogen on production potential of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* 49: 1–5.

Qin, J., F. Hu, D. Li, H. Li, J. Lu, and R. Yu. 2010. The effect of mulching, tillage and rotation on yield in non-flooded compared with flooded rice production. *Journal of Agronomy and Crop Science* 196: 397–406.

Saharawat, Y.S., B. Singh, R.K. Malik, J.K. Ladha, M. Gathala, M.L. Jat, and V. Kumar. 2010. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crop Research* 116: 260–267.

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Singh, V.K., B.S. Dwivedi, A.K. Shukla, and R.P. Mishra. 2010L. Permanent raised bed planting of the pigeon pea–wheat system on a Typic Ustochrept: Effects on soil fertility, yield, and water and nutrient use efficiencies. *Field Crop Research* 116: 127–139.

Chapter 2. Effect of conservation agriculture practices on the incidence of insect pests: A review of current findings

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Keywords: maize, pests, tillage, and wheat

Abstract

This paper reviews published literature on the effect of reduced tillage, rotations and cover crops on the incidence of insect pests and how this effect may differ between reduced and conventional tillage. Special emphasis has been given to maize, soybean, wheat, sorghum, and tomato. In addition, modification of crop rotations and cropping systems for reduced tillage and their effect on the incidence of insect pests were considered. In conclusion, the impact of reduced tillage practices compared to conventional practices increased or decreased the incidence of certain pests depending on the life cycle of a particular pest and particularly on the extent to which the life cycle of the pest takes place in the soil profile or soil surface. Rotations, living mulches, cover crops and strip-cropping, among other options, can interfere with pest populations by limiting dispersal, disrupting feeding, inhibiting reproduction, and enhancing mortality from predators and parasitoids.

Introduction

Conservation agriculture is gaining acceptance in many parts of the world as an alternative to conventional agriculture. Conservation agriculture is based on a series of principles that include: i) the use of minimum soil tillage; ii) the retention of adequate levels of crop residue to ensure sustainable production; and iii) the use of diversified crop rotations. Insect pest control is considered one of the major challenges to farmers in adopting conservation agriculture practices. The goal of this paper is to review published literature on the effect of reduced tillage, rotations and cover crops on the incidence of insect pests and how this effect may differ between reduced and conventional tillage.

Effect of conventional tillage on the incidence of insect pests

In conventional pest management strategies, pesticides typically constitute the first line of defense. Pesticides are followed by the cultural method of control which involves tillage, especially plowing. The plow is the most widely used form of tillage in mechanized agriculture (Stinner and House 1990). Tillage changes the physical and chemical properties of the soil, greatly altering the matrix that supports micro and macro population growth. Insects which have one or more life stages in the soil will be affected by tillage operations.

Tillage operations affect insects in three main ways: i) by killing soil insects or overwintering populations (mechanical effect); ii) by removing weeds or insect pest hosts (ecological effect); and iii) by changing the microclimate (e.g., faster warm-up of seed bed or water logging), which affects the plant growth and indirectly its susceptibility to insects (environmental effect). Lohmeyer et al. (2003) observed that the incidence of thrips was higher in tilled than in non-tilled plots. The disadvantage of the conventional pest management strategies is that the effects also affect beneficial insects through depravation of their natural habitat.

Effect of reduced tillage on the incidence of insect pests

A reduction in tillage influences different pest species in different ways, depending on their survival strategies and life cycles (Andersen 1999; Bockus and Shroyer 1998). A review of 45 investigations showed that 28% of the pest species increased with decreasing tillage, 29% showed no significant influence of tillage, and 43% decreased with decreasing levels of tillage (Stinner and House 1990). The species that spend one or more life cycle stages in the soil are the most affected by tillage.

No-tillage production systems offer several opportunities to regulate weed and pest populations. One of the biggest advantages of farming without tillage is the maintenance of plant residue on the surface of soils. The soil microclimate under residue avoids temperature extremes and maintains more uniform soil moisture which favors a wide array of organisms. These conditions lead to improvements in soil structure, tilth, nutrient holding capacity, and water-holding capacity as well as biological activity. These improvements to soil physical, chemical, and biological properties can act in a synergistic manner to create soil conditions that are more similar to that of natural ecosystems. The live and dead plant material associated with cultivating the soil with minimal disturbance favors natural suppression of weeds and pests. Generally, a more diverse biological and physical environment at the surface of soils, such as that associated with cover crops, offers opportunities for regulating and minimizing pest populations (Teasdale et al. 1998).

Specific effects of reduced tillage on incidence of insects that affect maize

The presence of residues and weeds, if they are not properly controlled, generates an environment that favors the presence and reproduction of certain insects. This has been observed for black cutworm moths, egg-laying armyworm moths, stalk borer moths, seed corn maggot, white grubs and wireworms. Residues constitute a favorable environment for these species to lay eggs and the wetter and cooler conditions associated with their presence favors increases in slug populations and in turn an increase in damage by them. On the other hand, when reduced tillage leads to delayed planting or slower germination (due to cooler soil temperatures), maize may be less susceptible to attack by first-generation corn borers and more susceptible to second-generation damage.

Specific effects of reduced tillage on incidence of insects that affect soybean

Reduced tillage favors the survival of grasshopper species that lay eggs within fields. As with maize, cooler and wetter conditions due to the presence of residues favor increases in slug populations and damage. On the other hand, since crop residues slow moisture loss the crop may be less drought-stressed than in conventional tillage, the effect of reduced tillage and residues in reducing drought stress reduces mite outbreaks.

Specific effects of reduced tillage on incidence of insects that affect wheat

Hessian fly populations show higher incidence and carry over across succeeding wheat crops where wheat stubble is not tilled and/or volunteer wheat is not controlled. Crop residues may decrease the population levels of airborne aphids.

Specific effects of reduced tillage on incidence of insects that affect sorghum

There are not many reports about grain sorghum except one study. In this study, the yield of sorghum grain was higher with no-tillage cultivated into a lupine living mulch than in all other treatments including no-tillage into rye mulch, no-tillage into rye stubble and no-tillage into lupine stubble, with no winter crop conventional tillage for a check. Since lupine is a legume and therefore fixes nitrogen in the soil, it can be argued that sorghum grown after lupine benefited from a higher N supply. Accelerated growth resulted in early sorghum flowering; thus facilitating escape of the crop from damaging midge populations.

Specific effects of reduced tillage on incidence of insects that affect tomato

Colorado potato beetle incidence occurred at a lower rate on tomatoes transplanted into hairy vetch than on those transplanted into black plastic mulch. The resulting tomato yields were significantly higher with the hairy vetch mulch treatment. These findings illustrate that a benefit of the use of legume living mulches for the production of tomatoes is greater tolerance of the crop to invasion and damage by Colorado potato beetle. An additional benefit is that soil and pesticide losses from runoff into the surrounding environment have been substantially reduced by employing a hairy vetch rather than a polyethylene mulch (Rice et al. 2001).

Modifications of crop rotations and cropping systems for reduced tillage on the incidence of insect pests

Crop rotations can satisfactorily control pests that are relatively less mobile, i.e., pests that feed on specific crops and that overwinter in the soil as eggs or partially grown larvae. By rotating to a different crop, the crop for which a certain pest is adapted to attack is replaced by a crop that is tolerant, resistant, or not attacked at all by the pest. Crop rotations can reduce the incidence of several pests, such as northern and western corn rootworm. Additional benefits of managing rootworms are reductions in insecticide use, costs, and environmental pollution.

Strip-cropping is a way to increase plant diversity and this often results in more balanced insect populations in terms of pests and beneficial insects. Mixed crop stands may make it more difficult for pests to locate their host plants.

Similarly, the response of insect pest populations to cover crops is related to herbivore insect responses to increased diversity. In a survey of the literature Altieri (1994) suggests that herbivore insect species tend to be less abundant and at the same time natural enemies of herbivores tend to be more abundant in diversified systems than in monocultures. Most reports show reduced pest incidence in more diversified cropping systems. Diversification with cover crops can provide similar reductions in pest populations. A complex of interrelated processes accounts for pest reductions in diversified systems (Trenbath 1993; Altieri 1994). Among these, specific crops can interfere with the capacity of pests to colonize hosts by imposing physical barriers, disrupting olfactory and visual cues, and creating diversions to non-crop hosts. Once pests are established in a field, cover crops can interfere with pest populations by limiting dispersal, disrupting feeding, inhibiting reproduction, and enhancing mortality from predators and parasitoids. Management systems for cover crops can be designed to limit pest populations by either disrupting pest colonization of hosts or attracting natural enemies.

Cover crop residue can affect factors that influence the biological activity of pests in soils. Residue on the surface of soil can interfere with the establishment of pests by: i) physically impeding their dispersal, ii) creating an unfavorable soil meteorological environment, or iii) releasing allelopathic substances. Cover crop and/or reduced tillage based cropping systems that increase soil organic matter and fertility can also reduce damage to crops by pests by improving the growth and vigor of crop plants. The formation of a physical barrier by cover crop residue is an important factor that can prevent the effect of insect pests such as Colorado potato beetles as well as the dispersal of pathogen spores. Residue properties such as area:mass ratio, solid volume fraction, light extinction coefficient, and decomposition rates are proposed to influence the activity of soil borne pests (Teasdale and Mohler 2000).

Conclusion

Reduced tillage practices were found to reduce the incidence of certain pests but increase others depending on the life cycle of the pests. There are very few studies to make general conclusions or develop specific management strategies for reduced tillage. Thus, one main finding of this review is the need to conduct specific research on the effect of reduced tillage on pests. It is especially important to investigate the reasons for different responses of major pests and how management strategies could be developed to reduce the incidence of pests under conservation agriculture practices.

Once pests are established in a field, rotations, living mulches, cover crops and strip-cropping, among other options, can interfere with pest populations by limiting dispersal, disrupting feeding, inhibiting reproduction, and enhancing mortality from predators and parasitoids. Management systems with cover crops in certain areas can be designed to limit pest populations by either disrupting pest colonization of hosts or attracting natural enemies. Reduced tillage based cropping systems that increase soil organic matter and fertility can also reduce damage to crops by pests by improving the growth and vigor of crop plants.

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Chapter 3. Conservation agriculture and soil compaction: A review

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Keywords: conservation agriculture, controlled traffic, soil compaction.

Abstract

Crop production depends largely on the complex interactions between dynamic and static soil properties. Soil compaction reduces rooting, infiltration, water storage, drainage, and crop growth. This paper offers suggestions on methods of alleviating soil compaction, which vary from gradual improvement using conservation tillage systems to the immediate improvement offered by sub-soiling. Additionally, producers can avoid compacting their soil by controlling the traffic. Soil degradation can be defined as a reduction in soil quality as a result of human activities. Unfortunately, vehicles are used to plant and harvest crops on the same soil that is used to produce crops. Thus there will continue to be soil compaction and an endless battle to reduce its ill effects.

Introduction

Soil compaction is a form of physical degradation resulting in densification and distortion of the soil where biological activity, porosity and permeability are reduced, strength is increased, and soil structure partly destroyed. Soil is a non-renewable resource, which needs to be sustainably managed (Kibblewhite et al. 2008). Intensive machinery use mechanical forces created by wheel traffic and inappropriate soil management leads to compaction. It is often measured as an increase in bulk density, soil strength, and porosity. For ideal plant growth soil must have a proper ratio of air and water. Although this ratio depends on soil texture, typically it is about 25% air, 25% water, and 50% solids (Ronald et al. 1992).

The ability of soil to bear a given load without compaction, or its trafficability, is dependent on soil texture, organic matter content and, primarily, on its moisture content. Shearing resistance refers to the strength of a soil's internal bonds between mineral and organic components and its ability to withstand external forces without breaking these bonds. If these bonds break, the resulting structural deformation reduces soil porosity and increases bulk density. When soil is compacted, the external pressure on soil structure has overcome its shearing resistance.

In compaction management, controlled field traffic is of great importance and conservation agriculture (CA) assists with controlling traffic (RWC-CIMMYT 2008). The three key principles of CA are permanent residue soil cover (30% or more), minimal soil disturbance, and crop rotations (Hobbs et al. 2008; Reeder 2000). Reduced tillage practices are increasing worldwide (El Titi 2003) due to their benefits on soil and water conservation (Holland 2004; Vogeler et al. 2006), as well as their reduced requirement for fuel, equipment and labor (Derpsch 2005). This review provides information on the effects of CA to soil compaction.

Mechanical properties of soils

Mechanical resistance is described by the compression characteristics that show the relationship between stress applied on a soil sample and volumetric parameters such as strain, void ratio or porosity. Compression curves mainly depend on bulk density, water content, texture, and organic carbon; these physical properties being closely related. The close relationship between these parameters and the diversity of experimental settings account in part, for the contradictory results found in the literature concerning the impact of water content on mechanical properties (Cui et al. 2010). Variation in mechanical resistance has been linked to dry bulk density and initial water content using measurements in remolded soil samples (Saffih-Hdadi et al. 2009).

Soil water content and soil structure

Soil moisture is influenced by the structure of the soil. The relationship between soil structure, described by the bulk density, and water content strongly depends both on the matric potential and on soil texture (Bruand et al. 2004; Groenevelt and Grant 2004; Hill and Sumner 1967; Schofield 1935). Soil water content is the most important factor influencing soil compaction (Hamza and Anderson 2005). An increase in soil moisture increases soil compaction.

Modern agricultural equipment such as 4WD tracked equipment allows operations in extremely wet soil conditions. The best strategy to minimize compaction is to avoid working wet soils (Ronald et al. 1992). On the other hand, controlled traffic allows for planting and harvesting at any time whilst minimizing potential yield losses from compaction. There are a number of interactions between tillage operations and soil compaction. Compaction is directly affected by field machine weight, tire size and tire inflation pressure. Increased use of flotation tires has encouraged field operation when soil is normally too wet to support machines, however, this also encourages deep compaction.

Effects of compaction

Bulk density, porosity and water retention capacity are usually recognized as important indicators of soil quality. Some farming applications can influence these soil physical properties. McGarry (2001) identified this as the most serious environmental problem caused by conventional agriculture. Compaction directly affects several physical soil properties. Bulk density increases due to a decrease in the number and volume of large soil pores, which in turn alters aeration, infiltration, and hydraulic conductivity.

Porosity and bulk density

Compaction reduces soil porosity, which is the ratio of pore space, or voids, to solid material in the soil. When compaction stresses exceed the soil strength, it results in compression of the air filled pore space because the mineral and organic particles and the liquid fraction are essentially incompressible (Hillel 1980). Compaction primarily destroys large diameter pores, made up of biopores (worm or other boring animal channels) and voids between soil aggregates. These large pores, also called macropores, are important for the internal drainage of water through the soil profile. As soil density increases, the number of large and non-regular pores decreases. Aerobic microbial activity decreases with less than about 25% air filled porosity. Larger pores are often filled with air rather than water; a reduction in pore sizes may lessen the ability of roots to obtain oxygen from the air above (Linn and Doran 1984). If microbes are sensitive to lower aeration, reduced nutrient mineralization or losses from denitrification may result in fertility problems.

No-tillage and reduced tillage systems generally result in greater bulk density and smaller soil porosity (Mahboubi et al. 1993; Hill 1990; Dam et al. 2005; Kravchenko et al. 2006). However, opposite conclusions from those previously presented can be found in the literature. For example, other studies have reported that no-tillage resulted in lower or no change in bulk density (Dao 1993; Blevins et al. 1994; Fausey et al. 1994; Arshad et al. 1999; Mahboubi et al. 1993) and lower soil water content (Wilkins et al. 2002; Hammel et al. 1981).

Hydraulic conductivity

Soil hydraulic properties are related to water storage or movement (Jury et al. 1991). By changing the shape, size and continuity of pores, compaction alters the water conductivity of soil. Poor internal drainage can reduce water movement to roots and increase surface water runoff. The results can be reduced plant growth and increased soil erosion. Increased organic matter may also lead to an increased amount of water in the soil profile that is available for crop use during the growing season (Hudson 1994).

Root growth and distribution

Compaction alters soil pore structure, reducing the number, size and continuity of the pores through which plant roots can grow. This also reduces the space where roots can displace soil material into as they elongate and expand with growth. Soil compaction, then, can affect a plant's ability to extend its roots throughout the soil and, as such, reduce the area of soil a root can utilize to absorb water and nutrients. Factors that limit the root's ability to supply water and nutrients will affect plant growth and yield. At higher levels of soil strength, roots are more sensitive to moisture deficits (Davis 1984). Dryness was the main factor impeding root growth, since the resistance diminished with rain or irrigation. The critical value of soil resistance at which plant roots will not elongate is affected by soil moisture and the stage of plant development.

For producers, the main concern with soil compaction is its impact on yields and soil productivity. Reduction in grain yield also means reduction in dry matter production and ultimately, the amount of crop residue left on the soil surface after harvest. Poor plant growth caused by compaction is due to the negative impact on soil moisture and air availability to the root system. It has been reported that compacted fields may experience yield losses in some years. The impact of compaction on yield and residue cover may not be observed some years, when favorable growth conditions such as moisture availability, timing of high rainfall, and fertilizer use can mask its effects for that particular growing season. On the other hand, if good growing conditions exist but plant productivity is not great, there is a need to investigate soil compaction as a potential culprit.

Solutions

Natural processes

Natural processes, such as freezing and thawing or wetting and drying can do much to alleviate compacted soils. Effects of compaction are usually less permanent in clay soils than in medium and coarse textured soils. Compaction can be alleviated by the shrinking and swelling forces associated with wetting and drying cycles of clay soils. Some soils may alleviate compaction in a few days, others may take months. Plant roots can also alleviate compaction (Byrnes et al. 1982) by growth through compacted zones and subsequent decay. Plant roots move particles, create new pores, expand fine pores, leave voids and add organic matter that stabilizes the remaining structural aggregates.

Management practices that reduce soil compaction

Reduction in mechanized operation

Typically, several passes with agricultural vehicles are necessary, including: initial primary tillage, secondary tillage, potential additional secondary tillage, planting, repeated spraying or cultivation operations throughout the growing season, and harvest. As much as 70% of a field is reportedly trafficked by vehicles in a conventional tillage system (Cooper et al. 1969). A conservation tillage system can reduce the need for vehicle traffic in the field because there are fewer needs for tillage or cultivation operations. Reduced tillage is also an important measure to prevent biological and physical soil degradation (Siegrist et al. 1998). Often the only passes necessary for crop production using conservation tillage systems are planting, spraying (if necessary), harvesting, and cover crop establishment. The opportunities for soil compaction are reduced as less intensive vehicle trafficking is required.

According to Shaver et al. (2002), no-tillage cropping systems that produce more biomass and return more residue to the soil surface have: decreased bulk density; increased porosity; increased sorptivity; increased overall soil aggregate size distribution, and; improved overall system water capture and storage.

Previous studies generally indicate that no-tillage and reduced tillage systems increase soil water content (Standford et al. 1973; Diaz-Zorita et al. 2004), enhance soil aggregation and stability (Arshad et al. 1999; Hobbs 2007), and increase penetration resistance (Mahboubi et al. 1993; Hill 1990). Other researchers found soil strength was increased in transitioning from intensive tillage to no-tillage (Wilkins et al. 2002; Larney and Kladivko 1989).

Controlled traffic

Controlled traffic is a system to reduce compaction by limiting compaction to designated areas of the field and CA allows for controlled traffic. It means spacing all vehicle wheels in the field to run along the center between rows, and then planting in the same row positions year after year. A main advantage of a consistent operating width for all equipment is that tire spacing is set to minimize the number of trafficked row middles and eliminates compaction. Any increased soil compaction found in conservation tillage systems may only be temporary, may not adversely affect crop yields, and may have increased infiltration and reduced runoff.

Soil organic matter can be influential in decreasing soil compaction. Additional field traffic required by intensive tillage compounds the problem by breaking down soil structure. The combined physical and biological benefits of soil organic matter can minimize the effect of traffic compaction and result in improved soil tilth (Reicosky 2001). Increased soil organic matter, commonly present in conservation tillage systems, may lead to reduced effects of soil compaction (Thomas et al. 1996).

Planting deep rooting crops and placement of fertilizer

The root system acts as a bridge between the crop management and plant growth responses (Klepper 1990). Root growth and development are affected by soil strength, if compaction restricts a plant's ability to utilize soil nutrients by reducing the soil volume utilized by roots, placing additional fertilizer in a compacted soil may allow the limited root system to draw adequate nutrients because of higher nutrient concentration in a smaller volume of soil. The root diameters may be indicative of the effect of soil strength on root growth and affect the utilization of nutrients in the soil. Sidiras et al. (2001) reported thicker barley roots under conventional tillage compared with no-tillage.

Some researchers have examined the effect of placement of fertilizer in a band to increased nutrient concentration near the plant roots of plants growing in compacted soil, and as such, increased availability. A study by Vasey and Barber (1963) suggested that banding would have a bigger effect on potassium uptake than phosphorous. Hallmark and Barber (1981) demonstrated that increasing soil potassium helped to overcome many of the detrimental effects of compacted soil. Similarly, Wilkins (1976) added hormones to plants growing in compacted soil and showed that the addition of 3,5-di-iodo-4-hydroxybenzoic acid (DIHB) would improve the root development of pea seedlings in compacted soils. Root length was increased substantially with small increases in the dry weight of the shoot and root. Alejar (1980) found that the low concentrations of ioxynil or 2,4-D significantly increased the root growth of wheat and barley seedlings.

Effects of conservation agriculture and soil compaction

Porosity and bulk density

No-tillage often results in a higher bulk density and strength of the soil, on the other hand, no-tillage results in a better soil structure and an extensive system of macropores, which benefit root growth (Martino and Shaykewich 1994). One of the goals of tillage is to reduce soil bulk density and consequently increase porosity. However, the effect of tillage on bulk density is temporary and following tillage the soil rapidly settles and returns to its former bulk density (Hernanz and Girón 1988). Past experiments comparing no-tillage with conventional tillage have shown different results, however, most of them showed that bulk density was higher in no-tillage in the first 5–10 cm of soil (Ehlers et al. 1983). A second group showed no differences in bulk density between the two tillage systems (Logsdon and Cambardella 2000). However, Crovetto (1998) showed that soil bulk density decreased with no-tillage because of increased amounts of soil organic matter. In general, the differences between bulk densities become smaller with increasing time. In some soils, porosity under no-tillage decreased compared to conventional tillage in the first few years until the soil recovered its natural structure (Kinsella 1995). Ait Cherki (2000) did not find a significant increase in dry bulk density under no-tillage systems compared to conventional tillage after 6 years of experiments in semi-arid Morocco (Table 1). It is also important to note that after 6 years the no-tillage system had lower soil bulk density at the plow pan zone.

Table 1. Tillage effect on bulk density (Mg m^{-3}) after 4 and 6 years of experimentation (Ait Cherki 2000; Mrabet 2006).

	After 4 years		After 6 years	
Soil depth	0–8 cm	8–16 cm	0–8 cm	8–16 cm
Direct seeding	1.56a	1.54a	1.26a	1.29a
Conventional tillage	1.45b	1.54a	1.23a	1.32a
Average	1.51	1.54	1.25	1.31

In each column, values followed by the same letter are not significantly different at P = 0.05 (LSD).

Martino and Shaykewich (1994) did not observe any differences in the Souris loamy sand environment (Table 2). Lack of differences in these two soils may well have been due to the short timeframe (3 years) in which the tillage treatments were imposed on the Fortier silty clay loam. Porosity tended to be lower, and water content higher, under zero tillage than under conventional tillage. Despite lower porosity, zero tillage had a higher proportion of pores in the size class between 300 and 1,000 m than did conventional tillage (Table 3).

According to Cassaro et al. (2011), soils under CT have greatly reduced macroporosity to larger depths as compared to soil from the surface (0–10 cm). Meanwhile, micro and also macroporosity of the soil under no-tillage was not importantly altered when different depths were compared.

Aggregate stability

Conservation agriculture (no-till with residue and crop rotation management), can play a major role in managing soil moisture conditions. If no-tillage is used without residue retention and crop rotation, it

Table 2. Topsoil (0–15 cm) bulk density, total porosity and volumetric water content at the four-leaf crop stage (Martino and Shaykewich 1994).

		Marquette C		Fortier silty clay loam		Souris loamy sand	
	Year	CT	ZT	CT	ZT	CT	ZT
Bulk density (Mg m^{-3})	1989	0.87	0.88	1.00b	1.09a	1.47a	1.45a
	1990	0.88	0.92	1.06a	1.12a	1.44a	1.41a
Porosity (%)	1989	67	67	60a	57b	43a	44a
	1990	67	65	58a	56a	45a	46a
Water content (% vol/vol)	1989	33	33	36a	38a	11a	11a
	1990	36	38	32b	37a	17a	16a

CT = conventional tillage, ZT = zero tillage. Means followed by the same or no letter within each year and site did not differ significantly (P<0.05).

can be more harmful to agro-ecosystem productivity and resource quality than conventional practices (Sayre 2000; Wall 1999). In semi-arid and rainfed areas of central Mexico, positive effects were observed with no-tillage and crop rotation with residue retention compared with common farming practices (Govaerts et al. 2007). Crop residues on the soil surface form a barrier to water loss by evaporation, increasing the amount of moisture stored in the root zone. Field research has shown higher moisture levels, decreased soil temperatures and more stable soil aggregates (improved soil structure) under no-tillage compared to conventional tillage (Carter 1992). Water infiltration and soil moisture levels were greater under no-tillage with residue compared to without. Higher infiltration rates and favorable moisture dynamics supported a yield increase of up to 30% (Govaerts et al. 2007). Differences between tilled and untilled soil in terms of retention of water by the soil are shown in Figure 1. Most remarkable is the observation that soil water tensions were affected by tillage system in all ranges. In the untilled soil, the soil water retention remained at a higher level.

Crop residues on the soil surface create tiny dams which enhance infiltration, reduce surface crust formation, and slow water runoff, which increases water infiltration and soil moisture (Edwards 1995). Continuous no-tillage improves soil structure by increasing soil particle aggregation, which aid water movement through the soil so plants expend less energy to establish roots (Mrabet 2006). No-tillage practices increased rain infiltration and minimized runoff which are important to increase water use efficiency (Ruan et al. 2001).

Root growth and distribution

Conservation tillage and no-tillage can utilize natural processes to alleviate compaction. Continuous pore systems, such as those left by earthworms or decaying plant roots, which are oriented parallel to compaction forces in the soil profile will help roots cross limited compacted layers (Sommer 1988; Trousse 1971). These pores are more predominant in soil where tillage has been significantly reduced. Wulfsohn et al. (1996) showed that roots in a no-tillage system accumulated largely in the 0–5 cm profile when compared to conventional tillage. Chan and Mead (1992) showed that the opposite occurred in the lower layers. The root diameters may be indicative of the effect of soil strength on root growth and affect the utilization of nutrients in the soil. In well-structured soils or those in which biochannels are preserved (as in non-tilled soils), roots continue to extend even with increased soil resistance because they can grow in the inter-aggregate spaces (Ehlers et al. 1983).

Conclusion

Compaction caused by traffic results in degradation of soil structure with possible agronomic and environmental consequences. On the other hand, no-till systems have a great impact on soil structure and can improve their mechanical resistance. Soil compaction can be a serious problem for farmers, however, with proper management, compaction can be minimized. It is possible to avoid harmful soil compaction and sustain soil functions by means of precautions using soil mechanical concepts that compare soil stresses with means for the bearing capacity.

No-till and conservation tillage affect the physico-

Table 3. Pore size distribution at l0 cm depth in samples taken at the mid-tillering crop stage (Martino and Shaykewich 1994).

Pore size sand class (µm)	Marquette C		Fortier silty clay loam		Souris loamy	
	CT	ZT	CT	ZT	CT	ZT
>1,000	3.7	3.6	0.8a	0.8a	3.0a	4.5a
300–1,000	2.6	2.5	0.6b	2.0a	1.5a	1.3a
110–300	2.8	3.5	1.3a	1.8a	2.5a	2.7a
40–110	8.6	9.4	2.0a	2.0a	13.0a	13.2a

CT = conventional tillage, ZT= zero tillage. Means followed by the same or no letter within each year and site did not differ significantly (P<0.05).

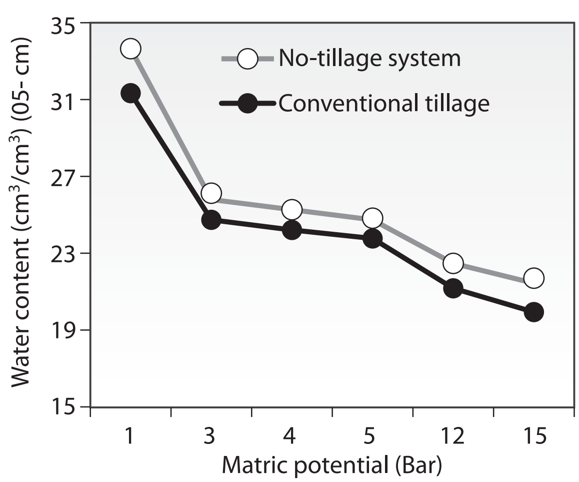

Figure 1. Water retention curve as affected by the tillage system (Ait Cherki 2000; Mrabet 2006).

chemical properties of soils such as bulk density, aggregation, hydraulic conductivity, pH, and organic content. However, the effect on soil health is still unclear, with sometimes contradictory effects being reported (Alvarez and Steinbach 2009; Strudley et al. 2008). Adoption of conservation tillage practices may, in principle, be a viable means for improving profitability and reducing energy use, and improving soil quality in production systems (Yancy 1996). In their many and varied forms, conservation tillage systems aim to reduce primary tillage operations such as plowing, ripping, disking and chiseling. As a result of this deliberate reduction in tractor operations, surface residues accumulate and must be managed.

The lesson to learn from such problems is to pay attention to the field conditions and make correct decisions on when to enter the field and whether the soil conditions are ready to till or plant. If traffic could be controlled so that wheels for all field machines used the same tracks compaction could be limited to a small portion of the field and the effect on plants would be minimized. Unnecessary tillage operations can be eliminated by using CA.

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Chapter 4. Potential benefits of resource conserving agricultural management practices for wheat production in Pakistan

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Keywords: bed planting, laser leveling, Pakistan, relay cropping, water savings, and zero tillage

Abstract

Pakistan depends on agricultural production and about 90% of production is achieved by irrigated areas. Wheat is a staple food in the country and is therefore most important in the context of food security. Changing climate, receding per capita water and land availability due to the increasing pressure of population, deficit in irrigation water supplies during the wheat season, and the increasing cost of fuel are among the factors which will increase the future demands on wheat to feed the nation. A conventional wheat production system will no longer be the right choice in the future. Keeping in view the 2020 scenario of wheat production demand, on the basis of literature related to Pakistan and farmer inputs, some conservation agriculture (CA) based systems for wheat production were compared with conventional systems for their potential benefits. The results showed that we can save 8.6 million-acre feet (MAF) of irrigation water, obtain a yield edge of 2.3 million tons, save 175.9 million liters of fuel and can reduce CO_2 emissions to the environment by 0.483 million tons. It is concluded that CA based systems for wheat production should be adopted to face the challenging future.

Introduction

Agronomic issues

Wheat is a staple food in Pakistan, being grown on an area of 9.04 million ha with a production of 23.86 million tons (Economic Survey of Pakistan, 2009–2010). In Pakistan, wheat is grown in different cropping systems, of these, cotton–wheat and rice–wheat systems together account for about 60% of the total wheat area.

The major reasons for low productivity and instability include: delayed harvesting of kharif crops (summer sown) like cotton, sugarcane and rice, and consequently the late planting of wheat, the non-availability of improved inputs like seed, inefficient fertilizer use, weed infestation, shortage of irrigation water, drought in rainfed and terminal heat stress, soil degradation, and inefficient extension services. Moreover, farmers are not aware of modern technologies because of weak extension service systems.

Resource scarcity

Pakistan, being an agricultural country, is facing complex problems. The country is facing receding per capita water and land availability as the population is increasing and has currently crossed 170 million. In 2020, at a medium rate of population growth, this number will touch 226 million (Economic Survey of Pakistan, 2009–2010). To nourish the people at the end of the second decade of this challenging century, 30 million tons of wheat will be required. To keep pace with the growing population pressure, food production, especially wheat as it is the staple food, needs to be maximized. Fuel costs are on the increase (Punjab Development Economics 2009–2010) and canal water supplies during the wheat growing season are not matching the requirements for good wheat production (Rosegrant et al. 2008). According to the 4th International Plant Protection Committee (IPCC) report, cereal yield could decrease by 30% by 2050 in South Asia along with the decline of gross per capita water availability for South Asia from 1,820 m^3 in 2001 to 1,140 m^3 in 2050. Almost all the models predict that climate change will place stress on wheat yields in the South Asia region (Janjua et al. 2012). The amount of water per hectare available for crop irrigation from canals has decreased. Sustainable agricultural practices could be used to meet the accelerated growth targets with reduced energy demand. Fifty percent of the average potential of food crops must be exploited to cater for human food requirements and curtail the supply of water and addition of more land, in addition to striving for high yielding crop varieties. […][1] Ahmad and Mehmood (2005) have suggested that bed planting should be adopted across all of the country to increase wheat yield and save irrigation water.

Potential for resource savings

There are many problems with the current conventional wheat production systems in Pakistan and there is much potential for improvement. […]. Conventionally, farmers use five plowings, three diskings and three plankings for fine seed bed preparation (Mann et al. 2008). We have used 20% water saving for laser land leveling (conservative value). It was taken into account that, on average, farmers in Pakistan use 21.7 L of diesel/acre in land preparation operations (disking, plowing, planking, rotavator usage etc). This accounts for 58.59 kg of CO_2 emissions as each liter of diesel consumption equals 2.7 kg CO_2 emission (http://timeforchange.org/what-is-a-carbon-footprint-definition).

It seems very difficult to attain the required production of wheat in a scenario of increasing temperature, late planting, increasing fuel costs and decreasing irrigation supplies. However, resource-saving practices such as laser land leveling, zero tillage, bed planting and relay cropping may offer some solutions to improve yields and resource use efficiency in wheat production systems in Pakistan.

The objectives of this paper were to (1) review the potential benefits of using resource saving agronomic practices, and (2) demonstrate the potential of resource saving agronomic practices for wheat production to benefit in Pakistan in terms of savings of fuel, water, environment and production costs.

Methodology

The below methodology keeps in view the 2020 scenario for wheat demand and focuses on research publications from Pakistan, or related to Pakistan, to make some projections for 2020.

Proposed assumptions for 2020

The following adoption rates of resource conserving technologies were assumed:

a) Adoption of precision land leveling to 50% of total wheat area in 2020
b) Adoption of zero tillage planting of wheat to 50% of area planted after rice
c) Adoption of bed planting to 50% of total wheat area
d) Adoption of relay cropping of wheat in standing cotton to 50% of area planted after cotton

Review of benefits of selected resource conserving technologies

Data relevant to wheat production systems of Pakistan were collected on the following resource conserving agronomic management practices:

a) Precision land leveling
- Water saving

b) Zero tillage planting of wheat after rice
- Irrigation water saving
- Fuel saving (due to elimination of land preparation operations)
- Reduction of (greenhouse gases; GHGs) CO_2 emissions
- Yield

c) Bed planting
- Irrigation water saving

d) Relay cropping of wheat in standing cotton
- Fuel saving (due to elimination of land preparation operations)
- Reduction of (GHGs) CO_2 emissions
- Yield

Results and discussion

Resource saving agronomic practices

Relevant data collected on the selected resource conserving agronomic management practices for wheat production systems of Pakistan are summarized in Table 1.

Surface seeding or relay cropping benefits

Surface seeding gives significantly higher yield than that of the farmers' practice and the cost of land preparation is zero (Hobbs et al. 1997). Relaying wheat by surface seeding produced 69% higher yields than wheat sown after cotton harvesting (Khan and Khaliq 2005).

Zero tillage benefits

Grace et al. (2003) reported savings of up to 98 L of diesel/hectare by using zero tillage practices. […]

[1] Some of the text had to be deleted since cited references were missing from the reference list. This will be indicated with […] throughout the text.

Benefits of bed planting

[…] Ahmad and Mahmood (2005) reported a saving of 40–50% irrigation water in bed planting compared to traditional flood irrigation and a 10–25% yield increase using bed planting rather than flat sowing. Permanent raised beds demonstrated 13%, 36% and 50% higher grain yield, water saving and water productivity, respectively, for the wheat crop. District farmers' experience with raised beds demonstrated similar results, with 34% water saving and 19% higher yields for wheat (Hassan et al. 2005). According to Gill et al. (2005) sowing of wheat on beds reduces irrigation water by 50%.

Projections of potential resource savings for Pakistan

Based on the current literature relevant to Pakistan (Table 1) the following values were used to project potential resource savings based on a 50% adoption rate:

- We have used 20% water saving due to precision land leveling
- We have used yield increases of 30% (due to timely planting) and all fuel saving for land preparation (21.7 L per acre = 53 L per ha) for relay cropping in standing cotton (most conservative values)
- We have used 10% water saving, 15% yield increase (due to timely planting) and fuel saving of 21.7 L per acre (53 L per ha) for zero tillage wheat after rice (conservative value)
- We have used 30% water saving for bed planting in wheat (conservative value)

Precision leveling

If precision leveling is adopted on 50% of total wheat area by 2020, we may save 3.25 MAF of precious irrigation water (Fig. 1).

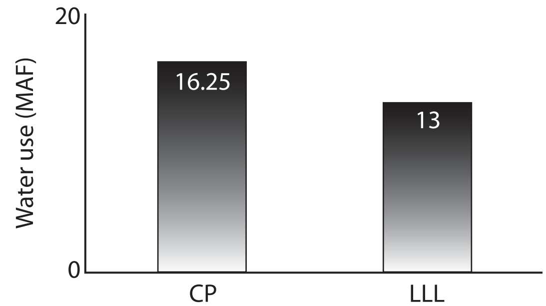

Figure 1. Water consumption (MAF) by laser land leveling (LLL) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the total wheat production area.

Zero tillage in wheat after rice

a) Water saving
   Adoption of zero tillage planting of wheat on 50% area coming after rice, 0.52 MAF of water can be saved because of residual moisture use (Figure 2).

b) Fuel saving
   For the same area, 84.6 million liters of fuel can be saved because of elimination of land preparation operations (Figure 3).

Table 1. The benefits of selected resource saving agronomic practices for wheat production in terms of water and fuel savings and yield improvements **(laser land leveling, LLL; zero tillage, ZT; bed planting and relay cropping).**

Practice	Source	Water saving (%)	Fuel saving (% or Liters)	Yield (%)
LLL	[…]			
ZT	(Grace et al. 2003)		98 L	
	[…]			
	(Mann et al. 2008)	22	53.3 L (78 %)	7
	(Iqbal et al. 2012)			7
Bed planting	[…]			
	(bed planting in rice–wheat systems)	30		20
	(Ahmad and Mahmood 2005)	40–50		10–25
	(Hassan et al. 2005)	34–36		13–19
	(Gill et al. 2005)	50		
	(Akbar et al. 2009)	7–38		4–14
	(Akbar et al. 2007)	10–36		6
	(Mollah et al. 2009)	41–48		21
	(Akbar et al. 2010)	3–22		15
Relay cropping in cotton	(Khan and Khaliq 2005)			69

c) Reduction in CO_2 emission
Due to elimination of land preparation operations, 0.23 million tons of CO_2 emissions to the environment can be avoided by adopting zero tillage (Figure 4).

d) Yield
Early/timely planting by zero tillage would add 0.73 million tons of grain to the production of the subject area (Figure 5).

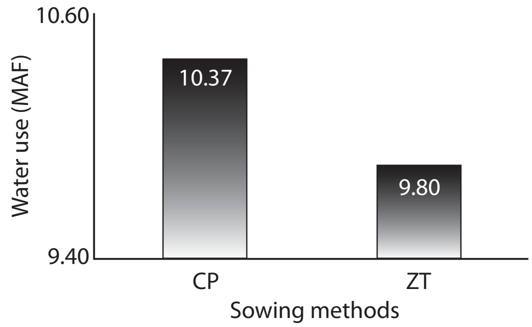

Figure 2. Water consumption (MAF) by zero tillage (ZT) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat after rice area.

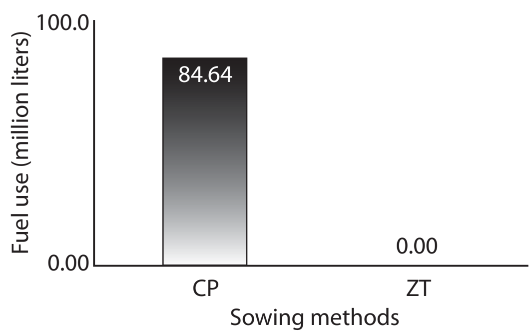

Figure 3. Projected fuel consumption during land preparation for Pakistan by zero tillage (ZT) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat after rice area.

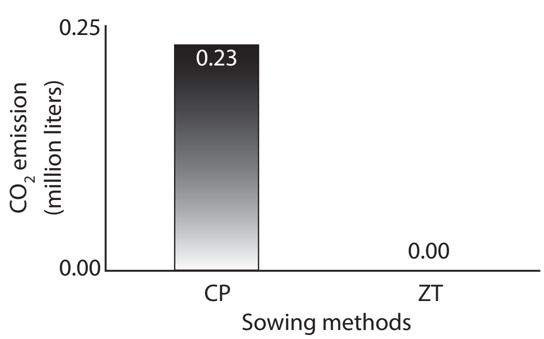

Figure 4. The CO_2 emissions from land preparation in Pakistan of zero tillage (ZT) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat after rice area.

Bed planting
Adoption of bed planting on 50% of the total wheat area will reduce the consumption of irrigation water and a saving of 4.88 MAF of irrigation water can be achieved (Figure 6).

Relay cropping of wheat in standing cotton
a) Fuel saving
Adoption of relay cropping of wheat on 50% of the area sown to cotton would save 91.3 million liters of fuel as no land preparation would be needed (Figure 7).

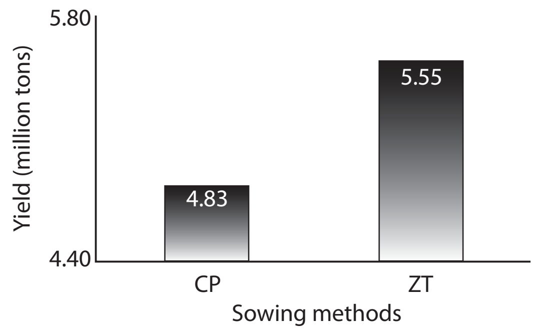

Figure 5. Projected wheat yield for Pakistan in zero tillage (ZT) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat after rice area.

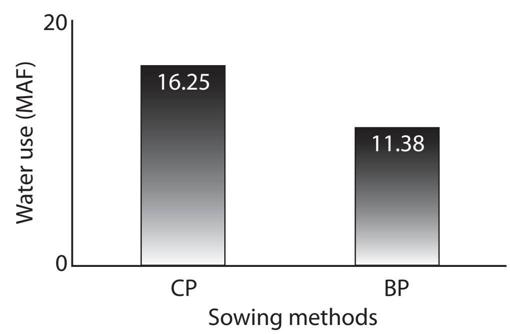

Figure 6. Water consumption (MAF) by bed planting (BP) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the total wheat area.

b) Reduction in CO_2 emissions
Due to elimination of land preparation operations, 0.25 million tons of CO_2 emissions to the environment could be avoided by adopting relay cropping (Figure 8).

c) Yield edge
1.58 million tons of extra grain from the same land could be attained from early/timely planting and better use of nitrogen fertilizer (Figure 9).

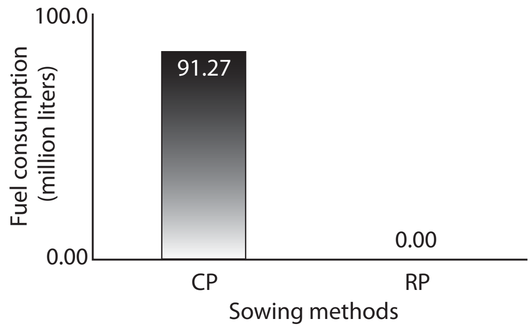

Figure 7. Projected fuel consumption during land preparation for Pakistan by relay cropping (RP) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat planted after cotton.

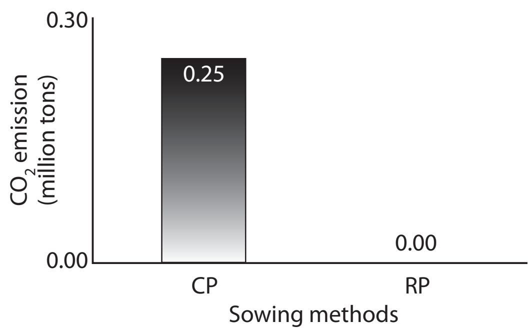

Figure 8. The CO_2 emissions from land preparation in Pakistan of relay cropping (RP) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat planted after cotton.

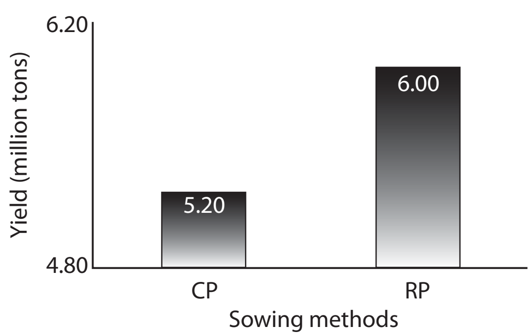

Figure 9. Projected wheat yield for Pakistan in relay cropping (RP) vs. the conventional practice (CP) based on a projected adoption rate of 50% of the wheat planted after cotton.

Conclusion

The results from these preliminary projections suggest that we can save 8.6 MAF of irrigation water which can help to overcome the shortage of water during the wheat growing season. A yield increase of 2.3 million tons will increase the availability of food to the ever increasing population. By the proposed adoptions we can reduce the use of fuel by 175.9 million liters which would result in a saving of 12.31 billion PKR. With the aid of such adoptions we can save our lovely planet by reducing CO_2 emissions to the environment by 0.483 million tons, thus helping minimize the introduction of GHGs into the atmosphere. The adoption of the agronomic practices discussed in this paper may not provide the whole solution to the changing environment, but based on the projected 50% adoption rate the situation can be improved dramatically.

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Chapter 5. Potential of raised bed planting to increase irrigation efficiency of wheat in the Yellow River Ningxia Valley

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Keywords: bed planting system, conventional planting system, Ningxia Valley, wheat, and Yellow River

Abstract

Planting wheat in raised beds is a promising option to increase water use efficiency in the Yellow River Ningxia Valley (YRNV). This study was conducted to: i) investigate if planting wheat on raised beds can increase irrigation water use efficiency; ii) to study the effect of raised beds on the yield and yield components of wheat (Triticum aestivum L.); iii) to identify higher yielding genotypes to be grown in raised beds, and; iv) to determine optimal bed planting methodology in the YRNV. Trials were conducted in two cropping seasons with spring and winter wheat to assess the effects of planting system (conventional practice vs. raised beds), seed rate (200, 230, and 260 kg ha^{-1}), the combination of bed width and number of rows (0.80 m with three rows, 0.65 m with 2 rows, and 0.65 m with three rows), and wheat genotypes (nine spring and five winter wheat lines) on grain yield. Wheat in raised beds attained similar yields as wheat cultivated under conventional practice but with the application of 14 to 29% less irrigation in each of the two years. Seed rate, the combination of bed width and number of rows, and genotypes were found to have significant effects on winter and spring wheat yield in raised beds. This study indicates that planting wheat in beds is a feasible option for increasing irrigation efficiency in the YRNV and that there are wheat genotypes with higher grain yield potential in raised beds.

Introduction

China is the most populated nation and the largest food producer and consumer in the world. Traditional farming systems in China are characterized by removal or burning of crop residues. Residue removal, together with agricultural intensification, has led to severe soil degradation. In addition to soil degradation, water is becoming the most limiting factor for Chinese agricultural development (McHugh et al. 2006).

Water limitation makes wheat (*Triticum aestivum* L.) production in the Yellow River Ningxia Valley (YRNV) highly dependent on irrigation. Wheat is the major crop in terms of planted area and output in this area. Current wheat management practice is threatened by increasing competition for ever-scarce water resources combined with the continued use by most farmers of highly inefficient irrigation systems. Raised beds have become an option in many irrigated areas to increase water use efficiency (WUE) with the additional potential to increase grain yields by, for example, escaping end of season drought (Borrel et al. 1998). Hobbs et al. (1998) identified the following advantages of raised beds: i) improved water distribution and efficiency; ii) reduced impact of excess water from rainfall; iii) reduced lodging risks; iv) more efficient fertilizer application and weed control, and; v) reductions in seeding rates. Although raised beds with furrow irrigation are recognized as a promising technique to improve water management in the region; currently almost all irrigated wheat is planted in narrow spaced rows on the flat and irrigated by flood irrigation within bordered basins (Wang et al. 2004). We hypothesize that adoption of this technique by local farmers is hindered by the lack of information on optimal cultivars and planting methods for raised beds.

The objectives of this study were: i) to investigate if planting wheat on raised beds can increase irrigation water use efficiency; ii) to study the effect of raised beds on the yield and yield components of wheat; iii) to identify higher yielding genotypes to be grown in raised beds; and iv) to determine optimal bed planting methodology in the YRNV.

Materials and methods

Experimental site

The study was conducted at the experimental station of the Crop Research Institute, Ningxia Academy of Agriculture and Forestry Science (38°N 106°E, 1120 m.a.s.l.). The station has an annual mean precipitation of 201.4 mm, of which approximately 62.2% falls from June to September. During the study, annual rainfalls were 89.2 and 78.3 mm in the 2003/04 and 2004/05 wheat season, respectively. The soil was a cumulic clay with light alkaline pH (7.2) and contained 1.51% organic matter, 28.2 mg kg^{-1} available P, 107 mg kg^{-1} K, and 11.9 mg kg^{-1} N.

Cropping and treatment

For this study a set of three different types of experiments were conducted (Table 1). Raised beds of 0.15 m height were made using a planter developed for raised beds (Wannongda machine company, Shandong, China). Except in Experiment III, space between rows in the raised beds was 0.15 m. In the 2003/04 season, winter wheat was planted on 26 September 2003 and was harvested on 27 June 2004 while corresponding stages of spring wheat were 6 March and 10 July in 2004. In the 2004/05 season, corresponding dates were 26 September 2004, 29 June, 13 March, and 15 July, 2005, respectively.

Experiment I: Effect of planting system on the amount of irrigation water and soil physical properties.

Spring wheat and winter wheat were grown in raised beds and conventional planting systems for 2 years during 2003/04 and 2004/05. The spacing from furrow to furrow (bed width) was 0.80 m with three rows of wheat in each bed. The spring and winter wheat genotypes, 04A5007 and Ningdong 10, respectively, were used in this experiment.

Winter wheat was irrigated three times (at jointing, heading and grain-filling stages) while spring wheat was irrigated two times (at jointing and heading stages) in 2003/04 and three times at the same stages as winter wheat in 2004/05.

Experiment II: Effect of planting system and genotypes on grain yield and yield components

This experiment was conducted in 2003/04. Nine spring and five winter wheat genotypes were planted in both raised beds and a conventional system. Seed rate of these cultivars and advanced lines was 230 kg ha^{-1}. The raised beds were 0.80 m wide with three rows of wheat. Plot areas were 16.0 m^2 and 3.6 m^2 for winter wheat and spring wheat, respectively. The experimental design was a split-plot with three replications. Planting methods (bed and flat) were the main plots and varieties were the sub plots.

Experiment III: Effect of bed type and seed rate on wheat yield and yield components.

This experiment was conducted in 2004/05. Three spring wheat cultivars and three winter wheat cultivars were planted in raised beds with three seed rates: 200, 230 and 260 kg ha^{-1}. Three raised beds of different characteristics were also compared in this experiment: i) 0.80 m wide with three rows separated at 0.15 m; ii) 0.65 m wide with three rows separated at 0.11 m, and; iii) 0.65 m wide with two rows separated at 0.15 m. The plots were 7.0 m long and as wide as the width of the beds. The experimental design was a split-plot with three replications. Bed widths were the main plots and factorial combination of varieties by seed rates were the sub plots.

Sampling of data

The amount of applied irrigation water was measured by using trapezoidal notch weirs at 0.10 m from the furrow or from the surface of flat field. Soil water content from 0–0.10 and 0.10–0.20 m depth

Table 1. Overview of experiments.

Experiment cropping season		I 2003/04 & 2004/05		II 2003/04		III 2004/05	
Wheat type		Spring	Winter	Spring	Winter	Spring	Winter
Genotypes		1	1	9	5	3	3
Seed rate (kg ha^{-1})		230	230	230	230	200/230/260	200/230/260
Plot area (m^2)		1,334.00	1,334.00	3.60	16.00	5.60/4.55	5.60/4.55
Replications		1	1	3	3	3	3
Bed planting	Width (m)	0.80	0.80	0.80	0.80	0.80/0.65	0.80/0.65
	Rows	3	3	3	3	3/2	3/2
	Row space (m)	0.15	0.15	0.15	0.15	0.11/0.15	0.11/0.15
Conventional planting	Row space (m)	0.15	0.15	0.15	0.15	/	/

was measured eight times using the gravimetric method, including: after planting, six in the middle of the season, and before harvest. Soil samples were taken from 0–0.10 m depth to evaluate soil physical properties at five stages during jointing, earing, flowering, grain-filling and maturity. During the growing season, additional relevant data were recorded. Grain yield and yield component data were collected at physiological maturity.

Statistics

The raised bed and conventional planting systems were treated as separate environments. Statistical evaluation and analysis of variance were performed using SAS (SAS Institute 1989).

Results and discussions

Effect of planting system on the amount of irrigation water and soil physical properties

The amount of irrigation water applied to the crop differed remarkably between the conventional and raised bed planting methods. The plots under the conventional method received the higher amount of water for both spring and winter wheat. Total water irrigation savings by bed planted spring wheat were 13.9% and 19.8% in the 2003/04 and 2004/05 seasons, respectively (Table 2). The corresponding savings by winter wheat were 23.3% and 29.3%. These values are slightly below those reported in previous studies where savings of irrigation water by bed planting of wheat ranged from 18% to 50% (Gupta et al. 2000, 2003; Yadav et al. 2002; Hobbs and Gupta 2003).

Table 2. Irrigation water (m^3) savings by bed planting of wheat over conventional method. Data from Experiment I.

Cropping season	2003/04		2004/05	
Wheat type	Spring	Winter	Spring	Winter
Bed planting	2,608	2,469	2,853	2,513
Conventional planting	3,028	3,221	3,559	3,556
Water saved over conventional (%)	13.9	23.3	19.8	29.3

This suggests there is still potential to optimize bed planting systems in the YRNV. Wang et al. (2004) reported that the use of flood irrigation in flat planting results in low irrigation water use efficiency. Thus, the optimization of the bed planting system is a feasible strategy to increase irrigation water use efficiency in the YRNV.

Means of soil moisture content, bulk density and porosity measurements in the two planting systems are presented in Table 3. Results were consistent for both spring and winter wheat. The soil moisture content was usually higher in conventional planting than in bed planting. This result was expected due to 14–29% less irrigation water being applied to the raised beds, in spite of the difference in soil water content in the topsoil (0–0.20 m) of the beds compared to conventional planting ranging from reductions of –1.65 % to an increase of +0.86%. The soil porosity was higher at the raised beds. Similarly, Wang et al. (2004) reported that flood irrigation can cause crusting of the soil surface and can contribute to the degradation of some soil properties.

Response of grain yield, yield components and phenological traits to different planting systems

Although higher grain yield was recorded for the conventional planting system for both spring and winter wheat, there were no significant differences between bed and conventional planting systems (Table 4). Similar results were also observed in studies in other regions (Sayre and Ramos 1997; Tripathi et al. 2005; Kazem and Somaye 2010). This indicates that reductions in the amount of irrigated water can be obtained whilst maintaining high grain yields.

Spring and winter genotypes showed significant differences in grain yield. Ningdong 11 and Pinyin 3 produced significantly higher grain yields (5,357 and 8,371 kg ha^{-1}) for winter and spring wheat, respectively. In contrast Ningdong 6, Xiongyin 1 and 04A5007 had the lowest grain yield. Sayre and Ramos (1997) noted that wheat genotypes generally performed well under flat planting but did poorly

Table 3. Soil moisture content, soil bulk density, and porosity at the two planting systems. Data from Experiment I.

Wheat type		Spring		Winter	
Planting system		Beds	Conventional	Beds	Conventional
Moisture (%)	0–0.10 m	10.47	11.91	14.06	15.71
	0.10–0.20 m	13.78	13.89	17.00	16.14
Bulk density (g cm^{-3})	0–0.10 m	1.50	1.54	1.55	1.57
Soil porosity (%)	0–0.10 m	25.29	24.88	26.17	23.22

on the flat, unless markedly differential lodging was involved. Since the genotypes used here and in other studies were not specifically improved to be grown in raised beds, there may still be high potential to increase grain yield in bed planting systems by specific selection.

Thousand grain weight of wheat under bed planting had a relatively higher value than under the conventional method, while other yield components performed differently (Table 5). Winter wheat under bed planting had a relatively lower spike number than conventional planting (–16.6%; Table 4). For spring wheat, the conventional planting system had higher seedling and spike numbers.

The rate of wheat growth was slower with bed planting compared to conventional planting at early stages, especially until emergence, but showed faster development during later growth stages. Days to maturity were slightly lower (–3 d) with bed planting than with conventional planting. This suggests that there is scope to select cultivars with later maturity under bed planting that can maximize radiation capture during the growing season and in turn have higher grain yield.

The planting system also had an effect on plant height; the average height of wheat was lower with raised beds than with conventional planting by 0.05 m for winter wheat and 0.06 m for spring wheat. This difference is probably associated with the decreased amount of lodging observed with bed planting since it played an important role in the lodging resistance of wheat in other regions (Sayre and Ramos 1997). Wang et al. (2004) also found that bed planting reduced plant height, lodging and the incidence of some diseases and increased the grains per spike and grain weight.

Effect of bed size, row spacing and seed rate on wheat yield and yield components

Based on the grain yield response to the bed planting in Experiment II, spring wheat genotypes 04A5003, 04A5006, Ningchun 30 and winter wheat genotypes Ningdong 10, 02AW5011, and Ningdong 11 were selected for further investigation.

Table 4. Effect of planting method and genotype on grain yield (kg ha^{-1}) of wheat. Data from Experiment II.

	Winter wheat			Spring wheat	
Planting method	**Raised bed**	**Conventional**	**Planting method**	**Raised bed**	**Conventional**
Genotype			**Genotype**		
Ningdong 10	6,426a	7,318a	Pinyin 3	8,162b	8,580a
02AW 5011	6,596a	7,234a	04A5002	7,717a	7,405a
Ningdong 11	6,672a	8,042a	04A 5003	7,979a	8,086a
Ningdong 6	6,219a	6,670a	04A 5004	7,689a	7,733a
Xiongyin 1	5,818a	6,270a	Ningchun 4	7,117b	7,711a
			04A 5006	7,397b	8,641a
			04A 5007	6,953a	6,291b
			Ningchun 30	7,495a	7,422a
			Ningchun 46	7,803a	8,139a
Mean	**6,346a**	**7,107a**		**7,590 a**	**7,779a**

Values in the same rows followed by the same letter are not significantly different (LSD test: P≤0.05). For the mean, values in the same columns followed by the same letter are not significantly different (LSD test: P≤0.05).

Table 5. Effect of planting method on wheat yield components. Data from Experiment II.

Wheat type	Planting method	Seedling (million ha^{-1})	Spikes (million ha^{-1})	Grains $spike^{-1}$	Thousand grain weight (g)
Winter	Bed	4.95	5.33	30.90	48.50
	Conventional	4.47	6.39	30.50	47.80
	Percentages over flat planting (%)	10.7	–16.6	1.3	1.5
	CV (%)	11.8	13.6	10.0	1.8
Spring	Bed	4.38	5.10	45.50	40.60
	Conventional	4.67	4.87	49.10	39.70
	Percentages over flat planting (%)	–6.2	4.7	–7.3	2.2
	CV (%)	7.4	3.9	9.8	2.2

CV = coefficient of variance.

Differences in wheat yield due to bed size and genotypes were highly significant (Table 6). Higher grain yields (6,290 and 6,896 kg ha^{-1} for winter and spring wheat, respectively) were recorded in beds of 0.65 m with three rows. The higher grain yield was associated with a higher number of spikes per area (Table 7).

Table 6. Effect of bed size, seed rate and variety on wheat yield (kg ha^{-1}). Data from Experiment III.

	Wheat type	Winter	Spring
Bed width (m)	0.80 (3 rows)	5,924ab	5,984c
	0.65 (3 rows)	6,290a	6,896a
	0.65 (2 rows)	5,608b	6,478b
Seed rate (kg ha^{-1})	200	6,316a	6,492a
	230	5,935ab	6,427a
	260	5,571b	6,439a
Genotype	1*	5,294c	6,334b
	2	6,513a	5,849b
	3	6,017b	7,174a
CV (%)		15.8	10.0

* Variety: 1–3 represent Ningdong 10, 02AW5011 and Ningdong 11 for winter wheat and 04A5003, 04A5006 and Ningchun 30, respectively. Values in the same columns followed by the same letter are not significantly different (LSD test: P≤0.05). CV = coefficient of variance.

Seed rate also had a significant effect on winter wheat yield. The highest grain yield was obtained with a seed rate of 200 kg ha^{-1}. This was the result of a higher number of grains per spike. In contrast, seed rate did not have a significant effect on the grain yield of spring wheat, but increasing the seed rate resulted in a relatively higher plant population. This result agrees with the findings of other researchers (Sayre 2004; Govaerts et al. 2005).

In terms of genotypes, 02AW5011 and Ningchun 30 produced the highest grain yield (6,513 and 7,174 kg ha^{-1}, respectively) among those tested. This was consistent with results from Experiment II and it was due to differences in several yield components such as thousand grain weight.

Conclusions

The utilization of raised beds to grow wheat in the YRNV has several important advantages such as to reduce the amount of irrigation water, reduce wheat lodging and promote wheat growth. This study shows that planting wheat in raised beds is a feasible option for irrigated areas in the YRNV. The main benefit from this planting system is the capacity to reduce the amount of irrigated water while maintaining high grain yield. It is also shown

Table 7. Effect of bed width, seed rate and variety on wheat yield components. Data from Experiment III.

Wheat type		Treatment	Seedlings (million ha^{-1})	Spikes (million ha^{-1})	Grains spike^{-1}	1,000 grain weight (g)
Winter	Bed width (m)	0.80 (3 rows)	4.16	5.62	28.0	41.7
		0.65 (3 rows)	3.81	6.37	27.2	36.6
		0.65 (2 rows)	3.51	5.35	29.1	37.6
	Seed rate (kg ha^{-1})	200	2.85	5.24	32.4	39.2
		230	4.09	5.88	28.0	40.1
		260	4.53	6.21	23.9	36.6
	Genotype	Ningdong 10	3.84	5.29	27.1	37.6
		02AW5011	4.10	6.10	26.4	40.0
		Ningdong 11	3.53	5.94	30.9	38.3
	CV (%)		24.0	14.1	7.9	22.9
Spring	Bed size (m)	0.80 (3 rows)	4.41	4.63	36.7	42.6
		0.65 (3 rows)	4.34	5.21	36.8	42.5
		0.65 (2 rows)	4.95	4.80	37.9	42.7
	Seed rate (kg ha^{-1})	200	5.37	4.96	35.8	42.0
		230	3.73	4.84	38.7	43.0
		260	4.60	4.84	37.0	42.8
	Genotype	04A5003	4.67	5.38	35.5	42.1
		04A5006	4.70	4.99	38.5	39.2
		Ningchun 30	4.32	4.26	37.4	46.4
	CV (%)		18.7	12.6	10.0	7.4

CV = coefficient of variance.

here that there is scope to increase grain yield in raised beds by using certain genotypes in narrow beds (0.65 m) with three rows spaced at 0.11 m.

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Chapter 6. Conservation agriculture based rice–wheat–jute cropping pattern in Bangladesh

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Abstract

Rice–wheat–jute is an important cropping pattern in Bangladesh with the potential to increase food security from rice and wheat production, and income, fuel, and improved soil quality from jute production. The rice–wheat–jute cropping pattern is growing in popularity due to the increasing market value for jute fiber. Production systems based on conservation agriculture (CA) are also being more widely adopted due to recognized benefits such as fuel and labor savings, improved water use efficiency, increased yields, and soil quality. The objectives of this review paper are to address the major agronomic issues of CA based rice–wheat–jute production systems and the benefits, constraints, opportunities of the system as well as directions for future research to improve the rice–wheat–jute rotation.

Introduction

Rice–wheat–jute is an important cropping pattern in Bangladesh that ensures food security from rice and wheat and income, fuel and soil quality from jute. The rice–wheat cropping pattern occupies about 18 million ha in Asia, of which 13.5 million ha is in the Indo-Gangetic Plains (IGP) of Bangladesh, India, Nepal, and Pakistan, and feeds about a billion people (20% of the world's population) (Ladha et al. 2003). This cropping pattern covers 0.4 million ha in Bangladesh (Jat et al. 2011). Rice and wheat are the main food grains where rice is the staple food of Bangladesh. Jute is a potentially beneficial crop to diversify the rice–wheat rotation practiced in Bangladesh. There are no exact statistics on how much area cover is occupied by the rice–wheat–jute cropping pattern but it is growing in popularity due to the increasing market value for this crop.

In Bangladesh, rice and jute are grown in rainfed conditions and wheat in irrigated conditions. In this cropping pattern, rice is grown during the monsoon period with full tilled puddled soil and wheat and jute in full tilled dry soil. Conventional tillage/crop establishment in an agro–system is the most input intensive process (Saharawat et al. 2010). Puddling and transplanting are highly labor, water, time, and energy intensive. Repeated and continuous puddling destroys soil structure, creates hard pans at shallow soil depth, and delays planting which in turn adversely affects the performance of successive wheat crops (Hobbs and Moris 1996). Intensive tillage increases soil erosion and breaks down soil structure. Conventional tillage (CT) is arable agriculture which is not guided by any principles but conservation agriculture (CA) is driven by principles; these being minimum disturbance of soil, surface crop residue retention, and profitable cropping patterns. CA is a better crop management practice than CT for sustainable agriculture. Though CA is a new concept for Bangladesh, farmers prefer this due to the labor shortage and low inputs required compared to conventional practices.

The objectives of this review paper are to assess the major agronomic areas of CA based rice, wheat and jute production and their benefits, constraints, and opportunities and to offer solutions in terms of market value as well as directions for future research to improve the rice–wheat–jute rotation.

Importance of rice, wheat and jute in Bangladesh

Rice (*Oryza sativa*) is grown intensively as a principal food grain in Bangladesh to ensure food supply to the huge population. Wheat (*Triticum aestivum*) is the second food grain and jute (*Corchorus capsularis* L. and *Corchorus olitorius* L.) is the main fiber and cash crop of Bangladesh. Jute is the most important cash crop and one of the major foreign currency earners of Bangladesh. Jute fiber is extensively used all over the world for its versatility, durability and fineness. It is used for the production of newsprint paper, carpet, hessians, gunny bags, ropes, juton and many other items. Currently, jute sticks are used in making partex (Haque et al. 2008). Jute is mostly grown in the Indo-Bangladesh region and in some countries of Southeast Asia. It has been reported that about 90% of the world's jute is produced in Bangladesh and India (Atwal 1976). With respect to production, Bangladesh ranks second among the jute growing countries of the world. In Bangladesh, about 4.72 lac hectares of land are under jute cultivation and the total yield is 821,000 million tons (BBS 2006). It is worthy to note that 100,000 traders and 250,000 industrial laborers earn their livelihood from the jute business (Khandakar 1987). In production, jute ranks second only to cotton among all of the natural fibers (Talukder et al. 1989). Jute leaves are used as vegetables and have nutritional as well as medicinal value and jute sticks are used for fuel and shelter in jute growing rural areas. The defoliated jute leaves have fertilizer value and enrich the soil nutrients (BJRI 2007).

Farmers grow rice for their food security; however, the market price is increasing for supply to the huge population. On the other hand, wheat and jute production fluctuate in different years due to there being no market policy for these crops. High market price encourages cultivation while a low market price discourages cultivation of these crops. For this reason, wheat and jute crop production vary year to year. For our food security we need to grow rice and wheat, and jute needs to be grown to earn foreign currency. Overall the rice–wheat–jute cropping pattern ensures food, money, rural fuel and shelter, organic matter, and clean air.

Agro-ecological benefits of jute

Jute fiber and its products are 100% biodegradable and recyclable. They are environmentally friendly and can also be disposed of without causing any environmental hazard. The defoliated jute leaves have fertilizer value and enrich the soil nutrients (BJRI 2007). The roots of jute plants play a vital role in increasing the fertility of the soil. By rotating with other crops, jute acts as a barrier to pest and diseases for others crops and also provides a substantial amount of nutrients in the form of organic matter and micronutrients. Jute plants have a high carbon dioxide (CO_2) assimilation rate and clean the air by consuming large quantities of CO_2, which is the main cause of the greenhouse effect. Theoretically, one hectare of jute plants can consume about 15 tons of CO_2 from the atmosphere and release about 11 tons of oxygen in the 100 days of the jute-growing season. Jute assimilates about 5.8 ton CO_2 from the atmosphere in its lifetime (Rahman and Bala 2009).

Factors affecting rice, wheat and jute production and the contribution of CA

Rice

In the rice–wheat–jute cropping system, rice is grown during the monsoon season known as Aman under rainfed conditions. Generally, farmers use long duration varieties (145–150 days) such as BR11, Swarna, and other local varieties. Variation of rainfall and temperature are increasing due to climate change. Sometimes drought occurs during transplanting time and seedlings become aged which delays transplanting. On the other hand, terminal drought also affects the yield because farmers have no arrangement for irrigation. Puddled transplanted Aman rice fields become dry and crack. Usually, rice is grown with full wet tillage in ponded conditions. Puddling and transplanting are highly labor, water, time and energy intensive. The advantages of puddling include weed suppression, reduction in percolation losses, and creation of anaerobic conditions; all of which are beneficial for rice. However, repeated and continuous puddling destroys soil structure, creates hard pans at shallow soil depth, and delays planting which in turn adversely affects the performance of successive wheat crops (Hobbs and Moris 1996). Conventional flooded rice receiving the largest amount of fresh water compared to any other crop is the major contributor to the problems of the declining groundwater table (0.1–1.0 m year^{-1}) and increasing energy use (Singh et al. 2002). During transplanting time there is a labor crisis because every farmer wants to plant their seedlings after getting sufficient water. Therefore, wages increase during this time.

Reducing production costs and the demand for labor at peak periods, and minimizing the "turnaround" between crops would contribute greatly to improving the sustainability and profitability of the intensive rice-based systems in northern Bangladesh.
Dry direct-seeded rice (DSR) under reduced or conservation tillage systems, as an alternative to transplanting rice after puddling, is an option to improve labor productivity and intensify these systems (Timsina et al. 2010). CA is a sustainable agriculture alternative to conventional tillage which would address the adverse issues related to intensive rice-based systems.

DSR is a great opportunity for direct seeding by machine with minimal or reduced tilled dry soil during the period it is required (15 June–7 July) and early maturing short duration varieties (SDV) such as BRRI dhan33 and BINA dhan7 (118 days for transplanting and 108–110 days for DSR) can be used to escape terminal heat. Potential solutions include a shift from intensive tillage to no or reduced tillage and/or from transplanting to direct-seeding. There can be several other modifications such as transplanting in unpuddled soil especially in light textured soil. The practice of transplanting on unpuddled soil is a potential technology for those farmers who are skeptical about DSR to avoid the adverse effects of puddling on the successive wheat crop. Puddling (wet tillage) takes up to 30% of the total irrigation water application in rice in light textured soils (Aslam et al. 2002). Thus, land preparation is more water-efficient for unpuddled transplanted or dry DSR compared to puddled transplanted rice. Saharawat et al. (2009) and Reddy et al. (2004) have reported similar yield and water application in unpuddled and puddled transplanted rice in farmer participatory trials in Haryana, India. Previously, it has been reported that dry direct seeding of rice and wheat after no-tillage performed as well as the conventional practice but with significant savings in water and labor use (Bhushan et al. 2007). In dry DSR, with alternate wetting and drying cycles, the crop is subjected to greater weed competition than transplanted rice because weeds emerge before or at the same time as the rice. Therefore, heavy weed infestation is a major problem in DSR and its success lies in effective weed control measures (Rao et al. 2007). Timsina et al. (2010) reported that one herbicide application coupled with a single hand weeding provided effective weed control and these plots had fewer weeds than other weed control methods. Compared with the clean weeded plots, in zero tillage DSR the yield losses were at least 12% in the T0–no weed control plots, compared with 14% losses in transplanted rice and 40% losses in conventional tillage DSR. On average, across establishment methods, replacing herbicide with one hand weeding gave only 3% less yield than the chemical weeding.

Wheat

There are many factors affecting wheat production. It has been reported that on average wheat yield is reduced by 8% when sown after puddled transplanted rice compared to wheat sown after DSR in unpuddled conditions (Kumar et al. 2008). Puddling can also delay wheat planting which results in yield losses of 35–60 kg day^{-1} ha^{-1} in the IGP (Pathak et al. 2003). Therefore, conventional tillage/crop establishment in an agro-system is the most input intensive process (Saharawat et al. 2010). Wheat is a winter crop facing high crop competition with other crops. Now the wheat area is shifting towards production of high value crops like vegetables (potato, tomato, cabbage, cauliflower, etc.), tobacco, maize, and others. Potato and tobacco are the main competitors of wheat. Nowadays, some large farmers and businessmen grow potato as a cash crop on their own and also on leased land. They achieve high benefits from potato within short timeframes (3–4 months). Land owners also get money (25,000–30,000 Bangladeshi Taka (BDT) per hectare i.e., US$ 333-400 per hectare) without any crop risk and after land return, they produce late boro rice, maize, and jute in full tilled and heavily fertilized potato fields with minimal cost. On the other hand, the Bangladesh Government discourages farmers from growing tobacco, but tobacco companies are giving loans without interest to farmers and guarantee the purchase of the produce. Resource poor farmers take this opportunity, replacing wheat with tobacco.

In addition to high temperatures during the grain-filling stage, high acidity and boron deficiency in soil also lower the grain yield of wheat. Higher acidity in soils is now being observed and farmers apply dolochune (liming) to their field during leisure time. Furthermore, farmers are sometimes unable to harvest their wheat crops on time due to a lack of clear sunshine which is required for wheat harvesting and threshing. The wheat then becomes over mature which causes grain shuttering and transportation losses. Sometimes pre-monsoon rain hampers crop harvesting.

An additional obstacle to wheat production is that laborers don’t show interest in working in pre- and post-harvest operational works due to the hazards of awns. Farmers don’t know in advance what will be the market price and sometimes leave wheat cultivation after a loss. For these reasons wheat production is declining in Bangladesh.

Dry DSR, along with early maturing varieties, mature from mid October to early November. This reduces the turnaround time and farmers are able to easily go to wheat planting again by machine in soil moisture residue. Wheat can be sown on flats by a two wheel tractor operated seeder (2WTOS), four wheel tractor operated (4WTO) zero till multi crop planter (ZTMCP), Turbo Happy Seeder and on beds using 2WT/4WTO bed planter. Farmers generally use broadcast with a high seed rate 150 kg/ha. A machine can seed directly in line with low seed rate (123.5 kg/ha) uniformly to a specific depth in minimal till or reduce till soil that reduces seeding rate by 16.7%. To date, the resource-conserving technology that has been most successful in the IGP is zero tillage planting of wheat after rice (Laxmi et al. 2007), particularly when using a tractor drawing a zero tillage seed drill. This specialized seeding implement allows wheat seed to be planted directly into unplowed fields with a single pass of the tractor, often with simultaneous basal fertilizer application (Mehla et al. 2000). In contrast, conventional tillage practices for wheat in these systems involve multiple passes of the tractor to accomplish plowing, harrowing, planking and seeding operations. On-station and on-farm trials with zero tillage wheat in the rice–wheat systems of the IGP have shown primarily positive impacts on wheat crop management, particularly through reduced inputs combined with potential yield increases (Aslam et al. 1989; Hobbs and Gupta 2003; Laxmi et al. 2007; Malik et al. 2002, 2005). The use of zero tillage significantly reduces energy costs, mainly by reducing tractor costs associated with conventional methods. The use of zero tillage also allows the wheat crop to be planted sooner than would be possible using conventional methods, which significantly reduces turnaround time (Erenstein et al. 2008). Bangladeshi farmers began crop production with full tilled soil. So, initially they do not believe the benefits of zero tillage and need to be introduced to reduced till using the 2WTOS, known as the Bangladesh Power Tiller Operated Seeder (PTOS) attachment of Power tiller which is used for tilling, sowing (six lines) and laddering operations simultaneously in a single pass. This Chinese made seeder machine is suitable for wheat seed sowing but rice, maize, jute, pulses, oilseeds etc can also be sown in six lines.

Jute

Bangladesh is the second largest jute growing country in the world and it is called the golden fiber of Bangladesh for its great contribution to the economy. But jute has gradually lost its market to synthetic substitutes, which are a lot cheaper than jute. Now it is known that these synthetic fibers are not beneficial to the environment and worldwide awareness of the environment and health is likely to provide new opportunities for jute due to its environmentally friendly characteristics. Jute is now being welcomed by the international community (Rahman and Bala 2009). Again, farmers are encouraged to produce jute by receiving a good price for the fiber.

Farmers are still using age old broadcasting methods, which consume about 15–20% more seeds than the desired seed rate of 6 kg/ha. The small size of land holdings (0.2–0.3 ha) limits the adoption of mechanized equipment by farmers. Due to low adoption of the new techniques there is currently a wide gap between the potential yield (2.7 tons/hectare) and the actual yield (2.1 tons/hectare) (Government of India, Ministry of Textiles, undated). Among the various factors, plant density is an important one that affects yield, quality, and cost of cultivation of a jute crop. BJRI (2007) recommended that 240,000–300,000 plant populations and a spacing with 30 cm by approximately 7cm should be used to achieve desirable yields. Seed rate varies with the method of sowing and the species being grown. For broadcast sowing, 6 and 10 kg seed/ha of *olitorius* and *capsularis* are required, respectively. Line sowing needs 4 and 6 kg seed/ha only (Gangaiah, undated).

The crop suffers from heavy weed infestation in the initial 6–8 weeks after sowing. Two–three hand weedings or mechanical hoeings are required to arrest weeds. The seeds are sown in rows which are 20 cm (*olitorius*) and 30 cm (*capsularis*) apart. The plants within the row should be thinned manually at two stages. The first thinning is done 20 days after sowing (DAS), when the plants are 5–10 cm high. At this stage, plants are thinned to a distance of 5 cm. In the second and final thinning, 35 DAS, when plants are 12–15 cm high they are thinned to a distance of 10 cm. Thus the optimum population varies from 0.33 (*capsularis*) to 0.50 (*olitorius*) milion/ha (Gangaiah, undated).

Jute is a labor intensive crop demanding 45% of the energy requirement and comprising 80% of the total cost requirement. Sowing, weeding, fertilizer application and fiber extraction (retting) are all labor intensive processes. A new four row seed drill has been developed which can sow one hectare of land in 5 hours. Using the PTOS (power-tiller-operated-seeder) for jute cultivation, farmers in the study areas saved about 23% of jute seed per hectare compared to PT using farmers. This saving would be more if all of the sampled farmers sowed seeds with PTOS (Miah et al. 2008). These new developments in machinery offer opportunities for incorporating jute into mechanized CA based systems.

Challenges to CA adoption

The new concept of CA to Bangladesh, the non-availability of CA based machinery and spare parts, lack of skilled manpower, farmers inability to purchase machinery, weed control, residue retention against shortage of fuel and livestock feed, and alternate rainfed and irrigated conditions are the main challenges to the adoption of CA.

For minimum disturbance of the soil, directly seeding with seeder machines is required. Use of these machineries depends on farmers' plot sizes, plot leveling, their economic ability, availability of machines, spare parts, price, local workshops for repair, and skilled manpower for their operation. Proper CA based machines are not available in Bangladesh. If they are available, farmers don't recognize these machines. An example is the Chinese made 2WTOS known as PTOS which is available in Bangladesh. This seeder machine is easy to handle in small plots and seeds drop in various depths due to undulating plots. Sometimes seeds drop on the soil surface in lower portions and bird damage occurs and some seeds go deep in the upper portion of the plot and don't uniformly germinate. Thus, a uniform plant population is not observed in seeding lines. Therefore, leveled land is essential for uniform seed sowing as well as irrigation to the field.

Again, weeds are a major constraint for direct seeded crops in zero or minimal tilled fields. Success of direct seeding depends on pre- and post-planting weed control. Suitable herbicides are essential for effective weed control. The pre-planting chemical weed control cost needs to be cheaper than the full tillage cost otherwise farmers don't get the benefit from CA. Therefore, pre-planting and post-planting (pre- and post-emergence) herbicides need to be available at a low price. Residue retention is another challenge for CA due to the crisis of fuel and livestock feeding. After all, it is not so far into the future that farmers will give preference to CA to achieve low crop establishment costs with seeder machines using optimum inputs without hazards.

Looking towards the future: A rice–wheat–jute cropping system based in CA

Water and labor scarcity are becoming major concerns for the productivity and sustainability of the rice–wheat based cropping systems in South Asia. Agriculture's share of freshwater supplies is likely to decline by 8–10% because of increasing competition from the urban and industrial sectors (Toung and Bhuiyan 1994; Seckler et al. 1998). In many parts of Asia, overexploitation and poor management of groundwater has led to a decreasing water table and negative environmental impacts. Conventionally flooded rice, which receives the largest amount of fresh water compared to any other crop, is the major contributor to the problems of declining groundwater (0.1–1.0 m year^{-1}) and increasing energy use (Singh et al. 2002).

The problem has further been intensified through the unavailability of labor and increasing wages. Farmers are now facing labor shortages because agricultural day laborers are shifting to non-agricultural works and migrate to rich districts and the Capital to be employed for rickshaw pulling, garment factories, in industry, and construction works. Considering the increasing scarcity of resources and labor, it is likely farmers will move towards the mechanized CA based systems with economical crop rotations such as rice–wheat–jute.

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Chapter 7. Tradeoffs in the use of residue in Sub-Saharan Africa: Mulch vs. feed

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Keywords: conservation agriculture, livestock, simulation model, and tradeoffs.

Abstract

In semi-arid and sub-humid parts of Sub-Saharan Africa, cereal residues are often the only source of feed available to livestock during the dry season. In the farming systems of these areas, livestock are often an important component as they provide manure, traction and various products, and represent a reserve that can be sold to overcome financial constraints. However, retention of residue as surface mulch has demonstrated to increase and stabilize yields in this area. Farmers in the area may therefore face hard tradeoffs between two competing uses of crop residue: mulching on the one hand, and livestock feeding on the other. In this study, we explored these tradeoffs for North Zimbabwe, using the simulation model FIELD (Field-scale resource Interactions, use Efficiencies and Long-term soil fertility Development) after adapting it for our situation. A summary functional relationship between surface mulching and water-limited yield was developed using DSSAT 4.5 (Decision Support System for Agrotechnology Transfer). The soil organic carbon module of FIELD was calibrated using empirical data from a chronosequence of 22 years. Climatic data were recorded in the area during the 2007–08 season whereas other parameters were taken from the literature. We then ran a number of simulations, with different proportions of the produced residue being retained as surface mulch (the rest being fed to cattle) and different levels of mineral fertilization. Outputs from the simulations suggest that water available overrules soil organic matter content and nutrient available, for the circumstances of North Zimbabwe and with the parameter values used. Therefore, from the model outputs, using crop residue as surface mulch appeared to lead to higher yields than feeding it to livestock in all the different scenarios simulated (from 2,000 kg ha^{-1} with full retention of residue to 1,200 kg ha^{-1} with full grazing by livestock). However, it did not always lead to higher farm production, as cattle (maintained alive during the dry season by feeding on residue) also provide traction enabling farmers to grow larger areas; various levels of residue grazing led to similar levels of total production. Although it was not possible to demonstrate with a simulation model its importance as a source of nutrients through manure, our study demonstrated the importance of livestock as a source of traction. This should be taken into account by projects aiming at adapting conservation agriculture principles in mixed crop–livestock systems. We also identified limitations in the models that we used to simulate mixed crop–livestock systems and we suggest ways to improve them.

Introduction

Smallholders in Sub-Saharan Africa use no or limited quantities of mineral fertilizers; 8 kg ha^{-1} on average in Sub-Saharan Africa according to Groot (2009). Therefore, most farming systems in the region rely on organic sources of nutrients for production. Manure often represents a key input (Rufino et al. 2007). Livestock can be considered a source of nutrient transfer from fields (where residues are grazed) and rangeland to night kraals (i.e., enclosure units for cattle) (Schlelcht et al. 2004; Rufino et al. 2006). In addition to this important role of manure production and nutrient transfer, livestock provide traction and various animal products, and act as an insurance in times of hardship (Herrero et al. 2010). Crop residues from cereals are often the only feed source for livestock during the dry season i.e., key for the survival of livestock from one year to the next.

On the other hand, the risk of soil degradation may rapidly reduce the production capacity in Sub-Saharan Africa. In an attempt to try to revert this, conservation agriculture (CA) is currently widely promoted in Sub-Saharan Africa, mainly as a means to increase food security and minimize environmental degradation, particularly in areas characterized by frequent droughts and dry spells. Firstly, CA enables early planting, as the number of operations to prepare land are reduced and often carried out before the first effective rains (Haggblade and Tembo 2003), which may result in more efficient use of rainfall, reducing the risk of crop failure when receiving below-average rainfall, and stabilizing yields when rains are poorly distributed (Friedrich 2008; Erenstein 2002, 2003). Secondly, retention of residue as surface mulch, another key component of CA, reduces water runoff significantly. For example, a 30% cover of soil surface usually is associated with a reduction of runoff by more than 50% (Findeling et al. 2003; Scopel et al. 2004). Thirdly, surface residue decreases evaporation of soil water (Scopel et al. 2004), as a result increasing water storage in the soil profile. Therefore, CA is expected to increase the amount of water available to the crop, potentially a major benefit in semi-arid and sub-humid parts of Sub-Saharan Africa where water is a major limiting factor. In addition, the residue retention associated with CA is expected to reduce soil erosion due to runoff and increase soil organic matter content. However, in mixed crop–livestock systems of Sub-Saharan Africa where CA is being promoted, hard tradeoffs may exist for residue use between soil mulching on the one hand and livestock feeding during the dry season on the other. In this study, these tradeoffs are explored by simulating long-term trends in cereal productivity using a simple farm-scale dynamic model with a seasonal time step. Data from a semi-arid area of North Zimbabwe are used to calibrate the model.

Materials and methods

Model description

The conceptual model used is described in Figure 1. To simulate grain, residue and root production, the sub-model FIELD (Field-scale resource Interactions, use Efficiencies and Long-term soil fertility Development) from the dynamic bio-economic model FARMSIM (FArm-scale Resource Management SIMulator) developed through collaboration among Wageningen University, Cirad and the University of Zimbabwe (Tittonell et al. 2007) was used. FIELD is based on the concept of production ecology (Van Ittersum and Rabbinge 1997). FIELD calculates actual yields as the minimum of water-limited, nitrogen-limited, phosphorus-limited and potassium-limited yield. Further reductions in grain yield are calculated considering other reducing factors such as weeds and pests. In this study, however, we did not include biotic reducing factors and simulated yields are therefore resource-limited yields rather than actual yields. Water-limited yield and nutrient-limited yields (N, P and K) were calculated following Liebster's law of the optimum, i.e., taking into account resource interaction. Liebscher's law of the optimum predicts an increase in the use efficiency of a given resource as other resources are closer to the optimum. In FIELD, soil organic C dynamics are simulated through three pools (Figure 2): a pool of organic amendment C (i.e., residue, manure, etc), a pool of active organic C (i.e., decomposing) and a pool of humified organic C. All pools are assumed to decompose following first order kinetics.

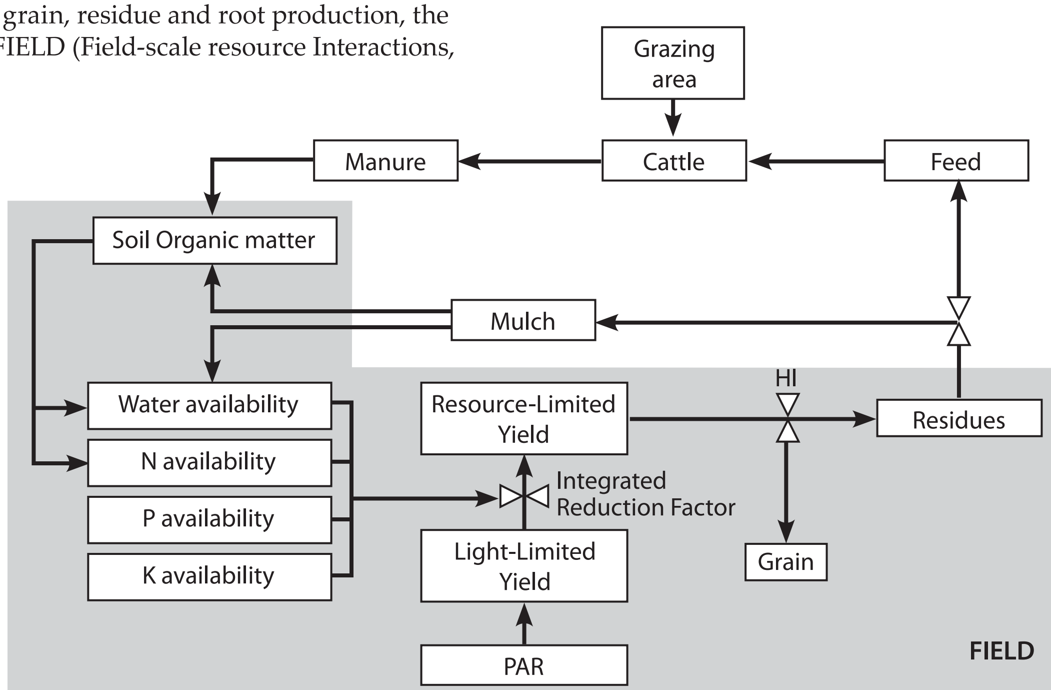

Figure 1. Overview of the conceptual model used. Annual production of residue and grain was simulated using the sub-model FIELD from FARMSIM (HI = harvest index, PAR = photosynthetically active radiation).

Manure from livestock was considered an organic amendment only (i.e., an input to the soil organic C sub-system), not a source of N, P and K. Water available to the crop was assumed to be influenced by (i.e., to be a function of) the soil organic C content and the proportion of the soil covered by crop residue (%). Thus, summary functions of water-limited yield as a function of the soil organic C and the proportion of the soil covered with residue were derived from the outputs of simulations using a dynamic model with a daily time step: DSSAT 4.5 (Decision Support System for Agrotechnology Transfer). Details of this procedure are provided below.

Empirical data from North Zimbabwe for model calibration

The model presented above was calibrated using empirical data from Mbire District in North Zimbabwe, an area located between 30°00 and 31°45 East and 16°00 and 16°30 South. Mbire District is part of the Mid-Zambezi Valley, a formation characterized by the former floodplains of the Zambezi River between the Victoria Falls and Cabora Bassa Lake, at an average altitude of 400 m.a.s.l. The area is part of the agro-ecological zone 'Natural Region IV' of Zimbabwe, which is characterized by low rainfall (450–650 mm), periodic seasonal droughts and severe dry spells during the growing season, resulting in a low agricultural production potential (Vincent and Thomas 1961; modified by Surveyor-General, 1980). Since aggressive campaign of tsetse eradication after the national independence in 1980, cattle numbers have increased dramatically (Baudron et al. 2011). There are two clearly defined seasons: a short rainy season with 110–140 days of rainfall from December to March and a long dry season from April to November. Rainfall is highly variable within seasons and across small distances due to localized storms, and mid-season dry spells of more than 30 days often occur. Cotton, sorghum and maize are the main crops. Sorghum is the major cereal crop and is grown on the interfluves, while maize is grown mostly along river banks.

To estimate the quantity of residue necessary to maintain a Tropical Livestock Unit (TLU, i.e., a hypothetical animal of 250 kg live weight, equivalent to 1.5 cattle) alive through the dry season, we used empirical data collected from 11 farms during the 2008–09 season. The quantity of crop residue grazed by livestock was estimated by first estimating the total quantity of residue produced (from estimated harvest, cropped area measured with a GPS and estimated harvest index). The percentage of residue grazed by livestock was then estimated by each farmer. The number of livestock – cattle, goats and sheep – was counted on each farm and converted into TLU. Results are provided in Table 1. From this analysis, 850 kg dry matter of cereal residue is estimated to be necessary to maintain one TLU alive through the dry season in Mbire District. From Schlecht et al. (2004), we estimated that one head of cattle produced 1,400 kg manure per year, and that half of it could be collected and applied to the field.

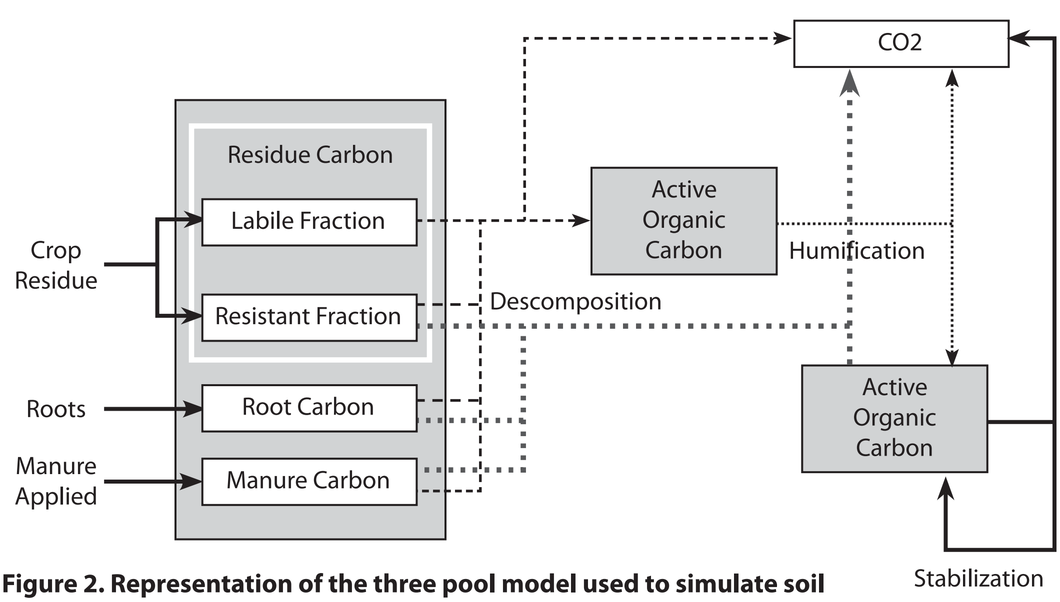

Figure 2. Representation of the three pool model used to simulate soil organic C dynamic.

Table 1. Number of livestock, estimated quantity of crop residue grazed by livestock and estimated quantity of crop residue grazed per tropical livestock unit (TLU) from 11 farms.

Farmer	Livestock (TLU)	Estimated quantity of crop residue grazed by livestock (kg dry matter)	Quantity of crop residue per TLU (kg dry matter)
A Mamombe	1.0	1,104	1,104
C Gonese	4.9	2,103	428
L Zongoro	2.3	2,155	924
M Chiusakara	8.8	3,786	432
M Guwa	2.3	1,463	650
M Lazarus	3.1	4,917	1,595
M Mugwagwa	14.6	13,348	912
M Watetepa	9.3	1,510	162
P Sharara	1.1	714	659
R Matongora	2.8	4,093	1,445
R Mavhura	1.8	1,792	1,024
MEAN	4.7	3,362	848
Std Err	4.4	3,571	438

Climatic data used to calibrate DSSAT were generated by a weather station (Hoboware Pro data logger, connected to a typing rain gauge, a thermometer and a radiation sensor) that was placed in Mbire District for three consecutive rainy seasons (from 2007–08 to 2009–10). Data collected during the 2007–08 season are provided in Figure 3. Gaps in rainfall data were filled with data collected by neighboring farmers equipped with a rain gauge. Gaps in minimum temperature, maximum temperature and radiation data were filled using equations obtained from linear regressions, from available data. Details of the calibration are provided below.

Soil data used as inputs in the model and to calibrate the soil organic C sub-model were obtained from a sample of 33 fields (including three plots under natural vegetation) representing a chronosequence of 22 years of cultivation in Mbire District, on a soil typical of North Zimbabwe (70% sand, 19% clay, 11% silt). Details of the calibration are provided below.

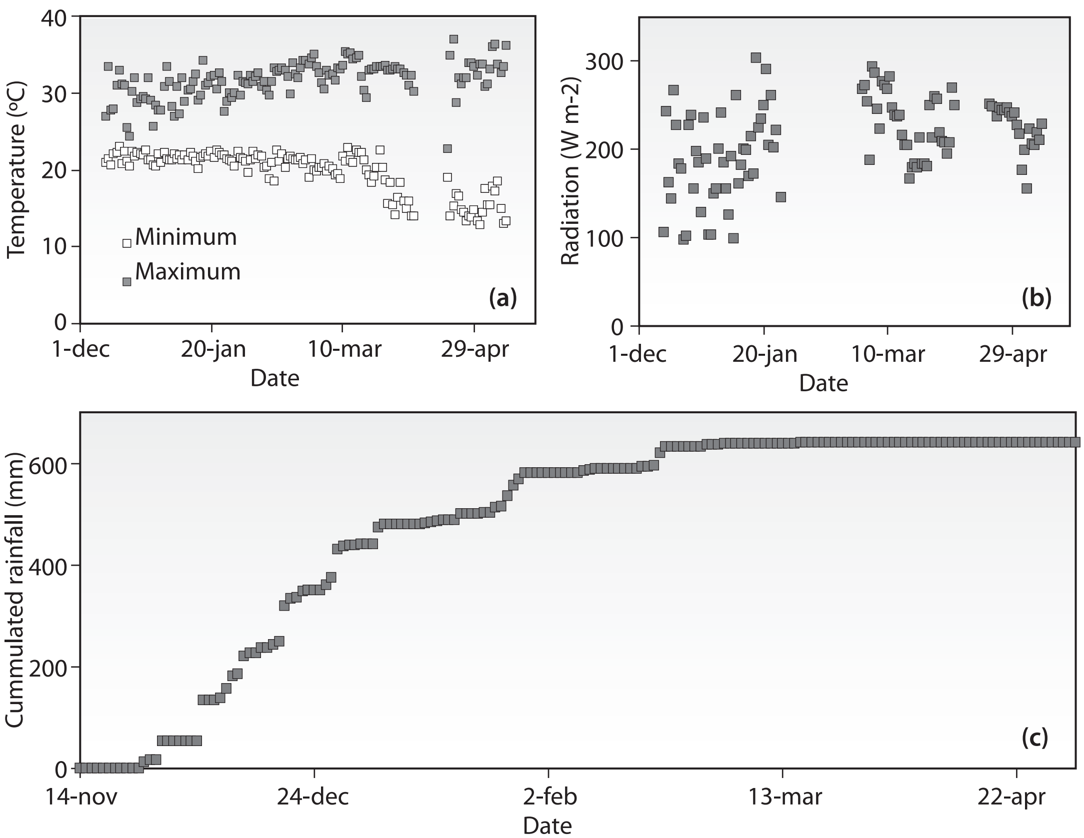

Figure 3. Climatic data recorded by the weather station during the 2007-08 season in Mbire District: (a) minimum and maximum temperatures; (b) radiation; and (c) rainfall.

Results

Effect of mulching: Generation of summary functional relationships using DSSAT

The main sorghum cultivars used in North Zimbabwe are Macia, DC75 (and cultivars having DC75 as a parent) and a number of local landraces. As none of these are provided by DSSAT, all the sorghum cultivars provided by DSSAT were screened, in order to select the one having performances as similar as possible to the ones of Macia and DC75, in the conditions of North Zimbabwe (with emphasis on productivity and phenology). Thus, we used DSSAT to simulate the potential yield of the different sorghum cultivars available, under the conditions of radiation, temperature and rainfall of North Zimbabwe. Although, this is not the potential yield *sensu stricto* as defined by Van Ittersum and Rabbinge (1997) (i.e., the yield with unlimited water and nutrients, with the conditions of radiation and temperature of the area), it gives a more realistic simulation of the attainable yield and the potential of sorghum to produce residues. Figure 4 shows the simulated potential grain yields of five cultivars provided by DSSAT, as a function of the time after planting. Pioneer 8333 was found to be the sorghum cultivar having performances closest to Macia and DC75: days to physiological maturity was approximately 90 days and maximum attainable yield (with total rainfall of 640 mm) was about 2,200 kg ha^{-1}.

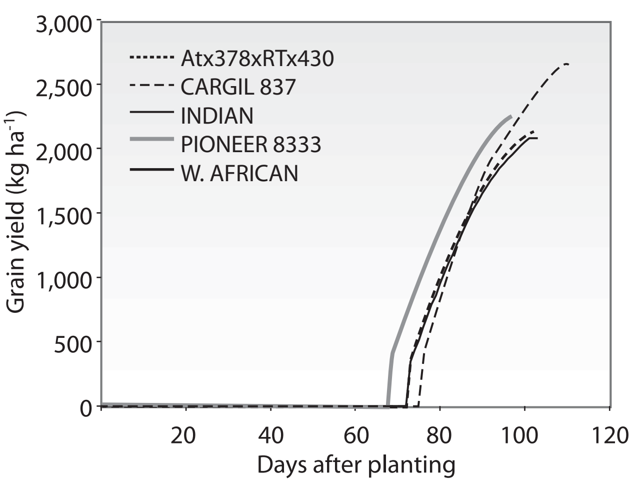

Figure 4. Potential grain yield as a function of time under the climatic conditions of North Zimbabwe during the 2007–08 season for five sorghum cultivars simulated in DSSAT (Decision Support System for Agrotechnology Transfer).

To derive summary functional relationships of the water-limited yield as a function of the soil organic C content and the quantity of residue retained as mulch, several simulations were run using DSSAT, each with different levels of soil organic C (within the range found in North Zimbabwe according to the results of the chronosequence i.e., between 29 and 16 t ha^{-1}) and different quantities of surface mulch (from 0 to 3,000 kg ha^{-1}). Only the two soil routines to simulate water and nitrogen were turned on in DSSAT simulation options while the other routines were turned off. The level of soil organic C (within the range of possible values in North Zimbabwe) for a given quantity of surface mulch appeared to not have any influence on the output results of the DSSAT simulation. However, the simulated grain yield was increasing with the quantity of surface mulch. When plotting the output results against the quantity of surface mulch, an almost perfect linear fit was found (Figure 5). This implies that DSSAT uses a simple linear function to calculate the influence of mulching on water-limited yield (implications are discussed in the Discussion section of this paper). The equation of the regression was used as the function to calculate the water-limited yield in the general model (Figure 1).

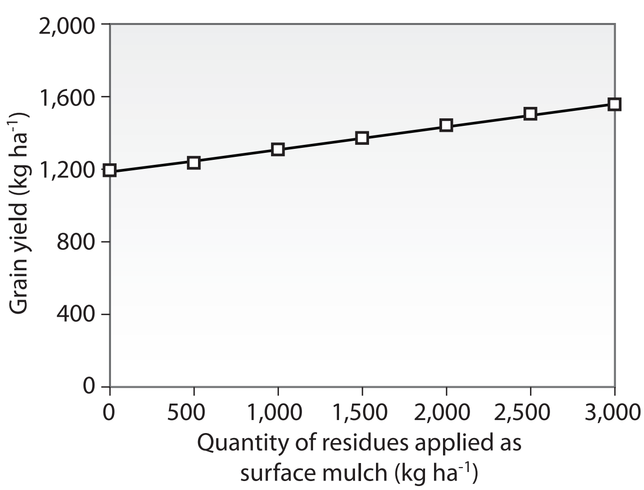

Figure 5. Grain yield as a function of the quantity of residues applied as surface mulch, simulated through DSSAT (Decision Support System for Agrotechnology Transfer). Each square represents an individual simulation. The line represents the fitted regression (*$GY = 0.1255 \times SM + 1183.5$; $R^2 = 0.9974$;* with GY the grain yield and SM the quantity of residue applied as surface mulch).

Calibration of the soil organic C sub-model of FIELD using data from a chronosequence in North Zimbabwe

The C sub-model of FIELD is one of the most important components of FIELD. Thus, calibrating it well is of paramount importance. Parameters related to decomposition, humification and stabilization (Figure 2) were adjusted in order for the output of the C sub-model to match empirical data. A satisfactory fit was obtained (Figure 6). The code in FST (Fortran Simulation Translator) for the calibrated model is provided in Appendix 1.

Simulation: Exploring various scenarios

The model described in Figure 1 was programmed on FST and calibrated in a stepwise manner as described above. Four levels of mineral fertilization (0 kg compound D and 0 kg ammonium nitrate; 50 kg compound D and 50 kg ammonium nitrate; 100 kg compound D and 100 kg ammonium nitrate; 150 kg compound D and 150 kg ammonium nitrate) combined with 11 scenarios of the proportion of residue produced being retained as mulch (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100%) were simulated, (i.e., 44 simulation runs). Grain yield outputs of these simulation runs, after 20 time steps (years in this case) are plotted on Figure 7.

For the four levels of fertilization, the simulated grain yield increased almost linearly with the proportion of residue used as mulch, from 1,200 to 2,000 kg ha^{-1}. For a given value of the proportion of residue produced being retained as mulch, mineral fertilization appeared to have little impact, implying that with the conditions of North Zimbabwe and with the current model construction, yield is limited by water more than by nutrients.

The simulated number of cattle that can be supported during the dry season by one hectare of sorghum, from the same runs as above, is plotted in Figure 8. For the four levels of fertilization, the simulated number of cattle per hectare decreased almost linearly with the proportion of residue used as mulch, from about 2 to 0 head ha^{-1}.

Finally, we used results from simulation runs above to calculate the total production of sorghum per farm. Farming systems of North Zimbabwe are limited by labor more than by land (Baudron et al. 2012). Therefore, the surface area grown per farming unit in North Zimbabwe increases with the manpower and the animal draught power available. For example, a farming unit owning no cattle to pull a plow or a cultivator has the capacity to produce around 1 ha of cereal. A farming unit owning a pair of cattle has the capacity to produce around 1.5 ha, and a farming unit owning two or more pairs of cattle has the capacity to produce around 2 ha of cereals (differences between these three categories of farming units are greater with the surface area in cotton, the main cash crop in North Zimbabwe). Simulated sorghum production per farm as a function of the proportion of residue retained as surface mulch is reported on Figure 9.

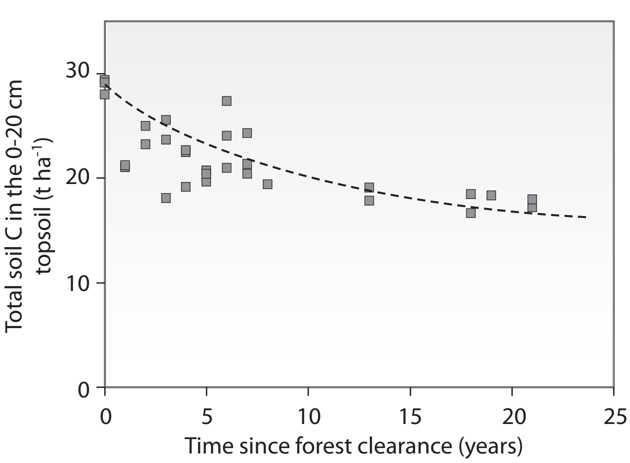

Figure 6. Change in total C content in the top 20 cm of the soil profile (TSC) against length of the period under cultivation (T) on a sandy loam soil typical of the study area. The squares represent empirical data and the line represents the output of the C sub-model of FIELD after calibration.

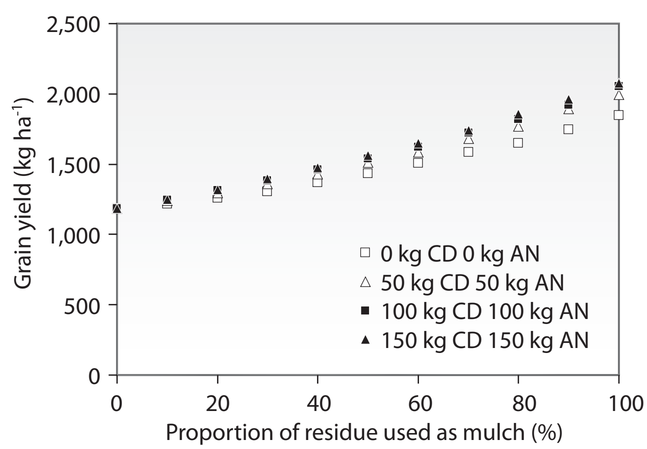

Figure 7. Simulated sorghum grain yield after 20 years, as a function of the proportion of residue used as mulch (the rest of it being used as cattle feed) and as a function of mineral fertilization. CD = Compound D; AN = ammonium nitrate.

If yield increased linearly with the proportion of residue being retained as mulch, Figure 9 shows that the total production as a function of surface mulch is more complex: farms with higher soil cover may achieve higher yields, but due to lower available draught power their production may not be higher than farms with no soil cover. The simulation suggests that leaving a residue proportion of 40% allows optimizing crop productivity and farming capacity by maintaining livestock alive. However, limitations from the model and its calibration may make this value different in reality. The simulation suggests that there exists a range for the percentage of residue left in the soil surface to optimize two processes that depend on residue supply.

Discussion

Results of the simulation

In the circumstances of North Zimbabwe, yield appeared to be strongly limited by available water (640 mm for the 2007–08 season used for model calibration), more so than by nutrients provided by mineral fertilizers, manure or soil organic matter content (Figure 7). This may be due to the fact that cultivation intensity is relatively low in North Zimbabwe, soil organic C content in the top 20 cm is declining only by about 10 tons between forest clearance and the long-term equilibrium. Manure application from the cattle that could be fed through the dry season with (part of) the residue had little impact on yield. Therefore, the role of cattle as a source of nutrient transfer through manure from (common) grazing areas to (private) fields appeared minor in the conditions of North Zimbabwe. However, our study revealed an important role of cattle as a source of traction (Figure 9). Feeding the bulk of crop residue to cattle may lead to lower yields, but it may enable more cattle to be kept and thus a greater area to be put under cultivation. Various factors may predispose farmers towards this intensification strategy, for example reducing the risk of crop destruction by flooding, pests, disease, and wildlife by spreading their production in different areas (Baudron et al. in press). In such context, large-scale CA adoption may only be possible (1) if risk mitigating measures are put in place, and; (2) if alternatives to animal traction become available (e.g., two-wheel tractors).

Limits of the model used

This work should only be considered as the first step of the exploration of tradeoffs in the use of cereal residue. More work is required to calibrate the model better. Firstly, genetic coefficients (of the Pioneer 8333 sorghum variety) should be calibrated to better fit the phenology and the productivity of the varieties grown in North Zimbabwe (using empirical data). Secondly, DSSAT appeared to simulate the effect of mulch in a very simplistic way (Figure 5). Rather than being linear, the effect of mulching on grain yield should level off after a certain threshold is reached. Moreover, soil organic matter content on water-limited yield should influence the shape of the curve;

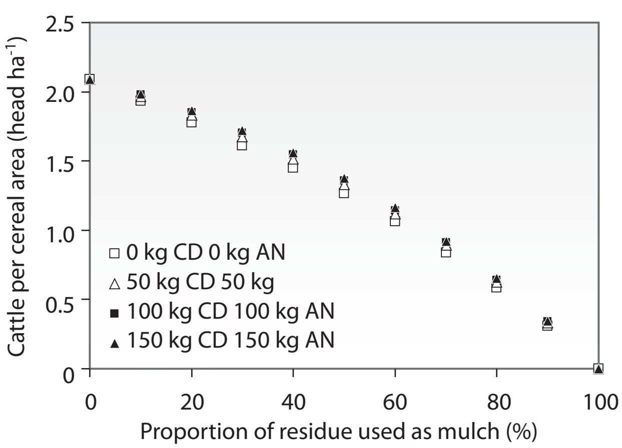

Figure 8. Simulated number of cattle per surface area of sorghum that can be fed during the dry season, as a function of the proportion of residue used as mulch and as a function of mineral fertilization.
CD = Compound D; AN = ammonium nitrate.

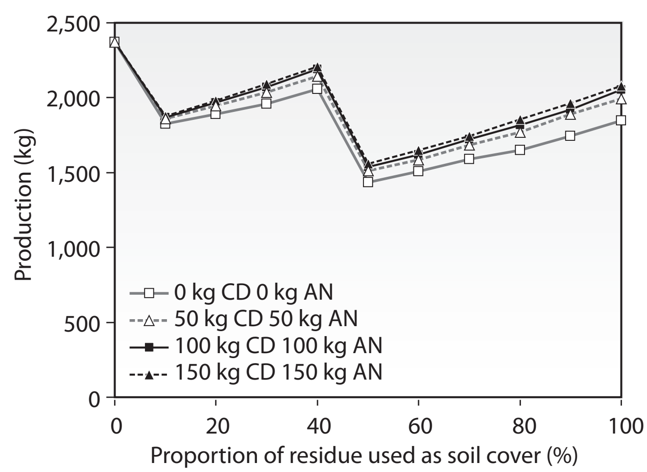

Figure 9. Simulated production of sorghum per farm, as a function of the proportion of residue used as mulch and as a function of mineral fertilization.
CD = Compound D; AN = ammonium nitrate.

whereas our simulation runs using DSSAT did not demonstrate any relationship. A more precise relationship of water-limited yield as a function of residue mulching and soil organic matter content could be derived using empirical data from another area having similar climate and soil conditions (to the best of our knowledge, this data is not available for North Zimbabwe). Finally, the nitrogen-limited yield module, the phosphorus-limited yield module and the potassium-limited yield module need to be calibrated for the circumstances of North Zimbabwe (this was not done due to limited time, but empirical data are available). The effect of water available to the crop on these nutrient-limited yields also needs to be better calibrated. When this is done, we assume that nutrients (and in particular nitrogen) would play a more important role in driving the system at intermediate to high levels of mulching than what the model predicted.

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Appendix 1

```
TITLE SOC_SUB_MODEL
**************************************************************************
INITIAL
**************************************************************************
*INITIAL CONDITIONS-----------------------------------------------------

INCON RESCRI = 0.; RESCLI = 0.
INCON ROOTCI = 1500.; AOMCI = 17280.; SOMCI = 11520.
INCON ZERO = 0.

*RUN CONTROL AND OUTPUT------------------------------------------------

TIMER STTIME=1.; FINTIM=250.; DELT=1.; PRDEL=1.

TRANSLATION_GENERAL DRIVER= 'EUDRIV'

PRINT TOTSC, AOMC, SOMC, SYSTC, ROOTC, RESC, NRCO2C

PARAM TOTSC0 = 28.8; CRRES = 900.; RTYLD = 1500.; FRINC = 1.
PARAM MANAPP = 0.
PARAM TDEPTH = 0.2; BULKD = 1.37; CLAY = 16.0; SILT = 14.0
PARAM CCRES = 0.45; FRESCL = 0.7; CCMAN = 0.1; DMCMAN = 0.7
PARAM MRDRRC = 0.9; MRDRRT = 0.8; MRDRMC = 0.15
PARAM FRSTRT = 0.5; FRSTMN = 0.5; GREFFM = 0.7
PARAM PCSOMC = 0.2; MRDRSC = 0.075; HUMFAC = 0.1
PARAM FRSOMC = 0.4; MRDRAC = 0.1
**************************************************************************
DYNAMIC
**************************************************************************
*Initialisation of residue C pool (kg/ha)
RESC0 = FRINC * CCRES * CRRES

*Total soil C pool (kg ha-1)
TOTSC = AOMC + SOMC

*Total C in the sub-system  (kg ha-1)
SYSTC = AOMC + SOMC + ROOTC + RESC

*Residue C pool (kg C ha-1)
RESC = RESCL + RESCR

*Labile fraction
RESCL = INTGRL(RESCLI, NRESCL)

*Resistant fraction
RESCR = INTGRL(RESCRI, NRESCR)

*Net rate of change of C in the residue pool, labile fraction
NRESCL = ARESCL - RESCLD

*Net rate of change of C in the residue pool, resistant fraction
NRESCR = ARESCR - RESCRD

*Residues incorporated (kg DM ha-1) - CRRES comes from cropsim
RESINC = CRRES * FRINC

*Annual C input incorporated with crop residues, labile fraction
ARESCL = RESINC * CCRES * FRESCL

*Annual C input incorporated with crop residues,resistant fraction
ARESCR = RESINC * CCRES * (1. - FRESCL)

*Decomposition of crop residues, labile fraction
RESCLD = RESCL * MRDRCL

*Decomposition of crop residues, resistant fraction
RESCRD = RESCR * MRDRCR
```

```
*Stabilisation of residue C in SOM, kg C/ha/yr [to stable soil C pool]
RESCST = RESCR * (1. - MRDRCR)

*Relative decomposition rate of stable residue C pool SET AT 1/3
MRDRCL = MRDRRC
MRDRCR = MRDRRC * 0.33

*Root C pool (kg C ha-1) - dead roots
ROOTC = INTGRL(ROOTCI, NROOTC)

*Net rate of change in the dead root C pool
NROOTC = AROOTC - ROOTDR

*Annual rate of root C added (k/ha/yr)
AROOTC = RTYLD * CCROOT

CCROOT = CCRES

*Annual decomposition rate of dead root biomass (kg/ha/yr)
ROOTDR = (ROOTC-ROOTST) * MRDRRT

*Stabilisation of dead root C in SOM, kg C/ha/yr [to stable soil C pool]
ROOTST = ROOTC * (1. - MRDRRT) *  FRSTRT

*C from Manure applications
MANC = INTGRL(ZERO, NRMANC)

*Net rate of change in manure C pool (kg/ha/yr)
NRMANC = MANCAR - MANCDR

*Annual rate of manure C added (kg/ha/yr)
MANCAR = MANAPP * CCMAN * DMCMAN

*Annual decomposition rate of manure C (kg/ha/yr)
MANCDR = (MANC - MANCST) * MRDRMC

*Stabilisation of manure C in SOM, kg C/ha/yr [to stable soil C pool]
MANCST = MANC * (1. - MRDRMC) * FRSTMN

*Active C pool (kg C ha-1)

AOMC = INTGRL(AOMCI, NRAOMC)

*Net rate of change of the active OM C pool (kg C/ha/yr)
NRAOMC = GREFFM * (RESCLD + RESCRD + MANCDR + ROOTDR) - AOMCDR

*Annual decomposition rate of the active OM C pool (kg C/ha/yr)
AOMCDR = AOMC * MRDRAC

*Soil C pool (kg C ha-1)

SOMC= INTGRL(SOMCI, NRSOMC)

*Net rate of change of the SOM C pool (kg/ha/yr)
NRSOMC = AOMCDR * HUMFAC - SOMCDR + SOMCDR * STABSC + ...
      MANCST + RESCST + ROOTST

*Protection capacity of SOM - stabilisation factor
STABSC = PCSOMC * TEXTCF
FINE = CLAY + SILT
TEXTCF = AFGEN(TEXTCT, FINE)
FUNCTION TEXTCT = 0.,0.1, 15.,0.4, 30.,0.6, 60.,0.7, 90.,0.8, 100.,0.9

*Decomposition of soil organic C (kg ha-1 season-1)
SOMCDR = SOMC * MRDRSC

*CO2-C production (kg C ha-1)

CO2C = INTGRL (ZERO, NRCO2C)

*Annual rate of CO2 emission from decomposition of C pools (kg C/ha/yr)
NRCO2C=(RESCLD + RESCRD + ROOTDR + MANCDR)*(1.-GREFFM) + ...
      AOMCDR*(1.-HUMFAC) + SOMCDR*(1.-PCSOMC)

END
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Chapter 8. Designing an implement for bed planting in Tunisia

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Keywords: bed planting, conservation agriculture, soil, tillage, and experimental protocol

Abstract

Traditional soil cultivation systems in Tunisia with intensive soil tillage (broadcast) and conventional tillage using seeders generally lead to soil compaction and loss of crop productivity compared to bed planting systems. The purposes of this work are to continue research and further explore new development options permitted by conservation agriculture using bed planting. The objective is to design an implement for bed planting, and develop an experimental protocol to compare conventional tillage, conventional beds and permanent beds at the experimental station of the National Institute of Crops in Tunisia, Chbika.

Introduction

Wheat is the major crop in the irrigated areas of northern and central Tunisia. Wheat is planted after tillage, either planted by hand (broadcast), with conventional seeders, or through direct seeding retaining residue. Conservation agriculture, based on minimum soil disturbance, retention of crop residue and crop rotation, has advantages compared to conventional tillage systems, but it still poses many problems like compaction, water consumption, and weed control. A potential way to apply the principles of conservation agriculture, which could possibly solve part of these problems, is bed planting where crops are planted on top of the bed and irrigation is applied in the furrow. This technique is suitable for crops that are sensitive to water stress and salinity. It aims at improving soil health, quality, increasing productivity, and saving time and money.

Materials and methods

Functional analysis

Functional analysis

Functional analysis of the need or the functional description is an approach that applies to the creation or improvement of a product. It occurs most often in the form of a graph or chart analysis.

Research the fundamental need

This is the express purpose and limitation of the study based on the tool "horned beast" which asks the questions grouped in Figure 1 for the system to be studied.

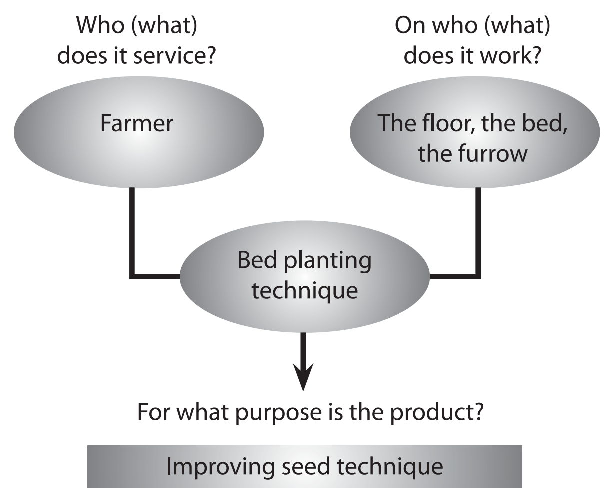

Figure 1. Diagram 'Horned Beast'.

Search service functions (Octopus Diagram)

This technique shows on a diagram, called the "Octopus Diagram", the elements of the product environment.

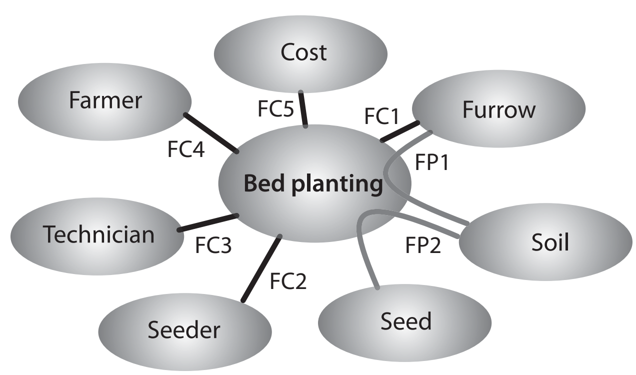

Figure 2. Octopus Diagram.

Main duties:
FP1: Forming the furrow irrigation for better irrigation
FP2: Place the seed on the bed (soil).

Operational constraints:
FC1: Furrow must be permanent.
FC2: Generate efforts that can withstand the planter
FC3: Must be flexible in setting up and dismantling
FC4: Must be adjustable by the operator
FC5: Must be inexpensive.

Prioritization of service functions
This operation is to quantify each function by a value ranging from 0 to 3 to assign an order of importance. Devaluation scale:

Note	Note level of importance
0	Level equal.
1	Slightly more than one.
2	Somewhat higher.
3	Significantly higher.

Method of pair wise comparisons:

	FP2	FC1	FC2	FC3	FC4	FC5	Points	%
FP1	FP1 1	FP1 2	FP1 1	FP1 3	FP1 3	FP1 2	12	40
	FP2	FP2 1	FP2 1	FP2 2	FP2 3	FP2 1	8	26.66
		FC1	0	FC1 2	FC1 1	FC1 1	4	13.33
			FC2	FC2 1	FC2 1	FC2 1	3	10
				FC3	FC4 1	FC5 1	2	6.66
					FC4	FC4 1	1	3.33
						FC5	0	0
						Total	**30**	**100**

Histogram of wishes
From the previous table, we can draw a chart of wishes concerning the service functions.

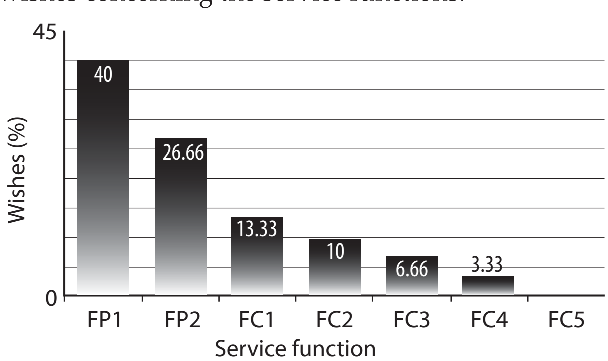

Figure 3. Chart of wishes about service functions.

Specification of functional loading

Overview of the problem
Designing an implement for bed planting.

Objective
The system should generate efforts to make permanent beds.

Fields of application
This system must be mounted in a semi-arid lower area.

Concepts to develop
It must make beds and furrows.
It must adapt to the soil type.
It must respect the space allowed in the planter

Functions to be undertaken
- FP1: Forming the furrow irrigation for good irrigation.
- FP2: Place the seed on the bed (soil).
- FC1: Furrow must be permanent.
- FC2: Generate efforts that can withstand the planter.
- FC3: Must be flexible in setting up and dismantling.
- FC4: Must be adjustable by the operator
- FC5: Must be inexpensive.

Requirements
- Reliability: Guaranteed continuous operation.
- Yield: Should be maximum.
- Simplicity: The system should be as simple as possible.
- Assembly and disassembly should be simple and easy.
- Manufacturing cost must be acceptable.

Functional analysis technique

The analytical method FAST
The analysis method “FAST” will allow us to achieve technical solutions based on service functions previously identified.

The method relies on an interrogative technique:
- **Why?** Why should a function be provided? Access to a technical function of higher order; this is answered by reading the chart from right to left.
- **How?** How should this function be provided? Then we decompose the function, and can read the answer to the question by traversing the graph from left to right.
- **When?** When should this function be provided? Search for simultaneity, which is then represented vertically.

In the following sections we develop the FAST diagram corresponding to the service functions of our system.

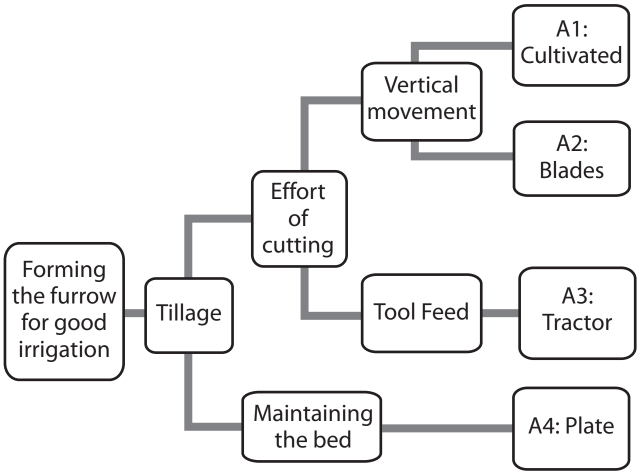

Figure 4. FAST diagram corresponding to FP1: Forming the furrow for good irrigation.

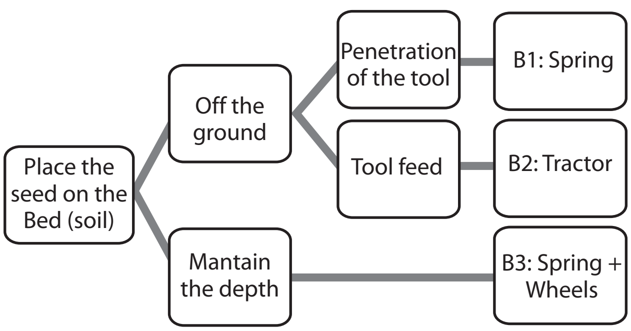

Figure 5. FAST diagram corresponding to FP2: Place the seed on the bed (soil).

Implement design

Elements of a planter

- It includes two hoppers (or safe): One for seed and one for fertilizer, distribution elements dosing the quantity of seed dropping, decent tubes, bodies coulter, and seed covering elements.
- The distribution mode is essentially mechanical.
- The mechanical method of distribution varies with the type of distributor that can be used: With pins (clumps) or grooves.
- In our case we will use the distribution groove.
- The bodies of a conventional drill line are usually the hopper, dropping tubes, disc coulters, and recovery devices (small pieces of harrows or claws sometimes accompanied by rolls of reconsolidation).
- The implement is made up of three different articulated bars making the main body of the implement.

For wheat we will use sowing elements from Semeato that we will attach to the three bars (main implement).

Figure 6. Sowing element of Semeato for wheat.

The same will apply in the case of maize. We will use sowing elements designed for this in Semeato implement.

Figure 7. Sowing element of Semeato for maize.

Groove distribution

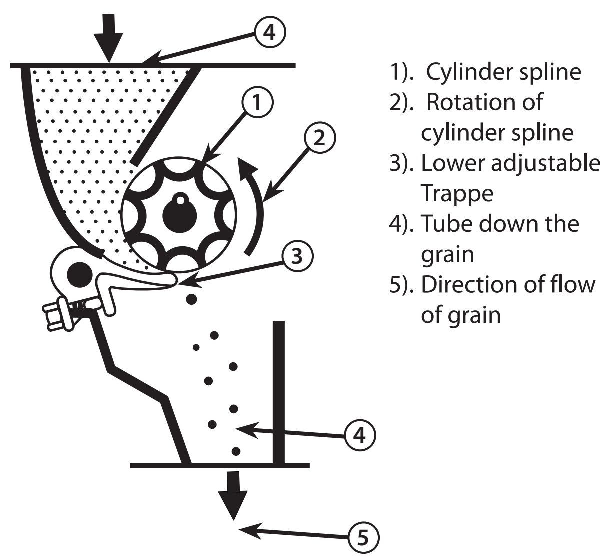

Figure 8. Groove distribution.

What is expected of a bed planter?

- Accuracy of the seed rate: The seed rate distributed by the planter and selected initially by the farmer must be constant regardless of the topography and condition of the plot.
- Compliance with the dose between sowing lines: The regularity of sowing starts with a good dose distribution of seedlings among the different lines of seed.
- The distribution of seeds on the seed row: The final quality of the distribution of seeds on the seed row depends on the distribution of the drill, transport to the coulter (gravity or pneumatic) and burying (plows, disks).
- The capacity and regularity of coulter depth control: Under the terms of seedlings (more or less loosened soil, more or less wet, etc.) and the species to seed, it is necessary to adjust the planting depth.
- The regularity of the planting depth: The regularity of sowing depth due to the characteristics of the sowing element, adjustments made and the condition of the seedbed.

Experimental protocol

Objective:	To compare bed planting system with conventional tillage
Location:	Kairouan, Chbika
Experimental design:	Three replications A1: permanent bed (narrow) (0 years) A2: bed planting conventional till A3: conventional till
Rotation:	Wheat–maize
Plot size:	Four beds wide (75 cm/bed) Two rows of wheat, one row of maize on top of each bed
Varieties:	Wheat – khiar Maize – to be specified
Seed rate:	Wheat – 180 kg/ha Maize – 25 kg/ha
Irrigation:	Irrigated bed planting (furrow)
Fertilization:	Normal treatment
Weed, disease and insect:	As needed and standard for station management
Data to be collected:	1. Plant population 2. Plant height 3. Productive tiller count 4. Yield 5. Thousand kernel weight 6. Grain N 7. Irrigation water savings

Results and discussion

Field observations and comparisons in Tunisia with the standard tillage system and bed planting system over a 1 year period indicate that wheat was more productive in bed planting. In the future we will make a similar assessment to the one that has been done in CIMMYT, Bangladesh, to evaluate a power tiller operated zero tillage planter for maize, wheat and mungbean (Hossain et al. 2006). The performance of this zero tillage planter for wheat and maize is shown in Table 1. The authors found that soil moisture content was the key factor for utilization of a zero till machine, with the planter being suitable to operate in soils having a moisture content below 35%, avoiding excess wheel slippage. The effective widths of the planter for wheat and maize were 80 cm and 140 cm, respectively. Fuel consumption during wheat and maize sowing was 1.4 l/h (Hossain et al. 2006).

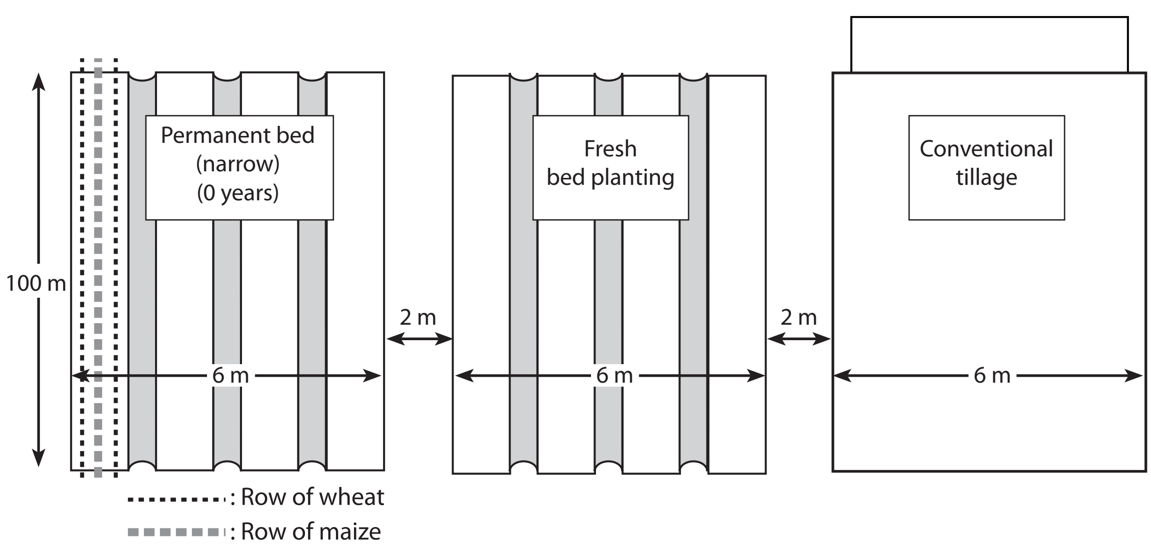

Figure 9. Experimental layout.

Table 1. Performance of power tiller operated zero tillage planter in planting of different crops (adapted from Hossain et al. 2006).

Parameters	Wheat	Maize
Fuel consumption (l/h)	1.4	1.4
Speed of operation (km/h)	2.2	2.25
Soil moisture content (%)	31	29
Wheel slippage (%)	9	8
Effective field capacity (ha/h)	0.14	0.23
Field efficiency (%)	80	73

Crop performance of the zero tillage planter is shown in Table 2. For the case of Tunisia, we will adjust the seed rate for wheat and maize to 180 kg/ha and 25 kg/ha, respectively, and the row spacing to 20 cm and 75 cm, respectively.

Table 2. Crop performance of power tiller operated zero tillage planter (adapted from Hossain et al. 2006).

Parameters	Wheat	Maize
Seed rate (kg/ha)	120	20
Row to row spacing (cm)	20	75
Depth of planting (cm)	3–4	4–5
Width of opening slit (cm)	1–2	1.2–2.4

The yield of wheat and maize for a zero tillage system and the conventional method in Bangladesh are compared in Table 3. The average wheat yield was 2.9 t/ha, which was competitive with the conventional method (2.5 t/ha). The yield of maize in zero tillage and conventional system was also similar (Hossain et al. 2006). Of course the yield of wheat in a zero tillage system varies from place to place due to land type, soil moisture, lack of fertilizer and weed management, but we hope to reach similarly positive results with bed planting in Tunisia.

Table 3. Comparison of yield between zero tillage and conventional planting (adapted from Hossain et al. 2006).

Planting system	Yield (t/ha) Wheat	Yield (t/ha) Maize
Zero tillage system	2.9	8.1
Conventional method	2.5	8.5

The costs of planting for different crops were different because the effective field capacity of the planter was different. The planting costs of wheat and maize in zero tillage were 37% and 75% less, respectively, than that of the planting cost of the conventional method (Table 4; Hossain et al. 2006).

Table 4. Planting cost comparison of zero tillage machine and conventional method (adapted from Hossain et al. (2006).

Planting system	Cost of planting (TK/ha) Wheat	Cost of planting (TK/ha) Maize
Zero tillage system	1,297	888
Conventional method	2,060	3,560

Improved profitability:

- Saving time by removing the work of soil preparation (4.75–5.75 h/ha)
- Improving fuel economy by reducing fuel consumption (36–46 l/ ha)
- Reduced average cost of mechanization and production of wheat and maize by 20% and 14%, respectively

We will make the same comparisons in Tunisia as those explained in Hossain et al. (2006) for bed planted and conventional tillage, adapting the tests to local conditions.

Conclusion

Results from other parts of the world indicate that bed planting is a promising technology for Tunisia and can potentially result in cost savings and highly productive crops. The functional analysis outlined in this paper highlights important points to be taken into account when developing a bed planter for Tunisian conditions. The bed planter will be tested using the developed protocol.

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Chapter 9. Conservation agriculture and its impact on soil quality: Highlights of Moroccan research results in semi-arid areas

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Keywords: conservation agriculture, no-tillage, residue management, soil degradation, and soil quality.

Abstract

Soil degradation is a serious concern in the semi-arid areas of Morocco which are characterized by low soil fertility and harsh climatic conditions. In these areas, where crop/livestock production systems predominate, a conventional farming system based upon intensive tillage, overgrazing and inappropriate crop management is practiced and, consequently, there has been a depletion in soil quality leading to reduced yield. The objective of this paper is to review and summarize available results on the effect of conservation agriculture (CA) on soil quality in semi-arid Morocco. CA is a promising technology for these agricultural systems and has been proven effective for improving soil quality to enhance beneficial soil physical properties and also for improving the chemical properties. Higher aggregation, carbon sequestration, nitrogen conservation, pH decline and organic matter buildup are major changes associated with the shift from conventional to CA based mainly on no-tillage.

Introduction

Soil degradation is on the increase worldwide and is becoming an important threat to global food production and security. In Africa, a study found that 75% of farmlands are plagued by severe soil degradation caused by wind and water erosion and the loss of essential mineral nutrients (Connor 2006). Thus, African countries face not only the challenge of increasing agricultural production with scarce overall resources, but must raise productivity in a way that conserves soils and prevents further degradation.

In Morocco, soil degradation, with its various facets, is a critical problem threatening agricultural and rural development (Mrabet 2007). In fact, more than 90% of the country's land is affected by desertification (Le Houérou 1995) and about 74% of the 22 watersheds are highly threatened by erosion (HCEFLCD 2007). Soil degradation is a serious concern especially in the semi-arid areas characterized by low soil organic matter and harsh climatic conditions. In these areas, where crop/livestock production systems predominate, a conventional farming system is practiced involving intensive tillage and crop residue removal. The custom is to plow frequently before sowing. Cultivation starts with summer intensive tillage that has been synonymous with farming performance (El Gharass et al. 2009). Harvesting is done to obtain both grain and straw yields, leaving no residue as soil cover. There is also free grazing of animals on the stubble after harvest. These practices based upon unnecessary abusive tillage, overgrazing, and inappropriate crop management have led, in the long-term, to depletion in soil quality leading in return to reduced yield.

This situation implies the need for a compromise between sustainable agricultural production that conserves soils, yet provides income to farmers at an acceptable level of productivity (Wall 2009). Conservation agriculture (CA) is a promising technology for these agricultural systems and has been proven effective for the conservation of soil resources, increasing the efficiency of water use and, of special importance, reducing the effects of droughts (FAO 1999). CA is defined as a sustainable production system that combines the following basic principles (Govaerts et al. 2009a):

1. Reduction in tillage: The objective is the application of zero tillage or controlled tillage seeding systems that normally do not disturb more than 20–25% of the soil surface;
2. Retention of adequate levels of crop residues and surface cover of the soil surface: The objective is to maintain an adequate soil cover through the retention of sufficient crop residues on the soil surface to protect the soil from water/wind erosion, water run-off and evaporation to improve water

productivity and to enhance soil physical, chemical and biological properties associated with long term sustainable crop production;

3. Use of crop rotations: The objective is to employ economically viable, diversified crop rotations to help moderate/mitigate possible weed, disease and pest problems and offer economically sound cropping alternatives to help minimize farmer risk.

These CA principles seem to be applicable to a wide range of crop production systems including low-yielding, dry rainfed as well as high-yielding irrigated conditions (Govaerts et al. 2009a). In the semi-arid area of Morocco, numerous studies have been done to identify the effect of CA on soil quality and productivity, compared with common farming practices. Therefore, the objective of this paper is to review and summarize available results on the effect of CA on soil quality in semi-arid Morocco.

Semi-arid areas of Morocco: Resource bases

Climate

The climatic context of the region is mostly Mediterranean, characterized by high variability of annual rainfall in amounts and distribution. In general, the precipitation is low and highly variable from one season to another and within the cropping year. Although drought can occur at any time during the growing season, two main periods of drought are more likely; the early one that coincides with seed germination and seedling emergence and the terminal drought that is more frequent and affects grain set and growth (Watts and El Mourid 1988). Moreover, a study conducted in the region showed that the total amount of rain is decreasing significantly (Figure 1) reducing the growing season from 180 days in 1960–1965 to 110–130 days for the period 1995–2000 (Benaouda 2001). In addition, an increase in temperature has also been observed, leading to a high evapotranspiration rate, increasing the water deficit. Hence, the challenge for sustainable productivity in this area is accentuated by extremely harmful climatic conditions making the soil more vulnerable to the different degradation processes. The effect of the climatic conditions is also exacerbated by low soil fertility and inappropriate farming practices.

Soils

Soils in semi-arid Morocco represent an enormous variability according to various soil taxonomic systems (Badraoui 2006). In general, these soils are characterized by their high content of calcium and calcium carbonates and are rich in clay (Kassam 1981). According to the French soil classification system, these soils are calcimagnesic with a tendency to vertic behavior, or Chromic Calcixerert in the US Taxonomy. This silty clay soil swells and shrinks, but is also susceptible to seal or crust formation. Organic matter content is low and therefore the structure of the soil is rather poor (Dimanche and Hoogmoed 2002). Also, these soils tend to have medium to poor fertility with low P and N levels (Ryan et al. 2006). These soil characteristics result in inherent fragility which can cause rapid deterioration of soil productivity (Mrabet 2007).

Cropping systems

In semi-arid Morocco the main crops are barley and wheat. The main farming systems are one crop per year or three crops in 2 years. Crop rotation based on cereals is either continuous cereals with fallow

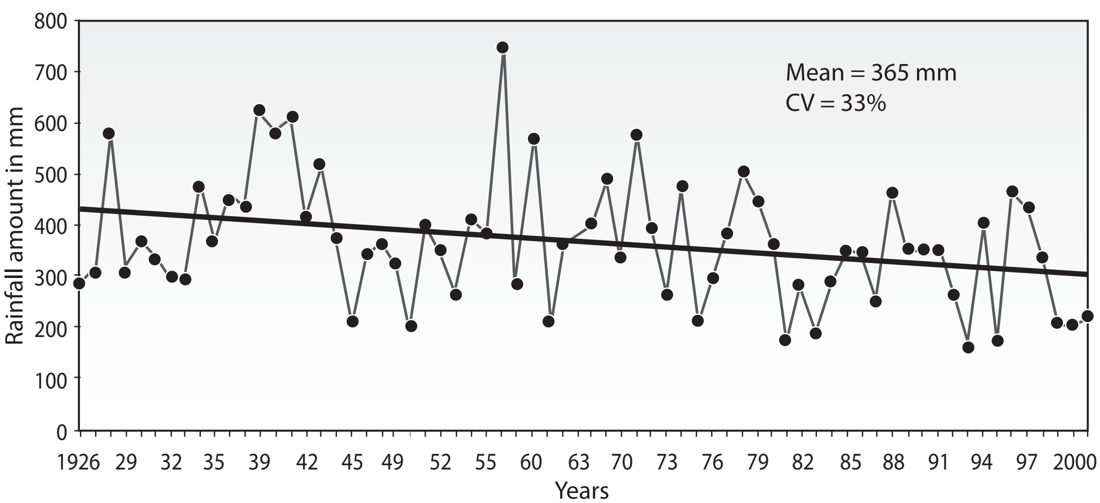

Figure 1. Rainfall evolution in Settat (Benaouda 2001). CV = coefficient of variance.

or in rotation with food legume, forage, or spring crops such as chickpea. However, wheat–fallow is the dominant cropping system. In these areas, most of the farming systems integrate crop and livestock production. This integration is stretched with rainfall scarcity and shallow soils. Beyond social and economic consideration, the cropping system is dictated by the average annual rainfall and the nature of soil and its water storage capacity (Table 1).

In these areas a conventional farming system is practiced involving intensive tillage and crop residue removal. The custom is to plow frequently before sowing. Indeed, cultivation starts with summer intensive tillage that has been synonymous with farming performance (El Gharass et al. 2009). Harvesting is done to obtain both grain and straw yields, leaving no residues as soil cover. There is also free grazing of animals on the stubble after harvest. These practices based upon unnecessary abusive tillage, overgrazing and inappropriate crop management have led, in the long-term, to depletion in soil quality leading to reduced yield.

Limiting factors for agriculture productivity

Besides climatic constraints, low soil quality is one of the major problems facing agriculture productivity in the semi-arid areas of Morocco. Indeed, the soils have some properties that limit crop production such as: (1) low structural porosity and consequently high bulk density which reduces root penetration and water circulation, (2) a tendency for compacting during the dry season that results in high runoff, (3) poor infiltration due to rapid surface crusting even after cultivation, (4) low values of available water, and (5) poor soil chemical fertility (Mrabet 2007). Moreover, long-term over use of machinery, intensive cropping, short crop rotations, intensive grazing, and inappropriate soil management have led to a further decline of soil quality. According to Lopez-Bellido (1992), tillage is responsible for most soil degradation in the Mediterranean basin. Repeated tillage operations can induce greater soil erosion.

To alleviate these problems, CA has been recognized as an alternative to conventional tillage in the semi-arid areas of Morocco (Mrabet 2006). In the early 1980s, Moroccan research has addressed the issue of CA based on no or reduced tillage as one of the main research programs in this area (El Gharass et al. 2009). Numerous studies have been conducted to identify the influence of CA on soil quality. Highlights of related results are outlined in the following sections.

Conservation agriculture and its impact on soil quality

The concept of soil quality can be defined as the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran and Parkin 1994). Good quality soil is critical for crop production sustainability and environmental health and is vital to global function. Research on CA systems all over the world has shown its positive effect on the indicators of soil quality (Verhulst et al. 2010). In semi-arid Morocco, it was found that the soil's attributes have drastically changed due to elimination of soil manipulation with tillage tools (Mrabet 2006).

Soil physical quality

Soil structure and aggregation

Soil structure research showed that the lack of annual tillage, as provided under continuous no-tillage management, encouraged the development and persistence of a soil surface horizon rich in stable aggregates in semi-arid Morocco (Mrabet 2002; Mrabet and El Brahli 2005). No-tillage was found to increase mean weight diameter and wet aggregation index compared to reduced tillage systems (Kacemi et al. 1995). Mrabet et al (2001a) reported a higher mean weight diameter and aggregation index at the surface (0–7 cm) of a self-mulching swelling clay soil under no-tillage than under conventional tillage. The

Table 1. Common crop rotations for different agro-climatic conditions (El Gharass et al. 2009).

	Rainfall (mm)		
Soil depth	< 300	300–400	> 400
Deep soil	wheat/fallow	wheat/wheat/fallow or wheat/wheat/faba bean or spring chick pea	wheat/wheat/sunflower wheat/wheat/winter or spring food legume
Shallow soil	continuous barley	wheat/forage wheat/lentils	wheat/forage crop continuous wheat

reduced aggregation in conventional tillage is a result of direct and indirect effects of tillage on aggregation (Beare et al. 1994; Six et al. 1998). The aggregate formation process in conventional tillage is interrupted each time the soil is tilled with the corresponding destruction of aggregates (Verhulst et al. 2010). Lahlou (1999) also found an increased wet aggregation index with increased residue cover under no-tillage, mainly at the soil surface (0–2.5 cm). Indeed, higher soil organic matter was often associated with aggregation improvement under no-tillage.

Soil moisture

CA can increase infiltration and reduce runoff and evaporation compared to conventional tillage and no-tillage removing residue. Consequently, the soil moisture is conserved and more water is available for crops (Verhulst et al. 2010). Tillage can influence the evaporation process because of its effects on the physical properties of the soil surface (albedo, roughness, mulch) and on the hydraulic properties (Mrabet 2007). Keeping residue on the soil surface is known to reduce soil evaporation. In fact, Mrabet (1997) proved that the soil can maintain its moisture above the wilting point in the seed zone for up to 5 weeks in no till with residue cover whereas it is only able to maintain it for 15 days in tilled plots (Mrabet et al. 2001a). As reported in Figure 2, no-tillage with residue cover of 60% permitted a higher time to reach wilting point than any applied tillage system.

Soil bulk density

The effect of CA on bulk density is a controversial issue. In fact, the influences of different tillage practices on bulk density are variable. Some studies reported that no-tillage results in a higher bulk density of the soil and consequently greater soil strength. However, in other studies, the bulk density was similar or lower with no-tillage than with conventional tillage.

In semi-arid Morocco, after 4 years of experimentation, Lahlou (1999) reported a natural consolidation and mechanical compaction in no-tillage causing denser packing of top soil. However, Ait Cherki (2000) did not find a significant increase in dry bulk density under no-tillage systems compared to conventional after 6 years of experiments. According to Kacemi (1992) differences in soil bulk density, between no-tillage and minimum tillage with V-swep, were negligible among rotations.

Water infiltration

Many studies have reported that the permanent soil cover in CA reduces run-off, leading to higher infiltration rates and more water available to crops (Le Bissonnais 1996; Govaerts et al. 2007; Govaerts et al. 2009b). The research on water dynamics in CA systems executed in Morocco under dry regimes showed clearly that not tilling the soil and mulching extended the humid period significantly (Mrabet 1997). Rainfall infiltration is improved under no-tillage systems, which increases the amount of soil water available for plants for heavy textured soils (Bouzza 1990; Kacemi 1992; Mrabet and Elbrahli 2005).

The rate of infiltration is controlled by pore size distribution and the continuity of pores or pathways. Hence, the effect of tillage and residue cover on water infiltration is probably due to changes in soil

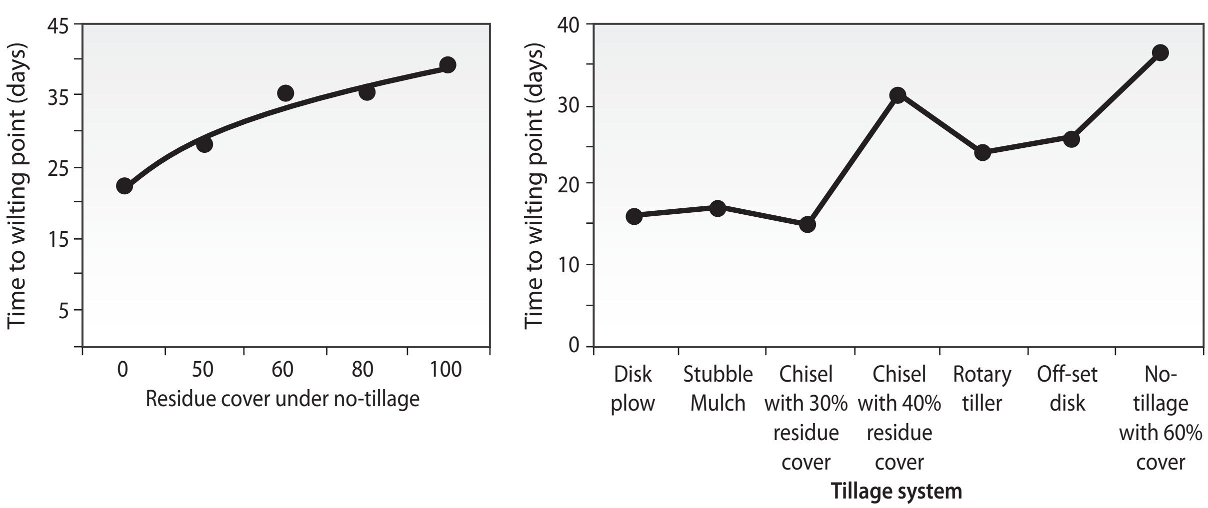

Figure 2. Evaporation of water as affected by tillage and residue management under no-tillage as expressed in terms of time to wilting point (soil wilting point is 0.16 g g^{-1}) (Mrabet 1997).

structure (Mrabet 2007). Indeed, the presence of crop residues over the soil surface prevents aggregate breakdown by direct raindrop impact as well as by rapid wetting and drying of soils (Le Bissonnais 1996). Moreover, aggregates are more stable under no-tillage with residue retention compared to conventional tillage and no-tillage without residue retention (Verhulst et al. 2010). Dimanche and Hoogmoed (2002) compared two soil tillage systems (off-set disking and reduced tillage with spring tine cultivator) under simulated rainfall on a Chromic Calcixert soil of the semi-arid region of Meknes and concluded that disc harrow caused excessive pulverization and seal formation. Consequently, reduced tillage systems had higher infiltration rates than conventional tillage.

In addition, the rotation of different crops with different rooting patterns combined with minimal soil disturbance in no-tillage systems promotes a more extensive network of root channels and macropores in the soil that helps with water infiltration to deeper depth (Kacemi 1992).

Soil chemical quality

Soil organic matter

Organic matter plays an important role in nutrient availability and soil aggregate stability. In semi-arid Morocco low organic matter is the major feature of soils. Hence, good organic matter management is essential for sustainable agriculture. There is evidence that elimination of tillage can result in sequestration of carbon (Mrabet et al. 2001a; Bessam and Mrabet 2003).

Mrabet et al. (2001b) recorded increases in soil organic matter of 13.6% with no-tillage, and 3.3% with conventional tillage over an 11-year period, with differences being greater in the top 25 mm layer. Generally, there is a trend towards a stratification of soil organic matter at the surface under no-tillage (Franzluebbers 2002). At 0–25 mm, soil organic matter increased from 5.6 to 7.2 Mg ha^{-1} under no-tillage, after 4 and 11 years, respectively. At the same horizon, soil organic matter level did not change under conventional tillage after the same periods (Mrabet 2006; Mrabet and El Brahli 2005; Bessam and Mrabet 2001). It is also reported that no-tillage soil has sequestered 3.5 and 3.4 Mg ha^{-1} of soil organic matter more than conventional tillage in the 0–200 mm horizon, after 4 and 11 years, respectively. No-tillage also increased organic matter content of aggregates in all classes of a Calcixeroll soil in Morocco (Bel Mekki 2005; Mrabet et al. 2003).

Soil nutrients

Tillage, residue management and crop rotation have a significant effect on nutrient distribution and transformation in soils (Verhulst et al. 2010; Etana et al. 1999). Due to its impact on soil organic C and N mineralization, CA can influence soil N availability (Gilliam and Hoyt 1987). However, the literature concerning the effect of reduced tillage with residue retention on N mineralization is inconclusive (Verhulst et al. 2010). Zero tillage is generally associated with lower N availability because of greater immobilization by the residues left on the soil surface (Bradford and Peterson 2000; Rice and Smith 1984).

After 4 years of experimentation at Sidi El Aidi, significantly higher nitrogen was recorded for no-tillage compared to conventional tillage, particularly at the surface (0–25 mm) (Mrabet et al. 2001a). The same authors found, after 7 years in the same site and under continuous wheat, that no-tillage sequesters more N than conventional and reduced tillage systems. It is also reported by Bessam and Mrabet (2001, 2003) that nitrogen in particulate organic matter (Npom) was higher under no-tillage than conventional tillage in the seed zone from 4 to 13 years of experimentation. However, the effect of these tillage systems was not significant in deeper soil layers (50–100 and 100–200 mm). The same authors showed that Npom is more influenced by residue management than total nitrogen.

A positive effect of no-tillage has also been observed on the availability of P and K. According to Mrabet et al. (2001a), no-tilled soil had a higher concentration of P and K near the soil surface than tilled soil, whereas in deeper layers the reverse has been observed. The same authors suggest that P and K were probably higher in the surface of no-tilled soil due to higher soil organic matter. Progressive mineralization of organic matter was the most important source of these nutrients in this soil under no tillage. Franzluebbers et al. (1995, 1994) explain this fact by the accumulation of microbial biomass near the surface.

Soil pH

Numerous studies have reported that the pH of the top soil in no-tillage is lower than in conventional tillage (Verhulst et al. 2010). The results obtained by Ibno-Namr and Mrabet (2004) and Ibno-Namr (2005) confirmed these findings in the semi-arid area of Morocco for Vertic Calcixerol soil after 11 years of no-tillage. According to Franzluebbers and Hons (1996), the pH decrease may be due to the decomposition of soil organic matter which has been accumulated with no-tillage. This lower pH could also be due to the acidifying effect of nitrogen and phosphorus fertilizers applied more superficially under no-tillage than under conventional tillage (Verhulst et al. 2010; Duiker and Beegle 2006).

Conclusion

In light of the above it is clear that CA can play a major role in improving soil quality in the semi-arid area of Morocco, thus limiting the devastating consequences of drought and ensuring sustainable productivity while reducing threats to the environment. Research on tillage management systems started in the early 1980s. Numerous studies have been conducted which show positive effects of CA in improving soil physical and chemical properties. However, the effect of this innovative management cropping system on soil biological properties has not been studied. Hence, studies on microbiological and faunal activity and biodiversity, C mineralization, and organic matter humification should be undertaken both in the short and long-term under CA systems.

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Chapter 10. Development of conservation agriculture based technologies in the Tianjin winter wheat region

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Abstract

At present, conservation agriculture (CA) is not used in the Tianjin winter wheat region in China. This project proposal outlines the development of appropriate CA technologies which are popular in developed countries and are very important to improve soil quality, save water resources, and increase crop yield over time. This paper also details how to use CA technologies and how to address the issues which would be met in the process of using CA technology in the Tianjin winter wheat region.

Introduction to the Tianjin winter wheat region

Tianjin is located in North China, about 100 km south-east of Beijing; 39°05′N, 117°04′E, 30 m.a.s.l. The soil type varies from sandy to moderate clay. Most of the soil is saline due to the Tianjin region being a plain receding from the sea, the pH is 5.86–8.00, and the organic matter content is 0.39–1.84%.

The climate of Tianjin is temperate and continental monsoon. In the last 10 years, the annual precipitation was about 500 mm. From seeding to heading, the area experiences precipitation of 133 mm, an average monthly air temperature of 5.31°C and a total of 1,273.3 hours of sunlight. From seeding to harvest, precipitation in the area is about 195 mm, average monthly air temperature is 11.38°C, and a total of 1,511.5 hours of sunlight.

The planting style for wheat production is flat planting, and there are only about 2–3 tillers/plant, so the seed rate in farmers' fields is high; about 150–225 kg/ha. The distance between rows is narrow; about 17 cm. The wheat crop is irrigated to complement rainfall. In the whole development stage, flood irrigation is undertaken 3–4 times, depending on weather conditions.

In the Tianjin region the main crops are winter wheat, maize, cotton and in some regions, there is a small area of rice. Farmers use conventional tillage without residue, and sometimes the farmers burn the residue in order to plant the following crop earlier. This reduces soil quality; the soil is saline, low in organic matter and prone to wind erosion.

I am a wheat breeder and believe that if good cultivars are planted in good fields with a high soil quality the cultivars will have a high yield and at the same time we can save fresh water. But how can we keep soil with good quality, and how can we save fresh water?

Conservation agriculture technology

Conservation agriculture (CA) involves minimum soil removal, appropriate crop rotation, and rational residue covering. It is very useful in improving soil structure, increasing the organic matter content of soil, reducing runoff, and saving fresh water. This is very important to maintain high soil quality, adapt to global climate change and increase crop yields to feed the increasing population, especially in China, where land is limited and the population is increasing over time.

Potential problems with using CA in the Tianjin winter wheat region

Machinery problem

In the Tianjin winter wheat region, all farmers are smallholders, and currently no CA technology is used. There is no public or private sector to support farmers using CA machinery. Within China, CA technology is used in a small area in north-western China, and these provinces perhaps produce some machinery that may be able to be used in the Tianjin winter wheat region. However, asking farmers to buy a special seeder for CA would still be a big problem.

Residue availability problem

In the Tianjin winter wheat region most of the families have livestock. Farmers have to remove residue from the field to feed livestock which feed people and earn additional income. Another issue with keeping residue in the field is that farmers need to use the residue for fuel. So every year, after harvest, farmers remove the residue quickly and plant the next crop.

Mindset problem

This is perhaps the biggest problem. CA technology is a type of sustainable technology which doesn't have high benefits in the short-term, especially in the first 5 years of using CA technology. For farmers, even though they know how good CA is, especially for sustainability of agriculture, they simply want to earn more money every year. So, if using CA technology in farmers' fields, agronomists have to do their best to make the crop yield equal to or a little higher than that obtained without CA technology in the first 5 years. It is therefore a great challenge for the agronomist to demonstrate CA.

Methodology

Through using CA technology, agronomists will be met with many problems including machinery, residue retention, mindset, and so on, but agronomists and most people in other fields know how beneficial CA technology is to maintain sustainable agriculture, improve soil structure, save water, and reduce wind and water erosion. It is therefore important that agronomists do something to address these issues to assist with the adoption of CA technology.

Solving CA technology problems in the Tianjin winter wheat region

Before using CA technology in production, agronomists need to do much work to prove how useful CA is, and need to find the best way to improve yield and reduce the cost to farmers. Agronomists need to test chemical, physical and biological soil quality. The following soil quality parameters will be measured:

Chemical soil quality:
- Soil organic matter
- Total N
- pH, EC
- Available P
- Macro-nutrients: Ca, Mg, K, Na
- Micro-nutrients: Fe, Cu, Zn, Mn

Physical soil quality:
- Time-to-pond
- Bulk density
- Dry aggregate distribution
- Wet aggregate distribution
- Dispersion
- Penetration resistance

Biological soil quality:
- Microbial biomass C and N

To quantify fresh water savings, the hours spent in irrigating the area of the field will be recorded.

Through using different agronomic treatments for several years, and testing chemical, physical, and biological characteristics every year, agronomists can know which CA technology is the best one to introduce CA into the Tianjin winter wheat region.

Strategy to apply for municipal and national projects

In general, municipal and national projects provide support for 3 years. In 3 years, agronomists can't expect yields to increase greatly, they can only hope that some positive changes are evident in the soils, test these and make clear these benefits or additional profits to the farmer. After 3 years, agronomists can apply for additional municipal and national items depending on the results obtained in the first 3 years with regards to improved soils and increased profits for farmers.

Extending CA technology in production

Collaboration with provinces where CA technology is currently used

In the north-western regions of China, such as Qinghai province, Gansu province, and Ningxia province, CA technology is very popular, so agronomists can collaborate with the academies of agricultural science and machinery industries. Through these corporations, agronomists can get technology and machinery support and CA technology can extend pretty easily into the Tianjin winter wheat region.

Residue management

All farmers need to keep residue to feed livestock and to use as fuel. It is therefore difficult to keep residue in the field. In some regions, farmers feed livestock with residue and put the manure into the field. In other regions farmers keep partial residue in the field and the remainder is used for animals and as fuel. So, with the use of CA technology in the Tianjin region, agronomists can test different treatments, however, for farmers, I believe the two styles mentioned above are the best options.

Change mindset
In agricultural production, any use of new technology must change a chain of production, and at the same time, the new technology has to beat resistance coming from different sectors such as the government, scientists, farmers, and so on. So agronomists must use generated experimental data to tell others what CA technology is, and how useful it can be. The central and local government support agronomists to use CA technology, however, the government should help agronomists encourage farmers to use CA technology. As soon as farmers get high yields and good soil quality with less costs they will easily adopt CA technologies.

Experimental design

Aim

Assess the effect of different tillage, common crop rotation, and residue management on wheat yield of commercial cultivar Jingdong 8, soil quality and irrigation water requirements.

Crop rotation
Wheat–maize–wheat and wheat–soybean–wheat (see treatments in Table 1)

Tillage practice:
ZTF-P: zero tillage, flat planting with partial residue (40% residue left)
ZTF-R: zero tillage, flat planting without residue
CT-P: conventional tillage with partial residue
CT-R: conventional tillage without residue
CT-B: conventional tillage with burnt residue
PB-P: permanent raised bed (80 cm, three rows) with partial residue
PB-R: permanent raised bed (80 cm, three rows) without residue

Fertilizer:
N : 75kg/ha banded in the soil, and 75kg/ha broadcast at 1st node.

Plot size:
6 m × 10 m = 60 m^2

Disease and insect control:
Only for control of aphids

Seed rate:
For wheat, 225 kg/ha

Weed control:
At the stage of three leaves of grass, according to different grasses, use herbicide to control.

Traits measured:
Including all development stages, height, biomass, and yield
Soil quality parameters as outlined above
Irrigation water requirements

Table 1. Proposed treatment design for the experiment.

Treatment	Rotation	Tillage	Straw management	Tillage practice code
1	wheat–maize–wheat	zero tillage	partial residue	ZTF-P
2			without residue	ZTF-R
3		conventional tillage	partial residue	CT-P
4			without residue	CT-R
5			burnt residue	CT-B
6		permanent raised bed	partial residue	PB-P
7			without residue	PB-R
8	wheat–soybean–wheat	zero tillage	partial residue	ZTF-P
9			without residue	ZTF-R
10		conventional tillage	partial residue	CT-P
11			without residue	CT-R
12			burnt residue	CT-B
13		permanent raised bed	partial residue	PB-P
14			without residue	PB-R

ZTF-P = zero tillage, flat planting with partial residue (40% residue left); ZTF-R = zero tillage, flat planting without residue; CT-P = conventional tillage with partial residue; CT-R = conventional tillage without residue; CT-B = conventional tillage with burnt residue; PB-P = permanent raised bed (80 cm, three rows) with partial residue; PB-R = permanent raised bed (80 cm, three rows) without residue.

Figure 1. Map of the experimental design.

1	2	8	9	3	4	5	10	11	12	6	7	13	14
4m													
8	1	9	2	10	3	11	4	12	5	7	14	6	13
4m													
9	2	1	8	5	12	4	11	3	10	13	6	14	7

N

Note 1: For each replication, the first four plots are zero tillage treatment, from the fifth to tenth plot the treatment is conventional tillage, and for the last four plots, it is permanent broad bed.

Note 2: For each plot, the width is 6 m (1.5 m × 4 m), the length is 10 m and the width of the road is 4 m.

Table 2. Treatment list for first replication.

Treatment	Rotation	Tillage	Straw management	Tillage practice code
1	wheat–maize–wheat	zero tillage	partial residue	ZTF-P
2	wheat–maize–wheat	zero tillage	without residue	ZTF-R
8	wheat–soybean–wheat	zero tillage	partial residue	ZTF-P
9	wheat–soybean–wheat	zero tillage	without residue	ZTF-R
3	wheat–maize–wheat	conventional tillage	partial residue	CT-P
4	wheat–maize–wheat	conventional tillage	without residue	CT-R
5	wheat–maize–wheat	conventional tillage	burnt residue	CT-B
10	wheat–soybean–wheat	conventional tillage	partial residue	CT-P
11	wheat–soybean–wheat	conventional tillage	without residue	CT-R
12	wheat–soybean–wheat	conventional tillage	burnt residue	CT-B
6	wheat–maize–wheat	permanent raised bed	partial residue	PB-P
7	wheat–maize–wheat	permanent raised bed	without residue	PB-R
13	wheat–soybean–wheat	permanent raised bed	partial residue	PB-P
14	wheat–soybean–wheat	permanent raised bed	without residue	PB-R

ZTF-P = zero tillage, flat planting with partial residue (40% residue left); ZTF-R = zero tillage, flat planting without residue; CT-P = conventional tillage with partial residue; CT-R = conventional tillage without residue; CT-B = conventional tillage with burnt residue; PB-P = permanent raised bed (80 cm, three rows) with partial residue; PB-R = permanent raised bed (80 cm, three rows) without residue.

Table 3. Treatment list for second replication.

Treatment	Rotation	Tillage	Straw management	Tillage practice code
8	wheat–soybean–wheat	zero tillage	partial residue	ZTF-P
1	wheat–maize–wheat	zero tillage	partial residue	ZTF-P
9	wheat–soybean–wheat	zero tillage	without residue	ZTF-R
2	wheat–maize–wheat	zero tillage	without residue	ZTF-R
10	wheat–soybean–wheat	conventional tillage	partial residue	CT-P
3	wheat–maize–wheat	conventional tillage	partial residue	CT-P
11	wheat–soybean–wheat	conventional tillage	without residue	CT-R
4	wheat–maize–wheat	conventional tillage	without residue	CT-R
12	wheat–soybean–wheat	conventional tillage	burnt residue	CT-B
5	wheat–maize–wheat	conventional tillage	burnt residue	CT-B
7	wheat–maize–wheat	permanent raised bed	without residue	PB-R
14	wheat–soybean–wheat	permanent raised bed	without residue	PB-R
6	wheat–maize–wheat	permanent raised bed	partial residue	PB-P
13	wheat–soybean–wheat	permanent raised bed	partial residue	PB-P

ZTF-P = zero tillage, flat planting with partial residue (40% residue left); ZTF-R = zero tillage, flat planting without residue; CT-P = conventional tillage with partial residue; CT-R = conventional tillage without residue; CT-B = conventional tillage with burnt residue; PB-P = permanent raised bed (80 cm, three rows) with partial residue; PB-R = permanent raised bed (80 cm, three rows) without residue.

Table 4. Treatment list for third replication.

Treatment	Crop rotation	Tillage practice	Straw management	Tillage practice code
9	wheat–soybean–wheat	zero tillage	without residue	ZTF-R
2	wheat–maize–wheat	zero tillage	without residue	ZTF-R
1	wheat–maize–wheat	zero tillage	partial residue	ZTF-P
8	wheat–soybean–wheat	zero tillage	partial residue	ZTF-P
5	wheat–maize–wheat	conventional tillage	burnt residue	CT-B
12	wheat–soybean–wheat	conventional tillage	burnt residue	CT-B
4	wheat–maize–wheat	conventional tillage	without residue	CT-R
11	wheat–soybean–wheat	conventional tillage	without residue	CT-R
3	wheat–maize–wheat	conventional tillage	partial residue	CT-P
10	wheat–maize–wheat	conventional tillage	without residue	CT-R
13	wheat–soybean–wheat	permanent raised bed	partial residue	PB-P
6	wheat–maize–wheat	permanent raised bed	partial residue	PB-P
14	wheat–soybean–wheat	permanent raised bed	without residue	PB-R
7	wheat–maize–wheat	permanent raised bed	without residue	PB-R

ZTF-P = zero tillage, flat planting with partial residue (40% residue left); ZTF-R = zero tillage, flat planting without residue; CT-P = conventional tillage with partial residue; CT-R = conventional tillage without residue; CT-B = conventional tillage with burnt residue; PB-P = permanent raised bed (80 cm, three rows) with partial residue; PB-R = permanent raised bed (80 cm, three rows) without residue.

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