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Improving the Sustainability of Wheat Production in Irrigated Areas of Punjab, Pakistan through Conservation Tillage Technology

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ABSTRACT

Wheat and rice are the major food staples around the globe including Pakistan. The challenge of increasing food production in the next 20 years to match population growth is daunting and warrants improvement in the quality of natural resources for growing more food from marginal and degraded lands. Cost of cultivation must be reduced and at the same time, efficiency of resources like irrigation water, fuel, fertilizers must be improved to make the crop production system more viable and eco-friendly. Resource Conserving Technology (RCT) must figure highly in this equation since it plays a crucial role in achieving the above goals. The RCTs include laser land leveling, zero-tillage, bed furrow irrigation method and crop residue management. These technologies were evaluated in irrigated areas of Punjab province where rice follows wheat. Water use efficiency was increased by 20% in laser leveled fields. Zero-tillage technology resulted in a significant saving of irrigation water (22%), fuel (78%), cultivation (88%) and herbicide use (33%) compared to conventional, thus increasing yields and farmer's profits. Soil properties and microbial population including bacteria, fungi and actinomyces improved in the zero-till fields. Planting of wheat on raised beds is making headway in low-lying and poorly drained areas. Thus, resource conservation tillage technology provides a tool for making progress towards improving and sustaining wheat production, helping with food security and poverty alleviation in Pakistan in the next few decades.

Key Word: Rice; Wheat; Cropping system; Sustainability; Resource conservation

INTRODUCTION

Wheat is the major food staple for the people of Pakistan with per capita consumption of 140 kg annum^{-1}. To meet the demand of ever increasing population, food production system in the country must be improved and sustained. Over the past several years, the yield of wheat has been stagnant around 2.5 t ha^{-1}, despite the use of high yielding wheat varieties (GOP, 2006). With the same area of wheat i.e., 8.45 million hectare (Mha), at least double wheat production (42 m.t.) can be achieved if better crop, nutrient, water management and tillage practices are used (Mann, 1988).

Rice-wheat is one of the major cropping systems in Pakistan, covering an area of 2.0 Mha. In this system, rice seedlings are transplanted into compact, puddled soil, often over a hard pan (Mann & Ashraf, 2001). The thick hard pan developed from long-term puddling restricts root growth of wheat crop. More importantly, in this system, soil structure is degraded and soil productivity is lost. Late harvesting of Basmati rice varieties lead to delay wheat planting in December instead of normal sowing time of November (Aslam *et al.*, 1993). A typical response of wheat to planting in South Asia shows an optimum wheat yield up to the end of November, followed by a linear decline in yield at 1-1.5% per day (Randhawa *et al.*, 1981; Ortiz-Monasterio *et al.*, 1994). Late planting not only reduces yield but also decreases the efficient use of applied fertilizers. In Punjab, more than 80% rice area is covered by Basmati rice varieties, which mature in November. Farmers remain busy with rice harvesting, threshing and handling of rice straw until early December. These factors combined with land preparation lead to delayed sowing of wheat crop. Planting of wheat is also delayed by a number of reasons including excessive tillage, soil moisture problems (too wet or too dry), non-availability of implements for plowing, prolonged land preparation period and other field operation related to threshing and handling the rice crop (Hobbs *et al.*, 1997). To achieve the potential yield production from the modern varieties, wheat crop must be planted at appropriate time.

About 80% wheat area in Pakistan is irrigated by extensive canal system, supplemented with tube wells. Due to continued dry spell over the past several years, both surface and groundwater sources are depleting (Gill, 2001). The escalating prices of inputs like fertilizers, herbicides, labor, fuel and irrigation water has worsened the situation.

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Therefore, strategies must be adopted to improve soil fertility, reduce the cost of planting, use of less chemicals and increase in efficiency of fertilizers and irrigation water for the development of economically viable and ecologically sound wheat production system. Hence, resource conservation tillage technology greatly helps achieve these goals. The conservation tillage refers to a tillage system that does not disturb the soil for sowing of next crop and leaves enough crop residues to adequately protect the soil from erosion (Reeder, 1992). The resource conservation technology includes laser land leveling, zero tillage and bed planting. The emphasis is on resource conservation of soil, moisture, energy, labor and even equipment. In zero-tillage technology, soil is left undisturbed from the harvest of one to the sowing of the next crop, with only slight soil disturbance associated with creating a narrow slot for placement of seed (and in some cases, fertilizer) (Dickey *et al.*, 1992). Moreover, the risks of ecological and environmental problems like air pollution due to burning of crop residues, water logging and secondary salinization, decline of organic matter, soil degradation, nutrient imbalances and injudicious use of fertilizers and pesticides are minimized in the conservation tillage system. Planting of wheat on raised beds with two or three seeding rows is practiced on the entire area of northwestern of Mexico (Sayre, 2000). Bed planting of wheat has special niche in Pakistan. In the low-lying areas with poor drainage system, bed-planting method is more promising than the zero- or conventional tillage (Mann *et al.*, 2002). Hence, conservation tillage technology is the right solution to all the problems endangering to sustainable and eco-friendly wheat production system in the country.

MATERIALS AND METHODS

The studies were designed for a period of three years and commissioned in July 1999 at farmers' fields in Punjab. Five farms were selected randomly. At each farm, two fields were then chosen—one for zero-tillage and one for conventional wheat planting method. The site consisted of mixed calcareous silty alluvium soil, moderately well drained and moderately fine textured having a Cambic horizon classified as Typic Camborthids.

Wheat planting was done either directly drilled without any tillage operation (zero tillage) or sown by broadcast manually after thorough land preparation with rototiller (one pass), conventional cultivator (four passes) and planking (two passes). All the data regarding labor use, fuel consumption, irrigation water, etc., with two tillage methods was recorded. Another experiment was also established at three different farms with four methods of wheat establishment zero-tillage, beds with two or three rows and farmers' practice (conventional tillage).

The data of insect pests, weeds and predators was recorded from five sampling sites, selected along the diagonal of field. The first site was marked at 10 and the remaining at 16 m. Total number of weeds and species were counted prior to first irrigation at about 35 days after wheat sowing. A suitable herbicide was then applied after the first irrigation. The hibernating larval population of rice stem borer was also recorded from January to April. For this purpose, rice stubbles from an area of 0.5 m^2 were collected and dissected. The population of predators was estimated by visual counting, or hand netting depending on the behavior of the predator. Population of major groups of predators such as spiders, coccinellids, etc., was recorded from 5 sweep strokes at each sampling site. Population of other predators such as Paederus was recorded by visual counting from one m^2 at each sampling site.

Soil samples (0-10 cm depth) from each field were collected at the start of studies and at the end, from both fields under zero tillage and conventional tillage practice. Phosphorus, NO_3-N and K were extracted with AB-DTPA method. From the soil samples, microbial population was also recorded. The microbes were grown on a selected media for their further classification into bacteria, actinomyces and fungi. At crop maturity, a representative area of 8 m^2 was harvested and threshed manually to calculate grain yield into t ha^{-1}. The grain yield data was also statistically analyzed using ANOVA at 5% probability level.

RESULTS AND DISCUSSION

Weed density. Zero-tillage system had a positive effect on wheat crop with emergence of weeds (Table I). For instance, at Rizwan Farm, weed density from 24 m^{-2} during 1999-2000 was reduced to 10 m^{-2} during 2001-2002. A similar trend was also observed at other farms. With better weed management practices, a declining trend was also noted at three farms under the conventional tillage. On average, 60% lesser weeds were recorded in zero tillage than the conventional tillage. This is plausible firstly due to the hard plow-zone in the zero-tillage field, which provided no favorable environment for the emergence and growth of small-seed weeds like grasses and secondly the rice straw or stubbles left over in field by the combine served as mulch for the weeds (Sayre, 2000). The situation in the conventional tillage is however opposite. The well-pulverized soil at optimum moisture condition is highly suitable for weed emergence and growth, which can reduce the grain yield if, not controlled properly.

Table I. Trend of weed density in wheat crop over the years

Farmers' Name	Conventional			Zero Tillage		
	2000	**2001**	**2002**	**2000**	**2001**	**2002**
Rizwan Ahmad	30	24	22	24	16	10
Imran Ahmad	40	32	38	32	24	22
Shahbaz Ahmad	46	48	36	24	26	16
M. Asghar	22	18	14	14	18	12
M. Bashir	24	36	30	20	14	18
Mean	**32.4**	**31.6**	**28.0**	**22.8**	**19.6**	**15.6**

Table II. Trend of major weed species in wheat crop over the time

Farmers' Name	Z-Tillage			Conventional		
	2000	2001	2002	2000	2001	2002
Rizwan	*C. rotundus*	*Chenopodium*	*Chenopodium*	*M. denticulate*	*M. indica*	*M. indica*
Imran	*P. minor*	*P. minor*	*R. dentatus*	*P. minor*	*P. minor*	*P. minor*
Shahbaz	*C. rotundus*	*P. indica*	*M. indica*	*P. minor*	*P. minor*	*P. minor*
Asghar	*M. indica*	*M. indica*	*R. dentatus*	*P. minor*	*P. minor*	*P. minor*
Bashir	*M. indica*	*M. indica*	*Chenopodium*	*M. indica*	*R. dentatus*	*M. indica*

Occurrence of weed species in the zero-tillage wheat crop indicated that most noxious weeds present during the first year were not present in the last year (Table II). *Cyperus rotundus* and *Phalaris minor* were disappeared particularly in the zero-tillage fields with the passage of time (Malik, 2002). Most of the broadleaf weed species like *Melilotus indica* and *Rumex dentatus* were present in the zero-till wheat crop, which were easily controlled with the use of low-cost herbicide. On the other hand, weeds like *P. minor* belonging to grass family were predominantly present in the conventional till fields, which were not easily controlled and cause serious loss to wheat yield. Moreover, the *Phalaris minor* has been found resistance to *Isoproturon* (Malik, 2002). Broadleaf weeds were predominantly found under traditional tillage system.

Insect pests and predators. Rice stem borer (*Scirpophaga incertulas*) has been a major insect pest of rice since long. If the paddy fields are not plowed for wheat sowing, the larvae of stem borer hibernate in the erect rice stubbles during the winter season (Ahmad, 1976; Chaudhry, 1976). Population of stem borer larvae in rice stubbles was comparatively higher in wheat fields sown with zero-till drill than the wheat fields with conventional tillage (Table III). Under both the tillage system, population of stem borer larvae was gone down the highest in the month of January and lowest in April. But due to non-availability of suitable host plants in April, natural mortality of the insect pests takes place, therefore, posing no serious threat to following rice crop. The population of predators recorded regularly from selected fields of wheat showed a comparatively high population with zero-till fields than the conventionally till fields (Table IV). Furthermore, the difference in the population of predators between zero-tillage and conventional methods was wide during early months of subsequent years.

The difference in the population of predators between two wheat establishment techniques may mainly be attributed to seedbed preparation for sowing wheat. After the harvest of rice crop, due to low temperature the predators take shelter either in the rice stubbles or crevices of soil, depending on their ecological behavior (Salim *et al.*, 2001). Rice stubbles provide shelter and food to predators. Sowing of wheat with zero-till drill does not destroy stubbles; therefore, the mortality of predators was negligible.

In the conventional method of sowing wheat, after the harvest of rice crop, land was prepared by number of plaguing and planking. Tillage operations destroyed rice stubbles and the proportion of destruction of stubbles depended on the type of tillage equipment and the number of tillage operations. One operation of rototiller plus two of cultivator and one planking caused 99% destruction of rice stubbles (Zafar & Razzaq, 1988). Rototiller destroyed rice stubbles completely and killed hibernating stem borer larvae. Low temperature, tillage operations, lack of food and non-availability of suitable habitat caused very high mortality of predators. Therefore, population of predators was higher in zero-tillage wheat fields than conventionally sown wheat fields. The new tillage system promotes early colonization of predators or natural enemies in wheat fields. Synchronization of rottening of rice stubbles and onset of favorable environmental conditions forced the predators to leave the stubbles, shift on wheat plants and play their role to suppress the population of insect pests of wheat.

Table III. Population of stem borer larvae (per m^2) in rice stubbles in wheat fields

Month	2000		2001		2002	
	ZT	CT	ZT	CT	ZT	CT
Jan.	1.3	0.6	4.0	1.1	1.1	0.6
Feb.	1.2	0.5	3.6	0.9	0.8	0.4
Mar.	1.0	0.4	2.3	0.6	0.4	0.2
Apr.	0.6	0.1	0.6	0.3	0.1	0.0
Mean	1.02	0.40	2.62	0.72	0.60	0.30

Table IV. Population of predators* in wheat crop sown after rice

Month	2000		2001		2002	
	ZT	CT	ZT	CT	ZT	CT
Jan.	5.6	2.6	6.4	2.4	10.9	2.0
Feb.	8.1	3.1	8.0	2.8	11.0	3.6
Mar.	7.9	3.8	7.5	4.2	11.4	5.3
Apr.	5.3	3.7	8.0	3.7	11.3	6.1
Mean	6.72	3.30	7.47	3.27	11.15	4.25

* Spiders, paederus, coccineldes

Table V. Chemical properties of fields under RCT

	pH	EC(1:1)	OM	NO_3-N	P	K	Zn	Cu	Mn
Initial	8.10	0.35	1.23	0.96	4.56	98	1.52	3.82	5.16
Zero	8.18	0.68	1.56	1.66	6.83	116	2.53	4.37	7.02
Conventional	8.09	0.44	1.21	1.36	4.44	106	1.42	3.78	6.86
Mean	8.12	0.49	1.33	1.33	5.27	107	1.83	3.99	6.35

Soil properties and microbial population. Soil samples collected from all the fields at initial stage were alkaline in nature with an average pH value 8.12 and non-saline having an average EC (1:1) value of 0.49 dS m^{-1} (Table V). Electrical conductivity ranged from 0.51 to 1.84 dS m^{-1} and pH ranged from 7.81 to 8.47 in case of zero tillage. While the soil samples collected from conventional practice, the

Table VI. Soil Microbial population as affected by cultivation practices in rice-wheat system

Farmer's Name	Tillage Practice	2000 – 01			2001 – 02		
		Bacteria	Actinomyces	Fungi	Bacteria	Actinomyces	Fungi
Rizwan	**ZT**	2.2×10^6	4.5×10^5	5.5×10^4	2.7×10^6	4.9×10^5	7.7×10^4
	CT	1.9×10^6	6.0×10^5	1.5×10^4	1.9×10^6	4.5×10^5	1.2×10^4
Imran	**ZT**	1.4×10^6	2.0×10^5	5.4×10^4	2.4×10^6	3.5×10^5	5.9×10^4
	CT	6.2×10^6	3.5×10^5	3.0×10^4	2.1×10^6	3.2×10^5	2.5×10^4
Shahbaz	**ZT**	1.6×10^6	3.5×10^5	6.5×10^4	3.7×10^6	4.1×10^5	6.1×10^4
	CT	1.0×10^6	1.5×10^5	2.0×10^4	1.1×10^6	1.8×10^5	1.7×10^4
Asghar	**ZT**	3.5×10^6	2.0×10^5	Nil	4.0×10^6	3.0×10^5	2.6×10^4
	CT	2.9×10^6	3.5×10^5	1.5×10^4	2.5×10^6	2.3×10^5	1.8×10^4
Bashir	**ZT**	5.5×10^6	3.6×10^5	2.6×10^4	3.8×10^6	3.9×10^5	4.6×10^4
	CT	3.9×10^6	2.1×10^5	2.4×10^4	2.0×10^6	3.2×10^5	2.8×10^4

average value of EC was 0.44 dS m^{-1} (0.23-0.95) and pH ranged from 7.90 to 8.54 with an average value of 8.09. These results indicated the increase of EC in case of zero tillage that resulted from the accumulation of soluble salts due to less downward movement of water in the upper layer. The organic matter content increased from 1.23 to 1.56% in zero-till fields as compared to 1.21% in the conventional-till fields.

Extractable P ranged from 2.05 to 7.02 with an average value of 4.56 mg kg^{-1} in initial soil samples while its average contents in case of zero tillage 6.83 mg kg^{-1}. Using this soil test, soil with ≤3 mg kg^{-1} soil are considered deficient, 4-7 mg kg^{-1} soil intermediate, and >8 mg kg^{-1} soil are high for crop growth. According to the criteria the samples belonging to zero tillage fell in the intermediate range for P and deficient for NO_3-N (Gupta *et al*., 2003). This indicated the importance of N application in all the practices. As regards K, zero-till fields had higher amounts of available K than the conventional-till fields. All the soil samples contained adequate amounts of Cu, Fe and Mn content. However, there was variation in soil samples collected at start and at the end of studies but the difference due to zero tillage and conventional is not very wide.

Zero-tillage, a different tillage system, causes some physical changes in the soil. The type and extent of changes depend upon soil type, climate and farming history. Farmers who practiced zero-tillage for some years usually noticed more soil moisture retention, better seedbed tilth, more organic matter and earthworms and improved traffic ability (Bell, 1997). These improvements are due to changes in soil physical, chemical and biological conditions, which occur with successive years of low disturbance seeding into standing crop residues. Soil compaction results primarily from mechanical forces created by wheel and/or tillage operations under moist soil conditions. Wheel traffic is the prime contributor compaction problems in rice and wheat belt. Zero-tillage system avoids soil compaction due to minimized wheel traffic. All these lead to improve soil health and sustain wheat productivity in the rice-wheat belt.

Soil bacterial population was found generally in the range of $1.4–6.2 \times 10^6$ g^{-1} of soil, whereas actinomyces and fungal population was found in ranges of $1.5–6.0 \times 10^5$ and $0–7.7 \times 10^4$ g^{-1} of soil, respectively (Table VI). In zero tillage plots, generally the population of all groups of microbes

Table VII. Wheat grain yield (t ha^{-1}) with two tillage systems

Farmers' Name	Z-Tillage			Conventional		
	2000	2001	2002	2000	2001	2002
Rizwan	4.92 ab	4.80 a	4.32 ab	4.72 a	4.62 a	4.15 a
Shahbaz	4.87 ab	4.52 ab	4.42 a	4.50 ab	4.07 b	3.87 a
Imran	4.47 b	4.12 bc	3.82 b	4.15 b	3.67 b	4.10 a
Asghar	4.72 ab	3.95 c	4.10 ab	4.25 ab	3.95 b	4.22 a
Bashir	5.07 a	4.30 bc	4.02 ab	4.65 ab	4.15 ab	3.97 a
Average	4.82	3.75	1.90	2.02	1.85	1.87

Table VIII. Grain yield (t ha^{-1}) in wheat planted with different techniques, 2001-2002

S.No.	Techniques	M.K. Farm	Zaidi Farm	Dogar Farm	Mean
1	Beds (two rows)	3.92 **a**	5.27 **a**	4.60 **a**	**4.60**
2	Zero Tillage (flat)	4.02 **a**	4.95 **ab**	4.15 **a**	**4.43**
3	Beds (three rows)	4.25 **a**	4.70 **b**	4.37 **a**	**4.42**
4	Conventional	3.45 **a**	4.25 **ab**	4.05 **a**	**3.95**
	Mean	3.92	4.80	4.30	4.35

(bacterial, actinomyces & fungi) was higher than the conventionally tilled plots. These results support previous findings (Doran, 1980) according to which soil organic matter and microbial population is increased when soil is not disturbed or vice versa. Compared to previous year, the microbial population increased slightly except in few cases where the microbial population was sustained. In conventional tillage the microbial population remained constant or reduced slightly as compared to previous year results. As a result of continuous tillage along with removal of crop residues, generally soil structure is degraded and soil organic matter/microbial population is reduced. The sustained/increased microbial population plays very effective role in many useful processes in soil, including nutrient recycling, nutrient availability, carbon turnover/transformation soil aggregation that ultimately lead to better soil health (Karthikeyan & Kulakow, 2003; Singh *et al*., 2004). These results confirmed that minimum or zero tillage is a key for sustainable soil microbial population that would lead to better soil health.

Wheat yield sustainability. Wheat yield with two tillage methods for three years revealed that zero-tillage produced higher yield than the conventional tillage (Table VII). The average yields in zero-till fields was 4.82 t ha^{-1} in 2000, 4.35 t ha^{-1} in 2001 and 4.15 t ha^{-1} in 2002 compared to 4.45, 4.02 and 4.07 t ha^{-1} in conventional-till fields during the

Table IX. Impact of conservation tillage technology on resource savings in wheat production, 2000-2002

Input/Item	Unit ha^{-1}	Conventional Tillage	Zero-Tillage	Saving	Benefit (Rs $acre^{-1}$)
Seed Rate	Kg	125	87.5	37.5	375
Land Preparation cost	Rs.	3,400	450	2,950	2,950
Energy (Diesel)	Liters	68.5	15.2	53.3*	-
Herbicide	Rs.	1,500	1,000	500	500
Irrigation Water	hectare-inches	43	35	8	375
Labour	Mandays	5	0	5	400
Grain Yield	T ha^{-1}	4.82	4.97	0.15	1,125
	Total	5725			

*Saving in energy was included in the land preparation.

corresponding years. This yield was about 7% higher than the conventional-till wheat fields. The higher yield in zero-tillage was attributed to timely sowing of wheat crop, better germination and crop stand and improved fertilizer use efficiency and light interception (Aslam *et al.*, 1993; Hobbs *et al.*, 1997; Sayre, 2000). Likewise, zero-tillage and bed planting wheat sowing produced comparatively higher grain yield than the conventional wheat sowing method (Table VIII). Bed planting either with two rows or three rows of crop plays an important role in water saving and the method is quite suitable for low-lying areas and quality seed production.

Resource savings. In conventional tillage system, an average of 5 ploughings, 3 disking and 3 planking are done to achieve fine seed-bed incurring an average cost of Rs.3, 400 ha^{-1} against the cost of Rs. 450 in sowing with zero-tillage drill (Table IX). Hence, a saving of Rs.2, 950 ha^{-1} in the cultivation cost was observed. In the conventional wheat sowing, 125 kg ha^{-1} seed rate was used compared to 87.5 kg in zero-till system, with a saving of 37.5 kg ha^{-1} wheat seed or Rs. 375 ha^{-1}. The reduction in seed rate was calculated to 30%. The drill dropped the seed effectively in the rows, which resulted into 95% germination, while in the traditional system seed is broadcast followed by two plowing and planking. More so, seeds are placed either too deep or at the upper soil zone resulting into sub optimal seedling emergence. Fine seedbed preparation involves the use of large amounts of fuel, which is becoming increasingly expensive. The results showed that zero tillage system considerably saved herbicide, irrigation water, labour, time, and increased grain yield leading to increase farm income (by Rs. 5725 ha^{-1}) and improve farmers' livelihood. The immediate reduction in the cost of land preparation in terms of the non-renewable fuel resource makes the zero tillage technology more attractive. The reduction in labor and other inputs per unit land for zero tillage compared to conventional system can be significant. Fewer trips over the field and reduced labor requirements can result in immediate and direct savings. Labors can have more time to work for other farm operations or working at off-farm jobs. Making fewer trips over the field also means that equipment or tractor lasts longer and/or covers more area. It also resulted in lower fuel and maintenance costs of machinery. Hence, timely sowing of wheat crop in lines rather than broadcast, with less use of seed rate gave healthy and vigorous crop leading to high grain yield.

Environment protection. Widespread adoption of zero-till practices could have substantial benefits for South Asia and for the world in general. Surface and ground water quality issues are often associated with pollution originating from point sources and urban areas. An increasing use of cultivation, chemical fertilizers and pesticides has a measurable and marked effect on freshwaters and the eutrophication of rivers, lakes and enclosed water bodies is a serious concern. Adoption of conservation tillage techniques can markedly decrease soil erosion and associated Non-Point Sources (NPS) pollution (Hobbs & Gupta, 2002).

Biological life in the soil is very significant for sustainable crop production system. In the new tillage system, population of nematodes, bacteria, fungi and earthworms are found higher than the conventional tillage system. These microorganisms are very beneficial for stimulating crop growth and development. Integrated pest management is very crucial in modern crop husbandry. There should be equilibrium between natural enemies (parasites, predators, etc.) and the insect pests. The natural enemies find shelter in crop residue during winter season.

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