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Effect of tillage, rotation and crop residues on wheat crop productivity, fertilizer nitrogen and water use efficiency and soil organic carbon status in dry area (rainfed) of north-west Pakistan

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Abstract

Crop productivity, soil organic carbon (SOC), fertilizer nitrogen and water use efficiency (WUE) in rainfed dry area is influenced by tillage, rotation and crop residues management. Field experiments were conducted during 2004-09 to study the effect of tillage, rotation and crop residues on wheat yield, nitrogen fertilizer and water use efficiency and SOC under semi-arid condition in north-west Pakistan. The treatments consisted of three rotations: i) Wheat–fallow–wheat (farmers' practice) ii) Wheat– summer legume–wheat and iii) Wheat–summer cereal–wheat with two tillage and crop residues management treatments: i) Tillage (crop residues removed) and Tillage (crop residues retained) and ii) No-tillage (crop residues removed) and No-tillage (crop residues retained). Basal doses of N_{60}: P_{60} (kg ha^{-1}) to wheat, N_{90}: P_{60} and N_{20}: P_{60} (kg ha^{-1}) to summer cereals and legumes rotation crops were applied respectively. Labeled urea having 1% ^{15}N atom excess at 60 kg N ha^{-1} was applied to wheat as an aqueous solution in micro plot within each treatment plot. Changes in soil water storage were monitored with neutron moisture probe for calculation of WUE. The results revealed that the wheat grain and straw yield was not increased by the tillage treatment. Crop residues retention significantly enhanced the wheat grain and straw yield. Crop residues with no-tillage resulted in 520 kg ha^{-1} greater wheat grain yield than residues removed treatment. Similarly WUE, N yield and fertilizer N utilization by wheat was increased significantly by crop residues under no-tillage compared to the tillage treatment. Maximum N fertilizer utilization 24.1 %, 62.7 % and 38.0 % in wheat were obtained under no-tillage + residues treatment during 2006, 2007 and 2008 respectively. The SOC in surface soil (0-15 cm) was higher in wheat-fallow-wheat and wheat-legume-wheat rotation under no-tillage + residues treatment. The results showed that no-tillage + crop residues and legume based rotation treatment were beneficial under the rainfed (dry) conditions.

Keywords: Rainfed wheat, conservation agriculture, fertilizer N utilization, soil organic carbon, water use efficiency, Pakistan

1. Introduction

Wheat (*Triticum aestivum L.)* is the major staple food crop of Pakistan. It is cultivated in irrigated as well as in rainfed areas of the country under arid and semi-arid climates to meet the demand of increasing population. In rainfed area, the average yield of wheat is static at around 1.0 t ha^{-1} for many years (MINIFAL, 2007), which is the lowest in the world. Low soil organic matter, drought and erratic rainfall, deficiency of nutrients (Rashid, 1994), unbalanced use of fertilizers (NFDC, 1997) and N losses from fertilizer are the major factors contributing to low wheat productivity in arid and semiarid rainfed area of Pakistan. During the past three decades, an intensive use of chemical fertilizers has contributed substantially in enhancing crop yields. The environmental hazards, poor maintenance of long-term soil productivity, high cost of balance fertilization and energy crises in Pakistan have generated an interest in alternative nutrients and crop management systems. The chemical, physical and biological fertility of soil is depending on soil organic carbon (Chan *et al*., 2008). Crop residues enhanced the soil organic matter and total soil N levels in the long-term (Cassman *et al*., 1996). Crop residue is a good source of nutrients in many agro-ecosystems for sustainable crop production and environment (Blanco-Canqui and Lal, 2009) and reducing dependency on chemical fertilizers. Mineral fertilizers and organic residues are often not available or affordable in sufficient quantities or qualities to be used alone, however integrated soil fertility management (ISFM) is currently promoted as a management approach that optimizes the use of all available resources within each target environment (Kimani *et al*., 2003). The combined use of organic residues and mineral fertilizers, which may resolve the practical limitation of input availability, but which may also benefit crop N synchrony and N loss reduction through interactive effects between both types of inputs (Gentile *et al*., 2009).

Conservation farming practices including no-tillage and stubble retention are known to minimize soil carbon losses from agricultural soils (Lal *et al*., 2003). Results from long term trials in Wagga Wagga have shown, over a 20 year period, the soil under traditional practice (stubble burnt and traditional tillage) was losing carbon at a rate of 400 kg $ha^{-1}year^{-1}$ compared to no-till and stubble retained (Heenan *et al*., 2004). Aslam *et al*. (1999) found that no-tillage produced 10% more wheat grain compared to farmers' practices of minimum three ploughings with planking in rice-based cropping system in Pakistan. In contrast, Iqbal *et al*. (2005) found that tillage and fertilizer treatments had a positive effect on wheat yield and N uptake in rainfed dry area. Retention of crop residues on soil surface, along with fertilization with organic manure and involvement of legumes in crop rotation coupled with minimum/no-tillage practices play an important role to sustain soil fertility, improving fertilizer/water use efficiency, physical conditions of soils and enhance crop productivity (Sainju *et al*., 2008; Mohammad *et al*., 2003; Dalal and Chan, 2001; Lampurlanes *et al*., 2001; Unger, 2000). Very little information is available on the effects of conservation agriculture on crop production, SOC, fertilizer nitrogen and water use efficiency in rainfed areas of the South Asia. Therefore, conservation agriculture practices need to be determined for improved crop yields, fertilizer/water use efficiency and sustainable soil fertility in semi-arid environments. The present study was conducted to reveal the effect of crops residues, tillage/no-tillage and rotation in dry area of north-west Pakistan on (i) yield and N uptake by wheat, (ii) fertilizer N and water use efficiency and (iii) SOC status.

2. Materials and methods

Field experiments were conducted during 2004-09 at Livestock Research Station, Surezai (rainfed area), Peshawar, north-west Pakistan (located at 33° 45' N and 70° 50' E). The objective was to improve/sustain soil fertility, water/soil conservation and efficient utilization of production inputs. The treatments consisted of three rotations: i) Wheat–fallow–wheat (farmers' practice) ii) Wheat– summer legume–wheat and iii) Wheat–summer cereal–wheat with two tillage and crop residues management treatments: i) Tillage (residues removed) and Tillage (residues retained) and ii) No-tillage (residues removed) and No-tillage (residues retained). Basal doses of N_{60}: P_{60} (kg ha^{-1}) to wheat, N_{90}: P_{60} (kg ha^{-1}) to summer cereal and N_{20}: P_{60} (kg ha^{-1}) to legumes crops were applied. Labeled urea having 1% ^{15}N atom excess at 60 kg N ha^{-1} was applied as an aqueous solution in micro plots within each treatment plot to study the nitrogen use efficiency by wheat. Neutron moisture probe was used to measure the changes in soil water storage.

2.1 Site Characterization

Soil of the experimental site was loam to clay loam (Inceptisol, Typic Calciustepts) and found deficient in organic matter, nitrogen and phosphorus. Before the establishment of experiment, composite soil samples were collected from various depths viz. 0-15, 15-30 and 30-60 cm and analyzed for various physico-chemical properties. The soil particle size analysis indicated that the proportion of sand in the soil profile ranging between 21 and 42%, silt ranging between 32 and 42%, and clay ranging between 26 and 37%. The amount of organic C in the surface 0-15 cm was 0.52%, which gradually decreased to 0.24% in the lower 30-60 cm depth. The amount of total N was 0.05% in the 0-15 cm to 0.032% in the 30-60 cm depth. The available phosphorus was 5.33 µg P g^{-1} soil in the 0-15 cm and decreased to 2.5 µg P g^{-1} soil in the 30-60 cm depth. The soil was alkaline in reaction (pH 7.6-7.9), non-saline (EC 0.39-0.22 dS m^{-1}), moderately calcareous in nature (11.6 to 18.5% lime), having bulk density 1.43 to 1.45 Mg m^{-3}. The site is located at the altitude of 525 m above sea level and has cool climate in winter and warm to hot in the summer and come under semi-arid zone. The annual rainfall for the last many years is ranging from 200 to 760 mm. The growing season precipitation is inadequate and varies greatly, both within the growing season and from year to year.

2.2 Experimental Design, Sowing, Plant Sampling and Analysis

Experiment was laid out according to the Split split plot design, keeping the tillage and no-tillage in main plot, rotation in sub plot and crop residues in sub sub plot. The size of the sub sub plot was 30 m^2 and replicated 3 times. Under conventional tillage, 15-20 cm deep moldboard plough (tractor-driven) was applied and cultivator was used at sowing time followed by planking while the zero- tillage has been left undisturbed. After necessary seedbed preparations, sowing was done using hand drill and recommended row to row distance was maintained for wheat and summer rotational crops. The wheat (cv. Tatara) was used during winter seasons (2004-09). In summer local cultivars of cereals (sorghum/millet/ maize) and legumes (mungbean, pigeon pea and mash bean) were used in rotation. Weedicide glyphosphate was sprayed before sowing of each winter and summer crop (total two spray in a year) and additional one spray of fenoxoprop-p-ethyl on wheat crop at tillering stage. The wheat crop at grain formation stage was attacked by termites and insecticide (Furedan granule) was applied for its control. For N fertilizer utilization by wheat, ^{15}N micro plots measuring 1x1 m was established within each treatment and was fertilized with labeled urea enriched with 1% ^{15}N atom excess as an aqueous solution, @ 60 kg N ha^{-1} in each year. The crop was harvested at its physiological maturity. Grain and straw yield was recorded. After harvest of each crop, plus residues and minus residues treatment were maintained. Grain and straw samples of wheat were dried at 70^0C and finely ground (< 0.1 mm) in a Willey's Mill and was analyzed for total N and ^{15}N on mass spectrometer at IAEA Siebersdorf laboratory Austria (Vienna). The nitrogen utilization from fertilizer was determined according to the method described in IAEA manual (2001). To study the effect of treatments (tillage, residue and rotation) on the soil water storage, Neutron access tubes down to 90 cm in soil profile were installed in each treatment. Neutron probe readings along with meteorological observations were recorded regularly. The water use efficiency was calculated according to water balance approach (Kirda, 1990). Total organic carbon in surface soil samples (0- 15 cm) collected after harvest in each season was determined by the Walkley and Black procedure (Ryan *et al*., 2001). Total nitrogen in soil samples were determined by the Kjeldahl method (Bremner and Mulvaney, 1982).

2.3 Statistical Analysis

Statistical analysis (ANOVA) of the Data was carried out using MSTAT C Software followed by testing for mean separation by Duncan's multiple range test (DMRT) for multiple comparisons of paired means of treatments (Steel and Torrie, 1980).

3. Results

3.1 Yield

Grain and straw yield of wheat in different growing seasons was not improved due to tillage as compared to no-tillage (Table 1). Retention of crop residues significantly increased grain and straw yield (Table 2). The interaction data showed that grain and straw yield increased significantly in residues retained treatment under both tillage and no-tillage treatment (Table 3). The residues effect on grain and straw yield was strongly depended on tillage. The grain yield was significantly highest in residue retained treatment under no-tillage compared to tillage treatment. On the average residue retained treatment produced 330 kg ha^{-1} more wheat grain than residue removed treatment. However no-tillage + residue retained treatment produced 520 kg ha^{-1} more grain yield than when residues were removed. In tillage system an improvement of 180 kg ha^{-1} was recorded in grain yield by residue retention. In over all highest grain and straw yields were obtained during 2006-07 than others seasons. The difference in yields was due to variation in rain received during the growing seasons. The wheat grain yield was significantly higher in wheat-summer legume-wheat and wheat-fallow-wheat rotation as compared to wheat-summer cereal-wheat rotation (Table 4). Almost similar wheat straw yield was obtained under these rotations during 2006-08. The straw yield was increased significantly in summer legume and fallow based rotation during 2008-09. In over all maximum average wheat grain and straw yield was recorded in wheat-summer legume-wheat rotation compared to summer fallow and cereal based rotation (Table 4).

Table 1. Effect of tillage on the grain and straw yield of wheat in dry area (rainfed) of north-west Pakistan.

Treatments	2004-05	2005-06	2006-07	2007-08	2008-09	Average
Grain yield (kg ha^{-1})						
No-tillage	2679.6 a	1875.8 a	2773.0 a	1306.5 a	1277.8 a	1982.54
Tillage	2750.4 a	1827.1 a	2691.1 a	1489.4 a	1442.6 a	2040.12
Straw yield (kg ha^{-1})						
No-tillage	5784.4 a	4031.0 a	6839.1 a	2162.0 a	2874.1 a	4338.12
Tillage	5785.6 a	3944.6 a	6946.4 a	2351.8 a	2946.3 a	4394.94

Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

Table 2. Effect of crop residues on the grain and straw yield of wheat in dry area (rainfed) of north-west Pakistan.

Treatments	2005-06	2006-07	2007-08	2008-09	Average
Grain yield (kg ha^{-1})					
Crop residues retained	2050.3 a	2882.1 a	1603.7 a	1475.9 a	2003.0
Crop residues removed	1652.6 b	2602.0 b	1192.2 b	1244.4 b	1672.8
Straw yield (kg ha^{-1})					
Crop residues retained	4296.5 a	7567.0 a	2409.3 a	3144.4 a	4354.3
Crop residues removed	3679.1 b	6218.4 b	2104.6 b	2675.9 a	3669.5

Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

Table 3. Interactive effect of tillage and crop residues on wheat grain and straw yield (kg ha^{-1}) in dry area (rainfed) of north-west Pakistan.

Year	Tillage				No-tillage			
	Crop residues Retained		Crop residues removed		Crop residues Retained		Crop residues removed	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
2005-06	2054.0 a	4007.2 a	1600.3 b	3888.6 ab	2046.7 a	4592.4 a	1705.0 b	3469.6 b
2006-07	2729.9 b	7329.5 a	2652.3 b	6563.2 b	2994.2 a	7804.6 a	2551.7 c	5873.6 c
2007-08	1570.4 ab	2270.3 b	1408.5 b	1940.7 c	1637.0 a	2659.3 a	975.9 c	1726.0 c
2008-09	1455.3 a	2970.4 b	1429.6 a	2922.2 b	1696.3 a	3318.5 a	1059.3 b	2429.6 c
Average	1952.4	4116.6	1772.7	3979.6	2093.6	4593.7	1573.0	3359.4

Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

Table 4. Effect of crop rotation on the grain and straw yield of wheat in dry area (rainfed) of north-west Pakistan.

Treatments	2005-06	2006-07	2007-08	2008-09	Average
Grain yield (kg ha^{-1})					
Wheat-fallow-wheat	1937.5 a	2700.4 b	1407.8 a	1469.4 a	1878. 8
Wheat-summer legume-wheat	1920.5 a	2872.8 a	1522.2 a	1386.1 ab	1925.4
Wheat-summer cereal-wheat	1696.5 b	2622.8 b	1263.9 b	1225.5 b	1702.05
Straw yield (kg ha^{-1})					
Wheat-fallow-wheat	3971.9 a	6767.2 a	2409.7 a	3205.5 a	4088.6
Wheat-summer legume-wheat	4049.7 a	7172.4 a	2452.8 a	3069.4 a	4186.1
Wheat-summer cereal-wheat	3941.8 a	6738.5 a	1908.3 a	2455.5 b	3761.0

Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

3.2 Water Use Efficiency (WUE)

The residue retention increased wheat WUE compared to residue removed treatment (Table 5). Maximum wheat grain WUE (11.6 and 6.5 kg ha^{-1} mm^{-1}) was recorded in no-tillage + residue treatment in wheat-fallow-wheat rotation during 2006 and 2008 respectively. In 2007 season, maximum wheat grain WUE (7.5 kg ha^{-1} mm^{-1}) was recorded under no-tillage + residue in wheat-legume-wheat rotation. The year wise data showed that in 2006 season, greater WUE was recorded than 2007 and 2008 season. Wheat straw water use efficiency was also improved in no-tillage + residue treatment under wheat-legume-wheat rotation (Table 5). Similar straw WUE was recorded under tillage and no-till treatment. The interaction data indicated that no-tillage without residues had no-positive effect on wheat WUE**.**

Table 5. Effect of rotation, tillage and crop residues management on wheat grain and straw water use efficiency (kg/ha/mm) in dry area (rainfed) of north-west Pakistan.

Year	Tillage				No-tillage			
	Residues retained (+)		Residues removed (-)		Residues retained (+)		Residues removed (-)	
	Wheat-fallow-wheat (W-F-W)							
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
2006	10.4 b	18.6 bc	7.5 de	20.0 bc	11.6 a	20.7 ab	8.0 d	17.3 bc
2007	6.05 de	17.0 b	5.95 e	14.4 cd	6.99 b	17.5 b	6.11 de	13.9 d
2008	5.08 d	6. 3 ef	4.05 f	8.3 bc	6.50 a	10.0 a	3.87 f	6.1 f
	Wheat-Summer legume-wheat (W-SL-W)							
2006	9.9 bc	20.7 ab	7.8 d	18.5bc	9.8 bc	24.4 a	9.6 c	14.6 d
2007	6.53 c	17.4 b	6.23 cde	16.4 c	7.49 a	20.3 a	6.45 cd	12.6 d
2008	6.24 ab	8.9 b	5.67 c	8.6 b	6.00 b	10.2 a	3.20 g	6.3 ef

Wheat-summer cereal-wheat (W-SC-W)								
2006	8.1d	18.6 bc	7.9 d	17.8 bc	9.5 c	21.3 ab	7.1 e	18.4 bc
2007	6.45 cd	16.7 bc	6.31cde	14.9 cd	6.39 cd	16.6 bc	5.23 f	14.4 cd
2008	4.74 e	7.2 de	4.63 e	6.9 de	5.00 d	7.5 cd	3.08 g	4.9 g

Mean Grain water use efficiency							
	Residues mean		Tillage mean		Rotation mean		
Year	+	-	Tillage	No-tillage	W-F-W	W-SL-W	W-SC-W
2006	9.9 a	8.0 b	8.8 a	9.0 a	9.3 a	9.2 a	8.1 b
2007	6.65 a	6.05 b	6.25 a	6.44 a	6.27 a	6.67 a	6.09 a
2008	5.59 a	4.08 b	5.07a	4.61 a	4.88 ab	5.28 a	4.36 b
average	7.38	6.04	6.71	6.68	6.82	7.05	6.18
Mean straw water use efficiency							
	Residues mean		Tillage mean		Rotation mean		
Year	+	-	Tillage	No-tillage	W-F-W	W-SL-W	W-SC-W
2006	20.7 a	17.8 b	19.0 a	19.4 a	9.1 a	19.5 a	19.0 a
2007	17.6 a	14.4 b	16.1 a	15.9 a	15.8 a	16.7 a	15.7 a
2008	8.3 a	6.8 b	7.7 a	7.5 a	7.7 a	8.5 a	6.6 a
average	15.5	13.0	14.3	14.3	14.2	14.9	13.8

Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

3.3 N yield, fertilizer N utilization and soil organic carbon

The total N yield of wheat was increased significantly by residue retention and summer legumes based rotation in all growing seasons (Table 6). The residues retention under tillage and no-tillage led to greater N utilization by wheat (Table 7). Maximum N fertilizer utilization 24.1 %, 62.7 % and 38.0 % in wheat was found under no-tillage + residues during 2006, 2007 and 2008 respectively. The average of three year data showed that residue retention significantly enhanced the fertilizer N utilization (38.7%) compared to residue removed treatment (31.2 %) (Table 8). Highest N utilization (39.0 %) was found in wheat-summer legume-wheat rotation followed by wheat-fallow-wheat (34.4 %) and lowest (31.8 %) in wheat-summer cereal-wheat rotation (Table 8). The fertilizer N utilization was slightly increased in tillage (34.4%) than no-tillage (32.6%). In over all, the N fertilizer utilization was increased in no-tillage + residue treatment (Table 7). Likely in residue retained treatment highest N yield was found under no-tillage compared to tillage operation.

The results of soil samples (0-15 cm) after wheat harvesting showed that soil total organic carbon (OC) was higher in no-tillage + residue treatment (Table 9). The summer legume inclusion in rotation system enhanced the OC content by 1.22 t ha^{-1} over summer cereal based rotation. The total OC content of soil was increased (0.79 t ha^{-1}) in residues retained treatment (13.25 t ha^{-1}) than residues removed treatment (12.46 t ha^{-1}). Similarly, on average the total OC content of soil was increased (0.43 t ha^{-1}) in no-tillage treatment (13.07 t ha^{-1}) than tillage (12.64 ha^{-1}). The residues retention in no-tillage increased the total OC (0.62 t ha^{-1}) than tillage + residues treatment. The residues retention practice in no-tillage system was found comparatively more beneficial than in tillage system.

Table 6. Effect of rotation, tillage and crop residues on wheat (grain + straw) N yield (kg ha^{-1}) in dry area (rainfed) of north-west Pakistan.

	Residues mean		Tillage mean		Rotation mean		
Year	CR +	CR -	Tillage	No-tillage	W-F-W	W-SL-W	W-SC-W
2005-06	90.3 a	76.8 b	84.6 a	82.5 a	84.3 a	82.2 a	84.2 a
2006-07	175.5 a	158.9 b	169.5 a	164.9 a	156.1 b	181.2 a	164.3 ab
2007-08	86.47 a	66.59 b	76.82 a	76.23 a	72.87 b	86.25 a	70.45 c
Mean	117.42	100.76	110.31	107.88	104.42	116.55	106.32

CR+ =Crop residues retained, CR- =Crop residues removed, W-F-W =Wheat-fallow-wheat, W-SL-W = Wheat-Summer legume-wheat, W-SC-W= Wheat-summer cereal-wheat. Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

Table 7. Interactive effect of tillage and crop residues on fertilizer N utilization (%) of wheat (grain + straw) in dry area (rainfed) of north-west Pakistan.

Year	Tillage		No-tillage	
	Crop residues retained	Crop residues removed	Crop residues retained	Crop residues removed
2005-06	22.87 a	22.17 a	24.1 a	19.77 a
2006-07	54.97 ab	47.8 b	62.67 a	46.7 b
2007-08	30.6 ab	27.4 bc	38.0 a	23.6 c
Average	36.14	32.44	41.61	30.02

Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

Table 8. N Fertilizer utilization (%) of wheat (grain + straw) as influenced by rotation, tillage and crop residues in dry area (rainfed) of north-west Pakistan.

Year	Residues mean		Tillage mean		Rotation mean		
	*CR +	CR -	Tillage	No-tillage	W-F-W	W-SL-W	W-SC-W
2004-05	-	-	38.5 a	25.9 b	-	-	-
2005-06	23.5 a	21.0 a	18.8 a	19.2 a	20.9 a	25.8 a	19.9 a
2006-07	58.3 a	47.2 b	51.4 a	54.7 a	52.3 a	56.8 a	50.1 a
2007-08	34.3 a	25.5 b	29.0 a	30.8 a	29.9 a	34.3 a	25.5 b
Mean	38.7	31.2	34.4	32.6	34.4	39.0	31.8

*CR+ =Crop residues retained, CR- =Crop residues removed, W-F-W =Wheat-fallow-wheat, W-SL-W = Wheat-Summer legume-wheat, W-SC-W= Wheat-summer cereal-wheat. Values followed by different letters are significantly different at $p \leq 0.05$ by the DMR test.

Table 9. Total OC (t ha^{-1}) in surface soil (0-15cm) as influenced by tillage (T1), no-tillage (T0), crop residues retained (CR+) and crop removed (CR-) and rotation treatment in dry area (rainfed) of north-west Pakistan.

Year	Effect of tillage and residues on total OC (t ha^{-1})					
	***CR +**	**CR -**	**Increase in OC due CR+**	**T0**	**T1**	**Increase in OC due to T0**
2005-06	13.41	12.66	0.76	13.28	12.79	0.49
2006-07	12.92	12.08	0.84	12.66	12.34	0.32
2007-08	12.41	11.65	0.75	12.31	11.75	0.56
Average	12.91	12.13	0.78	12.75	12.29	0.46
Interactive effect of tillage and residues on total OC (t ha^{-1})						
Year	T0 (CR+)	T0 (CR -)	Increase in OC in T0 due to CR+	T1 (CR +)	T1 (CR -)	Increase in OC in T1 due CR+
2005-06	13.75	12.82	0.93	13.08	12.50	0.58
2006-07	13.17	12.14	1.04	12.66	12.01	0.65
2007-08	12.76	11.86	0.90	12.05	11.45	0.61
Average	13.23	12.27	0.96	12.60	11.99	0.61
Rotation effect on total OC (t ha^{-1})						
	Wheat-fallow-wheat		Wheat-summer legume-wheat	Wheat-summer cereal-wheat		Increase in OC due summer legume
2005-06	13.47		13.44	12.21		1.22 t ha^{-1} increase over cereal rotation
2006-07	12.68		13.05	11.76		
2007-08	11.75		13.04	11.90		0.54 t ha^{-1} increase over fallow rotation
Average	12.63		13.18	11.95		

4. Discussion

The results obtained under rainfed conditions indicated that crop residues retention with no-tillage improved the crops productivity, fertilizer nitrogen use efficiency, water use efficiency and soil organic matter. The crop residues retention enhanced the wheat grain and straw yield significantly under no-tillage treatment (Table 3). No-tillage and crop residues retention on soil surface enhanced the organic matter in cultivated soil (Lal *et al*., 2003; Dalal and Chan, 2001; Heen and Chan, 1992) and was more beneficial for dry land crop production (Baumhardt and Jones, 2002) because of moisture conservation (Lampurlanes *et al*., 2001). The plant nutrients uptake and soil physical condition are dependent on soil organic matter that affects all three aspects of soil fertility, namely chemical, physical and biological fertility (Chan *et al*., 2008). Crop residues retention is a good source of nutrients in many agro-ecosystems that have sustainable crop productivity. The indiscriminate harvesting of crop residues for biofuel may deteriorate soil properties, reduce crop yield, and degrade the environment (Blanco-Canqui and Lal, 2009). Many researchers have found that crop residues retained on soil surface decomposed slowly and have a greater N immobilization potential or lower rate of net N release than incorporated residue (Alvarez *et al*., 1995). The combined use of organic residues and mineral fertilizers, benefit crop N synchrony and reduced N losses (Gentile *et al*., 2009). This experiment was conducted under a semiarid dry condition on a soil with low organic matter, deficient in essential nutrients and alkaline in nature. Thus the enhancement in yield in residues retained treatment is due to reduced N losses and improved moisture conservation and soil organic C. The summer legume and fallow based rotation produced higher wheat grain/straw yields than summer cereal based rotation (Table 4). After water, nitrogen is the most important limiting factor in wheat and other cereals production in Pakistan. For wheat, the most commonly grown cereal, the soil must supply around 30 kg N ha^{-1} in a plant available form (usually as nitrate) for each ton of grain produced. The farmers in Pakistan are facing problems that capacity of their soils to supply the quantities of N required declined rapidly. Next to soil and fertilizer N, biological nitrogen fixation is considered as an extremely important N source (Zepata and Cleemput, 1986). In Southern and Western Australia, the principal source of N for cereal crops is derived from biological N_2-fixation either by forage legumes or grain legumes in a rotation system (Clarke and Russell, 1977). Leguminous residues decomposed faster because of low C: N ratio increased the mineral N pool in soil and contributes to yield improvement. Evans *et al*. (1991) verified that N is a key factor in the response of cereals following legumes compared with cereals following non-legumes. Chalk (1998) reviewed that many studies have shown that cereals derive both yield and N benefits from rotations with grain legumes as compared with cereal monoculture. Differences in rotational effect amongst the crop legume species appears to be minor. In most cases, wheat following grain legumes yielded more than wheat following wheat, irrespective of the legume species (Marcellos, 1984).

The residues retention increased significantly the N yield and fertilizer N utilization by wheat (Table 6, 8). Maximum N utilization (41.6 %) was recorded under no-tillage + residue treatment (Table 7). In over all, the N yield and fertilizer N utilization was decreased under no-tillage residue removed treatment. Soil analysis showed higher N-uptake and SOC in no-tillage + residue treatment (Table 9). The results from 43 fertilizer trials in the Punjab (Pakistan) showed that fertilizer use efficiency decreased in a no-tillage system (Aslam *et al*., 1993). Organic residues have been considered as the preferable nutrient source to improve fertilizer use efficiency. Combining N fertilizer with medium quality residue has the potential to change N transformations through a negative interactive effect on mineral N (Gentile *et al*., 2008). Studies indicated that incorporation of groundnut residues two weeks before rice transplanting, resulted in highest benefits for growth and yield of succeeding rice (McDonagh *et al*., 1995). Similarly, straw incorporation resulted in an increase in microbial biomass and N mineralization (Singh, 1995) in the long-term and soil nutrient supply (Eagle *et al*., 2000). The legume based rotation along with no-tillage + residue enhanced the soil OC as compared to residue removed treatment (Table 9). The three year average results showed that soil organic C was consistently greater in the no-tillage + residue treatment. The residues in the no-tilled are decomposed slowly and thus organic matter gradually accumulate on soil surface. Higher levels of soil organic C were directly related to surface accumulation of residue promoted by conservation tillage (Dolan *et al*., 2006), residue quality (Hema *et al*., 1999), continuous cropping (Sainju *et al*., 2008) and due to greater C input via crop roots and shorter fallow (Franzluebbers *et al*., 1995).

The residue retention resulted in maximum WUE than residue removed treatment (Table 5). The no-tillage without crop residue did not showed positive results. Maximum WUE was recorded in no-tillage + residue treatment under wheat-fallow-wheat and wheat-legume-wheat rotation. In over all strong effect of residue on WUE of wheat was found under no-tillage system. These results showed that residue retention with no-tillage in legume based rotation enhanced the soil fertility and reduced the evaporation of moisture from soil that improved the water use efficiency. Bouzza (1990) also found that water storage increased from 50 to 85 mm as a result of surface applied straw as compared to treatment in which straw was deeply incorporated. Similarly, wheat grain yield in our experiment in no-tillage + residue treatment was higher than residue removed treatment because of better utilization of growing season precipitation. Soil surface conditions are of major importance in determining the water content of soil under different tillage systems. The no-tillage + crop residue management is potentially found better than tillage for dryland crop production (Baumhardt and Jones, 2002) because it maintained greater water content in the soil and greater root growth especially in years of low rainfall (Lampurlanes *et al*., 2001).

5. Conclusion

Retention of crop residues in no-tillage treatment enhanced the wheat grain and straw yield, WUE, N uptake and fertilizer N utilization and OC content in soil. It is recommended that zero/minimum tillage practices with crop residues retention should be adopted in rainfed agriculture for improving crop productivity, fertilizer N utilization, water use efficiency and soil fertility.

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