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Effect of Conservation Agriculture Practices on Oat Fodder Yield, Water Use Efficiency, and Microbial Biomass C and N in Rainfed Dry Area of North- West Pakistan

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ABSTRACT

Crop productivity, water use efficiency (WUE), and microbial biomass C and N in rainfed dry area are influenced by tillage, rotation, and crop residue management. Field experiments were conducted during 2005-08 to study the effect of tillage, crop rotation, and crop residue retention on oat fodder yield, water use efficiency, and microbial biomass C (MBC) and N (MBN) under semi-arid conditions in north-west Pakistan. The objective of the study was to identify suitable cultural practices and fodder cropping system with improved water use efficiency for a dry area. The treatments consisted of three rotations: i) oat–fallow–oat (O-F-O)-farmers' practice, ii) oat– summer legume–oat (O-SL-O), and iii) oat–summer cereal–oat (O-SC-O). For each rotation, there were two tillage and two crop residue 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 oat, N_{90}+P_{60} to summer cereals and N_{20}+P_{60} (kg ha^{-1}) to legumes were applied. Changes in soil water storage were monitored with neutron moisture probe for calculation of WUE. The results indicated that an average maximum dry matter yield (7.78 t ha^{-1}) and WUE (26.47 kg ha^{-1}mm^{-1}) was obtained under no-tillage+crop residues treatment. The tillage practices showed no-significant effect on oat dry matter yield and WUE. The oat yield and WUE was higher in O-F-O rotation compared to O-SL-O and O-SC-O. The surface soil (0-15 cm) analysis showed that MBC and MBN was consistently greater in the no-tillage+crop residues treatment. These results indicated that no-tillage+crop residue treatment was relatively more beneficial under the rainfed (dry) conditions.

Keywords: Crop rotation, Crop residues, Tillage, NP fertilizers.

INTRODUCTION

Oat (*Avena sativa* L.) is an important rabi cereal fodder crop of Pakistan and grown under irrigated and rainfed conditions. It is a quick growing, palatable, succulent, and nutritious crop. Oat, as a mixture with other cold season legumes, provides balanced feed to milch animals (Thomson *et al.*, 1990; Younis and Azam, 2003). However, the crop productivity is quite low in rainfed dry areas of Pakistan. Low organic matter (Wang, 2006), inadequate and erratic rainfall (Loss and Siddique, 1994), drought (Rockstrom *et al.*, 2007), deficiency of nutrients (Sahrawat *et al.*, 2007), low and unbalanced use of fertilizers (Rashid and Akhtar, 2006), and poor physical condition of soils and other undesirable environmental factors like dry air and high soil temperature are the major limiting factors causing low production under rainfed conditions.

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Conservation Agriculture (CA) involves minimum tillage operation, retention of permanent soil cover, and the use of rotation. CA has potential benefits, such as soil and water conservation, improved soil fertility, and reduced cost for tillage operation (Dalal and Chan, 2001; Lampurlanes *et al*., 2001; Lal *et al*., 2003; Shah *et al*., 2003; Mohammad *et al*., 2010; Mohammad *et al*., 2012). Crop residue is a good source of nutrients in many agro-ecosystems for sustainable crop production and environment (Blanco-Canqui and Lal, 2009). Results from long term trials in Wagga Wagga, Australia have shown that 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 practice (Heenan *et al*., 2004).

Very little information is available on the effects of conservation agriculture on crop production, water use efficiency, and microbial biomass C and N content of soil in rainfed areas of Pakistan. Therefore, conservation agriculture practices need to be evaluated for their effect on improved crop yields, water use efficiency, and sustainable soil fertility in semi-arid environments. The present experiment was conducted to study the effect of crops residues, tillage/no-tillage, and rotation in rainfed dry area of north-west Pakistan on (i) oat yield, (ii) water use efficiency, and (iii) microbial biomass C (MBC) and N (MBN) status.

MATERIALS AND METHODS

Trial Description

Field experiments were conducted during 2005-2008 at Livestock Research Farm, Surezai (a rainfed area), Peshawar, north-west Pakistan (33° 45' N, 70° 50' E). Neutron moisture probe was used to measure the changes in soil water storage. Surezai farm is located at an altitude of 525 m above sea level and has cool climate in winter and warm to hot in the summer. The annual rainfall for the last 20 years is ranged from 200 to 760 mm. The growing season precipitation (123–358.2 mm) is inadequate and varies greatly, both within the growing season and from year to year (Table 1).

Soil (0-60 cm) of the experimental site was loam to clay loam (Inceptisol, Typic Calciustepts), alkaline in reaction (pH= 7.6-7.9), non-saline (EC= 0.39-0.22 dS m^{-1}), moderately calcareous (11.6 to 18.5% lime), had a bulk density of 1.43 to 1.45 Mg m^{-3} and was low in organic C (0.24-0.52%), total N (0.032-0.05%) and AB-DTPA extractable P (2.5-5.33 µg g^{-1}soil).

Experimental Design and Sowing

Experimental design was a split-split plot with two tillage treatments (main plots), three rotation treatments (sub plots), two residue management treatments (sub-sub plots), and three replications. Tillage treatments were (1) conventional tillage and

Table 1. Monthly rainfall (mm) during the experimental period**.**

	Rainfall (mm)		
Months	2005-06	2006-07	2007-08
December	--	60.2	--
January	56.4	--	57.2
February	15.2	177	21.2
March	32.4	82.4	3.0
April	17.0	20.4	113.4
May	2.0	18.2	4.0
Total	123	358.2	198.8

(2) no-tillage. Rotation treatments were: (1) oat-summer fallow-oat (farmer's practice), (2) oat-summer legumes-oat, and 3) oat-summer cereal-oat. Residue management treatments were: (1) residue retained and (2) residue removed. The size of the sub sub plot was 30 m^2. Under conventional tillage, land was tilled once in two years with moldboard plough (20 cm deep) and, at the time of each sowing, with cultivator. No-tillage operation was performed on zero tillage treatment. For residue treatments, above ground residues of summer crops were either removed (- residue), or retained on the soil surface and spread across the plots (+residue). Crop residues of pigeon pea (4 t ha^{-1}) and millet (6 t ha^{-1}) were retained on the soil surface. Cultivars sown were S-2000 (oat) and local varieties of summer cereals (sorghum/millet) and legumes (mungbean, pigeon pea). All seeds were sown by hand drill into 5cm depth. Row spacing was 30 cm for oat and legumes and 60 cm for summer cereals. According to local recommendations, basal doses of N (as urea) and P (as triple super phosphate) applied to each crop were N_{60}+P_{60} kg ha^{-1} (oat), N_{90}+P_{60} kg ha^{-1} (summer cereal), and N_{20}+P_{60} kg ha^{-1} (legumes). All fertilizers were applied at sowing time. Weedicide glyphosphate N-(phosphonomethyl) glycine was sprayed on no-tillage treatment before sowing of each winter and summer crop (two sprays in a year).

To study the effect of treatments (tillage, residue, and rotation) on the soil water storage, neutron access tubes were installed down to 90 cm in the soil profile in each treatment. Before the start of experiment, the Neutron probe readings were calibrated with gravimetric moisture contents in soil profile in 30 cm increments. Neutron probe readings were recorded at regular interval of 30 cm increments within the soil profile from planting up to the 2^{nd} cutting. The readings were finally converted to volumetric moisture content using the bulk density of soil cores taken from each depth increment. The rainfall data of the growing seasons was obtained from meteorological station. The crop water use (evapotranspiration, ET) was calculated from rainfall and change in soil water storage to 90 cm depth assuming no or negligible losses as runoff and drainage below root zone (Kirda, 1990).

Plant and Soil Sampling and Analysis.

From the oat fodder crop, usually two cutting were obtained, but, in dry season, only one cutting was obtained. Fresh and dry weight of each cutting was recorded. Microbial biomass C and N in surface soil samples (0-15 cm) collected after harvest of each crop were measured by the chloroform fumigation method (Ryan *et al*., 2001).

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).

RESULTS

Oat Dry Fodder Yield

Dry fodder yields of oat in different growing seasons were not improved due to tillage operation compared to no-tillage (Table 2). Retention of crop residues, however, significantly increased the dry fodder yield (Table 3). The tillage×crop residue interaction showed that fodder yields increased significantly in residue-retained treatment under both tillage and no-tillage treatments (Table 4). The residues effect on yield strongly depended on the tillage system. The fodder yield was significantly highest in residue-retained treatment under no-tillage compared to tillage treatment. On the average, residue-retained (CR+)

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Table 2. Effect of tillage on oat dry fodder yield and Water Use Efficiency (WUE) in rainfed dry area of north-west Pakistan.

Treatments	2005-2006	2006-2007	2007-2008	average
		Oat dry fodder yield (t ha^{-1}) [a]		
No-tillage	6.66 a	9.28 a	5.42 b	7.12
Tillage	6.59 a	9.22 a	6.43 a	7.41
		WUE (kg ha^{-1} mm^{-1})		
No-tillage	32.05 a	21.56 a	18.77 a	24.13
Tillage	31.8 a	22.46 a	22.28 a	25.52

[a] Values followed by different letters are significantly different at $P \leq 0.05$ by the DMR test.

Table 3. Effect of crop residues on oat dry fodder yield and WUE in rainfed dry area of north-west Pakistan.

Treatments	2005-06	2006-07	2007-08	average
	Oat dry fodder yield (t ha^{-1})[a]			
Crop residues retained	7.06 a	9.37 a	6.45 a	7.62
Crop residues removed	6.19 b	9.11 a	5.44 b	6.91
	WUE (kg ha^{-1} mm^{-1})			
Crop residues retained	34.12 a	23.77 a	21.23 a	26.37
Crop residues removed	29.88 a	19.92 b	20.01 b	23.27

[a] Values followed by different letters are significantly different at $P \leq 0.05$ by the DMR test.

Table 4. Interactive effect of tillage and crop residues on oat dry fodder yield (t ha^{-1}) in dry area (rainfed) of north-west Pakistan.[a]

	Tillage		No-tillage	
Year	Summer crop residues retained	Summer crop residues removed	Summer crop residues retained	Summer crop residues removed
2005-2006	7.02 a	6.17 b	7.1 a	6.21 b
2006-2007	9.07 c	9.38 b	9.67 a	8.89 c
2007-2008	6.32 a	6.54 a	6.57 a	4.23 b
Average	7.47	7.36	7.78	6.46

[a] Values followed by different letters are significantly different at $P \leq 0.05$ by the DMR test.

treatment produced 890 kg ha^{-1} more fodder yield than residue-removed (CR-) treatment. However, no-tillage+residue-retained treatment produced 1,340 kg ha^{-1} greater yield than residue-removed. In the tillage system, an improvement of 110 kg ha^{-1} was recorded in yield by residue retention. The oat dry fodder yield was significantly higher in oat-summer legume-oat and oat-fallow-oat rotation as compared to oat-summer cereal-oat rotation (Table 5). Maximum oat dry fodder yield was obtained during 2006-2007 due to highest rainfall (346 mm) as compared to the other seasons (Table 1). The pattern of rainfall distribution showed that, during 2006-2007, significant portion of the seasonal rainfall was received in December and that contributed to better seed germination and yield, while during 2005-2006, low oat dry fodder yield was recorded due to less rainfall (123 mm). Although during 2007-2008, rainfall was greater (198.8 mm) than that received during 2005-2006 (123 mm), yield was slightly lower than 2005-2006, as the major portion of rainfall was received in the month of April,

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which could not contribute to yield improvement.

Water Use Efficiency (WUE)

Almost similar dry matter WUE of oat was recorded under tillage and no-till treatments (Table 2). The residue retention increased oat dry matter WUE compared to residue removed treatment (Table 3). In over all, higher WUE (26.47 kg ha^{-1} mm^{-1}) was recorded in no-tillage crop residues retained treatment. The interaction data indicated that no-tillage without residues had no-advantage for WUE (Table 5). The rotation treatment effect showed that maximum WUE (26.1 kg ha^{-1} mm^{-1}) was recorded in the oat-fallow-oat rotation.

Microbial Biomass C and N (MBC and MBN)

The average microbial biomass C content of soil was consistently greater in the no-tillage plus residues treatment (Table 6). Higher microbial biomass C (544.7 µg g^{-1}) was found in no-tillage residues-retained treatment. The residues retention treatment indicated an improvement in MBC (468.1 µg g^{-1}) compared to residues-removed treatment (291.9 µg MBC g^{-1}). The no-tillage in overall showed higher MBC than tillage treatment. Among the rotations, legume based and fallow rotations enhanced significantly the microbial biomass C than cereal- cereal rotation. Similarly, the microbial biomass N was also greater in the no-tillage plus residues treatment. On an average, the microbial biomass N was 45.4 µg, g^{-1} for plus-residues and 28.6 µg g^{-1} soils for minus-residues treatment. The rotation treatment showed no-significant effect on microbial biomass N. However, in no-tillage, the microbial biomass N was slightly higher than tillage treatment. The results indicated that crop residues-retained treatment enhanced the microbial biomass N and C in soil.

DISCUSSION

The results obtained under rainfed conditions indicated that crop residue retention with no-tillage improved significantly the oat crop productivity, water use efficiency, MBC, and MBN content in soil (Tables 5 and 6). The crop residue

Table 5. Oat dry fodder yield (dry t ha^{-1}) and WUE (kg ha^{-1} mm^{-1}) as influenced by tillage, crop residue management, and rotation in rainfed area of north-west Pakistan.[a]

Treatments			Average of three years (2005-2008)					
Rotation	Tillage	Residues	Yield	WUE	Treatments Mean			
		+	7.77 ab	26.00 ab			Yield	WUE
O-F-O	T1	-	7.82 ab	25.92 ab		+	7.47 ab	26.28 a
		+	8.84 a	30.05 a	T1	-	7.36 ab	24.76 ab
	T0	-	6.73 bc	22.44 bc		+	7.78 a	26.47 a
		+	7.10 bc	24.00 bc	T0	-	6.46 b	21.79 b
O-SL-O	T1	-	7.48 bc	25.29 bc	+		7.62 a	26.37 a
		+	7.32 bc	24.87 bc	-		6.91 a	23.27 b
	T0	-	6.93bc	23.84 bc	O-F-O		7.79 a	26.10 a
		+	7.53 bc	28.84 a	O-SL-O		7.21 ab	24.50 a
O-SC-O	T1	-	6.78 bc	23.08 bc	O-SC-O		6.80 b	23.88 a
		+	7.18 bc	24.49 bc	T1		7.41a	25.52 a
	T0	-	5.71 c	19.10 c	T0		7.12 a	24.13 a

[a] T0= No-tillage; T1= Tillage, + = Summer crop residues retained; - = Summer crop residues removed; O-F-O= Oat-fallow-oat; O-SL-O= Oat-Summer legume-oat, O-SC-O= Oat-Summer legume-oat. Values followed by different letters are significantly different at $P \leq 0.05$ by the DMR test.

Table 6. Microbial biomass C and N (μg g^{-1}) of soil as influenced by tillage, crop residue management, and rotation in rainfed area of north-west Pakistan.[a]

Treatments			Average of three year (2005-2008)					
Rotation	Tillage	Residues	MBC	MBN	Treatments Mean			
		+	442.8 bc	41.0 bc			MBC	MBN
O-F-O	*T1	-	349.6 de	31.2 de	T1	+	391.5 b	40.06 b
		+	590.4 a	49.1 ab		-	337.3 b	29.32 c
	T0	-	279.0 e	32.2 d	T0	+	544.7 a	50.90 a
		+	434.2 bcd	42.1 bc		-	246.6 c	27.93 c
O-SL-O	T1	-	373.4 cd	27.5 e	O-F-O		415.4 a	38.3 a
		+	541.9 ab	55.2 a	O-SL-O		401.4 a	37.5 a
	T0	-	256.4 e	25.0 e	O-SC-O		323.1 b	35.3 a
		+	297.5 e	37.0 cd	T1		358.0 a	37.6 a
O-SC-O	T1	-	288.8 e	29.2 e	T0		395.6 a	36.7 a
		+	501.8 ab	48.4 ab	+		468.1a	45.45 a
	T0	-	204.3 f	26.55 e	-		291.9 ab	28.6 b

[a] Symbols are explained under Table 5. Values followed by different letters are significantly different at $P \leq 0.05$ by the DMR test.

retention enhanced the oat dry fodder yield significantly under no-tillage treatment (Table 3). It is reported in literature that no-tillage and crop residue retention on soil surface enhanced the soil organic fertility (Lal *et al*., 2003; Dalal and Chan, 2001; Heen and Chan, 1992) and improved dry land crop production (Baumhardt and Jones, 2002) due to moisture conservation (Lampurlanes *et al*., 2001). The crop residues retained on soil surface decompose slowly compared to its incorporation/mixing in the soil, and have a greater N immobilization potential. In addition, they lower the rate of net N release compared to incorporated residues (Alvarez *et al*., 1995). The integrated application of organic residues and mineral fertilizers benefits crop N synchrony and reduces N losses (Gentile *et al*., 2009). We conducted this experiment under semiarid dry condition on an alkaline calcareous soil having low organic matter, and deficient in essential nutrients (NP). The improvement in oat fodder yield in summer-residues-retained treatment may be due to improved moisture conservation and possibly of low N losses and higher soil organic C. The summer legume and fallow based rotation produced higher yield than summer cereal based rotation (Table 5). In rainfed dry cultivated areas of the world including Pakistan, after water, nitrogen deficiency is the major factor of low cereal crops production. The farmers are facing the problem of declining capacity of their soils to supply the quantities of N required for crops.

Biological nitrogen fixation is considered as an extremely important N source (Zapata and Cleemput, 1986). In Southern and Western Australia, the principal source of N for cereal crops is the biological N_2-fixation derived from either the animal forage legumes or the grain legumes in rotation (Clarke and Russell, 1977). Under cereal-cereal rotation, the surface soil structure becomes crusted, which impedes germination and root growth. On the other hand, legume inclusion in rotation improves soil organic matter, stability of aggregates, and spare soil mineral N. Leguminous residues decompose faster than cereal residue because of low C: N ratio and increase the mineral N pool in soil that 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), after reviewing many studies, showed that cereals derived both yield and N benefits from legumes based rotations.

The residue retention resulted in more WUE than residue removed treatment (Table 3). The

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no-tillage treatment without crop residue retention did not prove to be effective. Maximum WUE was recorded in no-tillage+summer crop residue-retained treatment under oat-fallow-oat and oat-legume-oat rotation (Table 5). In overall, a strong effect of summer crop residue retention on WUE of oat was found under no-tillage system. These results showed that residue retention on soil surface under no-tillage system in legume-based rotation enhanced soil fertility and reduced evaporation of moisture from the soil, thereby improving 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. Soil surface conditions affected the water content in soil profile under different tillage and cultural practices. Due to efficient utilization of precipitation and soil moisture, the oat dry fodder yield was increased in no-tillage+residue treatment compared to the residue-removed treatment. Baumhardt and Jones (2002) found that the no-tillage+crop residue management to be potentially better than tillage for dry land crop production. The three year average results showed that MBC and MBN were consistently greater in the no-tillage+residue treatment (Table 6). The residues in the no-till treatment decompose slowly and, thus, organic matter gradually accumulates on soil surface. The microbial biomass depends on soil organic matter as it serves as a good source of energy. Higher levels of soil organic C, MBC and MBN were directly related to surface accumulation of crop residues promoted by conservation tillage (Dolan *et al*., 2006), residue quality (Hema *et al*., 1999), continuous cropping (Sainju *et al*., 2008) and greater C input *via* crop roots and shorter fallow period (Franzluebbers *et al*., 1995).

CONCLUSIONS

Retention of crop residues in no-tillage treatment enhanced the oat fodder yield, WUE, MBC, and MBN content in soil. It is recommended that zero/minimum tillage practices with crop residue retention should be adopted in rainfed agriculture for improving oat crop productivity, water use efficiency, and soil fertility.

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اثر عملیات کشاورزی حفاظتی روی تولید علوفه جو دو سر(یولاف)، بهره وری آب، و کربن و نیتروژن زیست توده میکروبی در دیمزار های شمال شرق پاکستان

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چکیده

تولید محصول و بهره وری آب و کربن و نیتروژن زیست توده میکروبی در دیمزارها تحت تاثیر خاکورزی، تناوب زراعی، و مدیریت بقایای گیاهی است. در این پژوهش مزرعه ای، که در سال های ۲۰۰۵–۰۸ اجرا شد، اثر عملیات خاکورزی، بهره وری آب، و کربن و نیتروژن زیست توده میکروبی(MBC) و(MBN) در شرایط دیم منطقه ای نیمه خشک در شمال شرق پاکستان بررسی شد. هدف این مطالعه شناسایی عملیات مناسب کشت وکار و سامانه کشت علوفه و افزایش بهره وری آب در منطقه ای خشک بود. تیمارها شامل سه تناوب:۱) جودوسر–آیش–جودوسر، روش زارع، ۲) جودوسر– لگوم تابستانه- جودوسر، و ۳)جودوسر–غلات تابستانه–جودوسر بود. برای هر تناوب، دو نوع خاکورزی با دو مدیریت بقایای گیاهی اعمال شد که شامل بود بر: ۱)خاکورزی(برداشت بقایای گیاهی) و خاکورزی (حفظ بقایای گیاهی)، ۲) بدون خاکورزی(برداشت بقایای گیاهی) و بدون خاکورزی(حفظ بقایای گیاهی). کودهای شیمیایی پایه بر حسب کیلوگرم در هکتار برای جو دوسر $N_{60}+P_{60}$ ،برای غلات تابستانه$N_{90}+P_{60}$ ، و برای لگوم ها $N_{20}+P_{60}$ مصرف شد. برای پایش رطوبت خاک و محاسبه کار آیی مصرف آب **(WUE)** از نوترون متر استفاده شد. نتایج نشان داد که میانگین بیشینه عملکرد ماده خشک (۷/۷۸ تن در هکتار) و کارآیی مصرف آب (۲۶/۴۷ کیلوگرم در هکتار برای هر میلی متر) در تیمار بدون خاکورزی همراه با حفظ بقایای گیاهی به دست آمد. عملیات خاکورزی هیچ تاثیر معنی داری روی عملکرد ماده خشک جودوسر یا کار آیی مصرف آب نشان نداد.

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عملکرد جودوسر و کار آیی مصرف آب در تیمار جودوسر-آیش-جودوسر بیشتر از تیمار جودوسر-لگوم تابستانه-جودوسر و تیمار جودوسر-غلات تابستانه-جودوسر بود. تجزیه خاک سطحی (۱۵-۰ سانتی متر) نشان داد که (MBC) و(MBN)همواره در تیمار بدون خاکورزی همراه با حفظ بقایای گیاهی بیشتر از بقیه بود. نتایج کلی حاکی از آن بود که در شرایط دیم، تیمار بدون خاکورزی همراه با حفظ بقایای گیاهی منافع نسبی بیشتری داشت.

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