TILLAGE AND MULCH EFFECTS ON PROFILE MOISTURE DYNAMICS, FALLOW EFFICIENCY AND RAINFED WHEAT YIELDS IN POTOWAR

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The field experiment was conducted in Potowar plateau for two years (2004-05 and 2005-06) to monitor the effect of different fallowing practices on soil moisture dynamics, fallow efficiency and wheat yield. At summer start, conventional cultivator (CC), sub-soiler (SS), mouldboard plow (MP) and minimum tillage (MT) were applied as main plot treatments and no mulch and straw mulch @ 4 Mg ha^{-1} in subplots. During winter the whole plot was under wheat. It was observed that the soil moisture increased significantly after the summer and winter rainfalls and dropped significantly in the periods in between, the highest being after summer rainfall (average $0.23 m^3 m^{-3}$). The tillage systems differed significantly for Volumetric Soil Water (VSW) at wheat sowing, where MT showed significantly low VSW than other tillage systems (15-23% lower than CC). The differences in VSW on other sampling months were practically minor. Though numerically higher, mulch treatments generally showed non-significant differences. Fallow efficiency (FE) ranged from 22.82% to 33.25%. The MP showed higher or equal FE than CC, while MT consistently showed lowest. Wheat dry matter ranged between 4.86 and 9.34 Mg ha^{-1} and did not differ among tillage systems except that MT showed lower values in 2004-05. The MP and MT gave 29% and 30% higher grain yields than CC during 2004-05 and 2005-06, respectively. Grain yield was 33% higher in mulch than no mulch. The mouldbaord plow with mulch was more promising system for better wheat production in the area.
Key words: Summer fallow, tillage, mulch, soil moisture, wheat, Potowar

INTRODUCTION

The climate of Potowar ranges from semi-arid to sub-humid subtropical continental (Nizami *et al.,* 2004). Although in the northern part, total rainfall is adequate for crop production, the seasonal pattern of rains does not coincide with the plant growth requirements (Sahi *et al.,* 1997). Rains are erratic and about 60-70 percent of total annual rainfall is generally received during monsoon. In order to store this moisture for winter wheat production, fallow in the area starts in May after wheat harvest and ends after six months at wheat sowing.

It is well known that with many soil management systems, fallow efficiencies are very low. Fallow efficiency is defined as the percentage or fraction of the total precipitation received during the fallow period that is stored in the soil for the subsequent crop (Papendick, 1986). For enhanced water storage, three of the major avenues of moisture loss, i.e. evaporation, runoff and transpiration by weeds can be significantly reduced in dry areas with new technologies including effective tillage practices (McDonald and Fischer, 1987) and proper soil cover with mulch material (Voss, 1988).

Despite the great deal of work by the scientists to discover the best soil management system for better soil moisture storage during summer fallow, the controversy still remains. Even mouldboard plowing, a worldwide practice, has been sometimes reported to be inefficient for soil water conservation (Aase and Siddoway, 1982; Dao, 1993). Conservation tillage systems, including zero tillage and minimum tillage are being advocated as alternative (Lampurlanes *et al.,* 2002; Lal, 1997; Gicheru *et al.,* 2004; Bellido *et al.,* 1999). However, their benefits are not consistent for different agro-ecological conditions. Some authors have not observed differences in soil water storage between conventional and reduced tillage (Unger, 1994; Tanaka and Anderson, 1997). Even in some experiments negative results have been reported for no-till fallow (Cooke *et al.,* 1985). Crop residues, soil type, antecedent soil properties, type and depth of tillage and various climatic conditions modify the effects of tillage on various soil properties (Singh and Malhi, 2006).

Despite the significance of fallowing for crop production there had only been a limited number of field measurements of moisture profile dynamics and corresponding fallow efficiencies. Therefore, the following field research was conducted in high rainfall region of Potowar with the objectives to monitor the effect of different tillage systems and mulching on year-round changes in the soil moisture profile, fallow efficiency and subsequent wheat production.

MATERIALS AND METHODS

Location, climatic conditions and soil

Two-year field experiment was initiated in summer 2004 at Research Farm of University of Arid Agriculture Rawalpindi (33^0 38' 48" N, 73^0 04' 59" E), situated in higher rainfall region of the Potowar plateau. The rainfall incidence pattern is of bi-model type with the two maxima occurring in late summers and during the winter-spring periods. About 70% of the total annual rainfall is received during monsoon season i.e from June to September. These rains are torrential causing erosion. The winter rains are received in January-February. And are gentle and considerably less in amount than summer rains. Mean annual rainfall at Rawalpindi is approximately one meter. The mean maximum temperature in summer ranges from 36^{0}C to 42^{0}C with extremes sometimes as high as 48^{0}C (Nizami *et al.,* 2004). The experimental soil was of Rawal Soil Series (Sitly clay loam, weak to moderate medium sub-angular blocky, strongly calcareous, Typic Ustochrepts) (Calcaric Cambisols; FAO). The soil was poor in total organic carbon (6.1 g kg^{-1}), deficient in NO_3-N (3.84 ug g^{-1}) and available P (6.50 ug g^{-1}), however abundant in extractable K (130.0 ug g^{-1}). Saturation percentage was 36% and ECe 0.25 dS m^{-1}. Bulk densities were 1.48, 1.52 and 1.60 Mg m^{-3} for 0-30, 30-60 and 60-90 cm layers, respectively.

Table 1. Total monthly rainfall (mm), mean minimum temperature ($T_{min.}$, ^{o}C), mean maximum temperature ($T_{max.}$,^{o}C) and pan evaporation (PE, mm day^{-1}) during the experiment

Months	2004-05				2005-06			
	Rainfall	T_{min}	T_{max}	PE	Rainfall	Temp.	Temp.	PE
May	12.0	19.4	36.9	6.5	30.4	13.6	33.2	5.5
Jun	124.3	22.7	36.4	6.8	14.0	18.7	39.6	7.5
Jul	161.9	23.4	35.2	6.8	193.0	17.2	34.1	3.8
Aug	343.1	21.6	33.6	7.6	214.1	20.9	34.2	4.0
Sep	30.5	20.8	34.6	4.1	58.6	19.0	34.0	3.6
Oct	80.8	12.6	27.8	3.2	54.3	8.4	31.5	3.0
Nov	19.8	6.86	25.6	1.3	6.3	7.0	25.5	1.9
Dec	35.6	4.19	2.1	2.1	0	1.1	21.8	1.3
Jan	91.3	1.97	16.0	1.5	63.2	3.8	18.3	1.2
Feb	191.8	4.98	16.2	2.0	25.6	9.7	25.0	1.9
Mar	79.4	9.8	23.7	2.7	45.5	11.4	26.2	2.1
Apr	16.4	12.73	29.9	4.2	20.3	15.3	32.7	4.0

Treatments and operations

During summer, the tillage and mulch treatments were laid down in a split-plot design randomized in RCBD with four replications. The main plot treatments were conventional tillage (CC), sub-soiling (SS), mouldboard plowing (MP) and minimum tillage (MT). The sub plot treatments included no mulch and mulch of chopped wheat straw at the rate of 4 Mg ha^{-1}. The main plot size was 5 m x 12 m and each one was divided into two equal sub-plots of 5 m x 5 m. The conventional tillage (CC) practice was the farmer's practice that involved plowing with cultivator at a depth of 15 cm. In SS plots the soil was tilled with sub soiler upto 40 cm depth. Mouldboard plowing was carried out around 25 cm depth. Weeds in these plots were eradicated with cultivator. Minimum tillage (MT) consisted of maintaining the soil free of any tillage throughout the fallow period except for the seedbed preparation. Weed control in the MT plots was carried out with herbicide glyphosate [N- (phosphonomethyl) glycine]. Wheat straw was applied at the start of the summer fallow and mixed in the plow layer with cultivator.

During winter the whole plot was under wheat (*Triticum aestivum* L., cv. Wafaq 2001). Wheat was sown in the first week of November with seed rate of 60 kg ha^{-1} using seed drill. All the plots received basal dose of 80 kg N ha^{-1} and 40 kg P ha^{-1} as urea and DAP. No K fertilization was necessary. Hoeing was done during the initial stages of crop. The harvesting was done manually in May.

Sampling stages and data collection

Soil samples for moisture content were taken with king tube upto 90 cm depth. The core was divided into three samples of 30 cm incremental depth (0-30 cm, 30-60 cm, and 60-90 cm). The whole year was divided into six stages for soil moisture sampling, depending upon the seasonal changes. Which are as follows:

- S_1 Summer Fallow start (May)
- S_2 End of summer rainy season (Sep)
- S_3 End of summer fallow/wheat sowing (Nov)
- S_4 Before winter rainy season (Dec)
- S_5 After winter rainy season (Mar)
- S_6 Wheat harvest (May)

Volumetric soil water contents (VSW) were determined by multiplying gravimetric moisture content (θ_m) with bulk density of soil (Brady and Weil, 2002). The fallow efficiency was calculated by using the formula (VSW_{start} – VSW_{end} / Fallow rainfall) x 100 (Lampurlanes *et al.,* 2002). For bulk density samples from the walls of the pit were taken at three 30 cm incremental depths using core sampler (Blake and Hartge, 1986).

Plant samples for dry matter and grain yields were collected from 1m^2 area from each sub plot at wheat harvest. Rainfall, minimum and maximum air temperatures and pan evaporation data necessary for interpretations was obtained from Regional Agro-met Center situated at the university farm (Table 1).

Statistical analysis

The data collected for VSW content at various stages was subjected to time series analysis while fallow efficiency, wheat dry matter and grain yield were combined over years and analyzed by Analysis of Variance in a split plot. Treatment means were separated by using F-protected DMRT at a priori p>0.05 (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Moisture profile dynamics

The soil profile moisture differed significantly between different sampling stages during 2004-05 as well as 2005-06 (Figure 1). And within a stage different tillage treatments differed significantly for VSW content (Table 2). However, there was non-significant difference of VSW content in mulched and unmulched plots at any given stage.

dropped significantly during November (S_3) because this period was characterized by little rainfall. The moisture loss was more from minimum tillage (MT) plots as they showed significantly lower VSW content than CC, SS and MP during both the experimental years. However these differences disappeared in the later three stages. At S_4 stage the profile moisture again significantly increased owing to winter rains but not as higher as at S_2 due to simultaneous utilization by the crop. Moisture gradually dropped significantly in the last two stages (S_5 and S_6) due to evapotranspirational losses. Though mulched plots generally had numerically higher VWC, however it was statistically non significant.

Low moisture retention till wheat sowing shown by minimum tillage system in both experimental years may be attributed to lack of sufficient soil cover. The conservation tillage systems (including minimum tillage) are characterized by the presence of considerable (> 30 percent) soil cover as straw or stubble (Braddy and Weil, 2002). However, as evident from little or no difference between mulched and unmulched plots, the applied rate of mulch straw was insufficient to perform well for desirable period of time. It might be due to quick decomposition under our climatic conditions, leaving the soil unprotected against evaporation. Lopez *et al.*, (2003) observed that immediately after primary tillage the initial 60 percent of

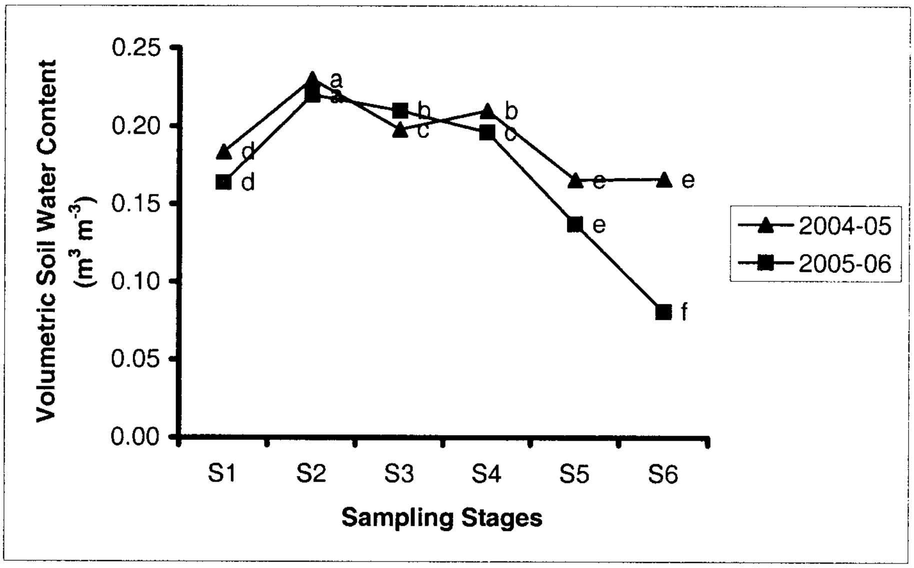

Figure 1. Average volumetric soil water content through six sampling stages

The highest VSW content was observed at S_2 (during September) where all the tillage systems captured equal amounts of water and there was non-significant difference in the tillage treatments. The highest VSW content at S_2 was the result of the greatest amount of rainfall received during monsoon. The moisture profile

crop residue decreased to less than 1 percent in conventional tillage, 12 percent in reduced tillage and 23 percent in no-till. Lampulanes *et al.*, (2002) while working in Ebro Vally of Spain, reported that during February to October period, greater evaporation owing to reduced soil cover significantly lowered water

Table 2. Volumetric soil water content of four tillage systems through six sampling stages

Sampling Stages	Volumetric Soil Water Content (m^3 m^{-3})							
	2004-05				2005-06			
	CC	SS	MP	MT	CC	SS	MP	MT
S_1	0.18 ab[b]	0.18 ab	0.17 b	0.19 a	0.16 c	0.17 bc	0.15 c	0.18 ab
S_2	0.24 a	0.23 ab	0.22 b	0.24 a	0.22 b	0.24 ab	0.22 b	0.25 a
S_3	0.21 b	0.21 ab	0.21 b	0.17 c	0.21 ab	0.22 a	0.21 ab	0.19 b
S_4	0.22 a	0.21 ab	0.21 b	0.21 b	0.20 bc	0.21 a	0.19 bc	0.18 c
S_5	0.16 b	0.16 b	0.16 b	0.18 ab	0.15 a	0.14 a	0.15 a	0.14 a
S_6	0.17 b	0.17 b	0.16 b	0.18 ab	0.08 a	0.08 a	0.07 a	0.08 a

[a] Average of two mulch treatments and three sampling depths, each replicated four times.
[b] Means followed by the same letter (s) are not significantly different (P<0.05) according to Duncan's Multiple Range Test (DMRT). The LSD value at the 5% level of significance for comparing the same tillage system between two stages is 0.16 (m^3 m^{-3}) during 2004-05 as well as 2005-06.

storage efficiency under NT. Therefore it is recommendable that in order to increase water storage, more residues must be left on the soil surface at wheat harvest to prevent evaporation.

Generally non-significant difference among different tillage systems at five of six sampling stages is in line with the findings of Lopez *et al.* (1996) who in a long-term experiment reported that reduced and conventionally tilled treatments generally had similar soil water content. Similarly, in a study conducted by Fuentes *et al.* (2003) to evaluate effect of conventional (CT) and no-till (NT) cropping systems on soil water dynamics the differences in soil moisture between NT and CT was less than 0.05 m^3 m^{-3}.

Fallow Efficiency

The mouldboard plowing (MP) appeared to be more promising for fallow efficiency during 2004-05 (Table 3). The MP treatment whether mulched or unmulched showed significantly higher fallow efficiency during 2004-05 than all other tillage mulch combinations. However, during 2005-06 SS and CC treatments also performed equivalent to MP treatment. Mouldbaord plowing has also been reported for better soil water storage by Nizami and Salim (1996) under similar conditions. The minimum tillage whether mulched or unmulched showed lowest fallow efficiency, significantly lower than other tillage mulch combinations during 2004-05 as well as 2005-06.

The lowest fallow efficiency recorded under minimum tillage might be attributed to lack of sufficient soil cover. The conservation tillage systems (e.g minimum tillage) require more than 30 percent residue cover (Braddy and Weil, 2002). However, as evident from little or no difference in moisture storage of mulched and unmulched plots, the applied quantity of mulch was insufficient to resist quick decomposition under our climatic conditions, leaving the soil unprotected against evaporation. Lopez *et al.*, (2003) observed that immediately after primary tillage the initial 60 percent of crop residue decreased to less than 1 percent in conventional tillage, 12 percent in reduced tillage and 23 percent in no-till. Lampulanes *et al.*, (2002) also reported that reduced soil cover significantly lowered water storage efficiency under NT. Therefore it is recommendable that in order to increase water storage, more residues must be left on the soil surface at wheat harvest.

Table 3. Effect of tillage systems and mulching on fallow efficiency

Treatments		Fallow Efficiency (%)[a]	
Tillage Systems	Mulching	2004-05	2005-06
CC	No mulch	28.52 b[b]	31.01 b
	Mulch	32.13 b	31.41 ab
SS	No mulch	29.98 b	31.50 ab
	Mulch	31.39 b	33.25 a
MP	No mulch	33.26 ab	29.63 ab
	Mulch	36.74 a	31.44 ab
MT	No mulch	22.82 d	29.02 c
	Mulch	26.40 c	27.86 d

[a] Average of four replications.
[b] Means followed by the same letter (s) are not significantly different (P<0.05) according to Duncan's Multiple Range Test (DMRT).

Wheat dry matter yield

The wheat dry matter was most of the times numerically higher in mulched plots than in unmulched plots, however the differences were statistically non significant (Table 4). The tillage treatments did not differ significantly for wheat dry matter in both the experimental years, except that the MT produced significantly low values during 2004-05. The results are inline with the finding of Schlegel *et al.,* (2002) who reported that tillage systems had little impact on wheat production.

Wheat grain yield

The wheat grain yield varied significantly with different tillage and mulch treatments within as well as between the years (Table 4). The mulched plots mostly showed significantly higher grain yields than the unmulched plots. This might be due to physico-chemical improvements of the soil by decomposed wheat straw, other than moisture content. The tillage treatments MP and SS produced significantly higher wheat grain yield than the CC and MT treatments, during 2004-05. This pattern changed in 2005-06 where the MT treatment produced significantly higher grain yield than all the other tillage treatments followed by MP and CC. The SS system produced significantly lower grain yield than all the three other tillage systems this year. The results are in line with the findings of Sharma *et al.* (1998) who reported that application of mulch increased grain yield of wheat crop. In another study carried out to document the yield increases that occurred from 1939 to 1997 in Southern Great Plains, USA, revealed that increased yields were attained due to the adoption of improved crop residue management practices (Unger and Baumhardt, 1999).

Table 4. Effect of tillage systems and mulching on wheat dry matter and grain yields

Tillage System	Mean Wheat Yields (Mg ha^{-1})[a]							
	Dry Matter Yield				Grain yield			
	2004-05		2005-06		2004-05		2005-06	
	No Mulch	Mulch	No Mulch	Mulch	No Mulch	Mulch	No Mulch	Mulch
CC	8.31 bc[b]	9.81 a	5.22 cd	7.13 ab	0.77 e	1.45 bc	1.44 ef	2.37 b
SS	8.19 bc	9.34 ab	4.86 d	5.50 cd	1.56 b	1.58 b	1.10 g	2.04 c
MP	8.90 ab	8.78 ab	5.62 cd	6.55 bc	1.17 cd	1.70 ab	1.97 cd	2.08 bc
MT	7.31 cd	6.28 de	6.30 bc	7.28 ab	1.10 d	0.97 de	2.21 bc	2.77 a

[a] Average of four replications
[b] Means followed by the same letter (s) for tillage mulch interaction within a year are not significantly different ($P<0.05$) according to Duncan's Multiple Range Test (DMRT).

The difference in two seasons for the performance of tillage systems in terms of wheat grain yield could be attributed to the difference in rainfall i.e 2004-05 received higher rainfall equivalent to the normal while the season 2005-06 received about 25% lower rainfall. As observed during 2004-05, moldboard tillage has also been reported to produce greater grain yield than conventional cultivator by Gill *et al.,* (2000) and Shahid and Akhtar, (2002). The lesser productivity in conservation tillage systems, like during 2004-05 in our case is inline with findings of Camara *et al.,* (2003). Better results with minimum tillage under lower precipitation conditions (2005-06) are inline with Bonfil *et al.,* (1999).

CONCLUSION

The soil moisture increased significantly after the summer and winter rainfalls and dropped significantly in the periods in between The mouldbaord plow was more promising system to perform summer fallow, as it gave equal or higher fallow efficiency, wheat dry matter and grain yields than the conventional cultivator (farmer's practice). Other systems were not consistent in their performance. Further, research is needed to find out the rate of wheat straw mulch and ways of residue management, to withstand the extreme summer temperatures of the area for a longer period, especially for conservation tillage system.

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