Influence of Tillage and Mulch on Soil Physical Properties and Wheat Yield in Rice-Wheat System

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Abstract

Zero tillage along with application of mulch is an important strategy for soil conservation which maintains sustainability of agricultural system. A randomized complete block design in a split plot arrangement was used with four tillage methods [conventional tillage, (CT); deep tillage, (DT); zero tillage with zone disc tiller, (ZDT); and happy seeder, (HS)] in main plots and five mulch materials [no mulch, (M_0); rice straw, (M_{Rice}); wheat straw, (M_{Wheat}); plastic sheet, ($M_{Plastic}$) at 4 t ha^{-1}, and natural mulch, ($M_{Natural}$)] in subplots during 2009-10 and 2010-11. Results showed that DT significantly decreased soil bulk density, penetration resistance, and volumetric moisture content when compared with CT, ZDT, and HS. However, wheat yield parameters such as germination count, fertile tillers, grain yield and water use efficiency were significantly higher in HS compared with other tillage treatments while root length and grain protein were higher in DT. Plant height remained non-significant during 2009-10, while in 2010-11 it differed significantly and was higher in HS than other tillage treatments. Wheat yield parameters were significantly higher in $M_{Plastic}$ at 4 t ha^{-1} than other mulch materials. Happy seeder and deep tillage along with plastic mulch have positive impact on soil physical properties, root growth, water use efficiency and yield parameters by creating a favorable soil environment.

Introduction

In Pakistan, wheat (*Triticum aestivum* L.) is an important staple food that has distinguished cereal crop in regulating agricultural policies and dominates all agronomic crops in the form of total acreage and yield. However, wheat yield is stagnant due to late sowing, unwise tillage operations, water shortage and lack of organic matter. It is substantially adapted to the physiographic and climatic conditions of Punjab, Pakistan. Rice-wheat cropping system plays an important role in world food security (Timsina & Connor, 2001; Ladha *et al.*, 2003a). In Pakistan, 50% area of rice-wheat cropping system is under fine and long quality specialty rice varieties (Basmati), which are late maturing and often delay spring wheat planting (Khan, 2002). Farmers' burn rice stubbles that cause air pollution (Gajri *et al.*, 2002), while some do several tillage operations (Yadvinder-Singh *et al.*, 2008).

Conventional tillage not only improves soil tilth but also reduces soil compaction, nutrient stratification, risk of weeds, soil-borne diseases (Boydas & Turgut, 2007) and

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enhances soil temperature, aeration, incorporation and decomposition of crop residues, disseminates soil structure and soil organic matter (Crovetto, 2006). However, continuous plowing at same depth causes formation of subsurface hardpan (Alakukku *et al*., 2003) which reduced nutrient and water use efficiencies and root growth (Ishaq *et al*., 2001a). Deep tillage is done to overcome the problem of soil compaction, improves rooting depth and control weeds by deep burial and exposing seeds to sunlight. Akinci *et al*. (2004) reported that reducing the subsoil compaction two-passes of deep plowing were more effective than one-pass sub soiling for improving the soil tilth. Deep tillage has more moisture content at 50–100 cm soil depth and reduces at 0–50 cm (Honglingl *et al*., 2008). However, deep plowing is expensive in terms of fuel and time.

Conservation agriculture practices like zero tillage have been introduced since the 1990,s to enhance water-use efficiency and to reduce soil erosion, costs of fuel and time. In general, ZT system increased the soil bulk density than CT (Francis, Tabley & White, 1999) that is the only way to reduced soil erosion, farming costs and improves ecosystem services (Sundermeier *et al*., 2011). Zero tillage reduced the operational costs 50–60% and sow directly in standing and loose straw (Gathala *et al*., 2009). Mulch is one of the resource conserving techniques that has an important role in agronomic practices by soil moisture conservation, modifying soil physical properties and enhancing water use efficiency that maximizes crop yield (Chakraborty *et a*l., 2008). In plant growth and development soil bulk density has crucial role on root growth and proliferation that are affected when grows beyond the specific values (Islam *et al*., 2006). Mulch influenceds the soil physical properties like soil temperature, moisture conservation, bulk density and penetration resistance that affect positively in crop growth and development (Feng-Min *et al*., 2004).

Plastic mulch enhanced the crop yield by changing soil properties, increased nutrient and water use efficiency and soil moisture (Feng-Min *et al*., 2004). Mulch materials lowered soil temperature in summer and increased in winter while conserved water at 100 cm soil depth than unmulched soil (Zhang *et al*., 2009). Mulch materials are the most effective water saving technique, which improved water use efficiency (about 14%), reduced soil evaporation and increased crop growth and yield (Chakraborty *et al*., 2008; Shanging & Unger, 2001). Plastic mulch significantly reduced the evapotranspiration, evaporation and increased the crop growth and yield by enhancing water use efficiency than other mulches (Zhong-kui *et al*., 2005).

Crop residues use as mulch has a rich source of organic matter, which is suitable in dry land areas (Cook *et al*., 2006). Zero tillage in combination with crop residue used as mulch held soil moisture content, reduced soil erosion (Bhatt & Khera, 2006) and increased organic matter content, which has positive effects on crop yield (Gla & Kulig, 2008). Moreover, black plastic mulch performed better and gave higher crop yield due to maintenance of soil conditions than un-mulched (Anikwe *et al*., 2007). Straw mulch along with zero tillage potentially enhanced the crop yield by effectively improving soil physical quality (Zhang *et al*., 2007). The overall benefit of mulches are to avoid yield reduction by zero tillage, and no significant yield difference occurred among different tillage systems but higher yield than tilled un-mulched (Gla & Kulig, 2008). Sarkar & Singh (2007) observed that deep and shallow depth plowing with mulch had marked impact and increased grain production and WUE than un-mulched.

The objectives of the study were to evaluate the effects of conventional tillage, deep tillage, zone disk, and happy seeder with different mulches on (1) soil bulk density, volumetric water content, and penetration resistance, and (2) growth and yield of irrigated wheat under a semiarid climate.

Materials and methods

Study site

The study was conducted in a rice-wheat system at the research farm of the University of Agriculture, Faisalabad (latitude 31^{O}26' N and 73^{O}06' E, altitude 185 m) in 2009–10 and 2010–11 growing seasons. The climate of the region is subtropical semi-arid with annual average rainfall of 490 $\pm$ 5 mm, and more than 70% of the rainfall occurs during June–September. The soil is the Hafizabad series (fine-loamy, mixed, hyperthermic, Typic Calciargids) and the soil texture is sandy clay loam. Selected chemical and physical characteristics were *p*H 7.7 ± 0.1, electrical conductivity 2.82 ± 0.3 dS m^{-1}, soil organic matter content 0.73%, total N 0.04%, available phosphorus 62 mg kg^{-1}, exchangeable potassium 83 mg kg^{-1}, and sand 53, silt 20 and clay 27%, respectively.

Experimental design and cultural practices

A randomized complete block design in a 4 × 5 split plot arrangement with three replications was established in 2009 in a post-harvest puddle rice field. Four tillage systems (conventional tillage, CT; deep tillage, DT; zero tillage with zone disk tiller, ZDT; and happy seeder, HS) were randomized in the main plots while five mulching materials [no mulch, (M_0); rice straw (M_{Rice}); wheat straw (M_{Wheat}); plastic sheet ($M_{Plastic}$) at 4 t ha^{-1}; and natural mulch ($M_{Natural}$)] were applied in 5.4 m by 8 m as subplots. Wheat (var. Seher 2006) was planted at 125 kg ha^{1} in the third week of November 2009 at 23 cm apart between rows having 24 rows in each replicated plot. Nitrogen, phosphorous and potash fertilizers were applied at 120, 100 and 60 kg ha^{1}, respectively. A full rate of phosphorous and potash and half of the N were applied at planting. The remaining half of the N was applied with first irrigation. Buctril super 60 EC (Bromoxynil + MCPA) at 700 ml ha^{-1} and Topik 15WP (Clodinafop propargyl) at 250 g ha^{-1} were applied to control both dicot and monocot weeds.

While CT operations consisted of two disk harrows, one rotavator and two planking, DT operations comprised one 30–40 cm deep mould board plow, one rotavator and two planking with a wooden plank. For no-till, only zone disk tiller and happy seeder drill were used. Hoeing along with herbicides was used to control weeds in all tillage systems. The evapo-transpiration (ET) and rainfall were measured at a field weather station to calculate total water requirement for wheat. Wheat was irrigated (a total of about 400 ± 35 mm water) using nearby canal water, and the irrigation was applied using a cut-throat flume (90 cm × 20 cm).

Yield and quality parameters, water-use efficiency of wheat

Agronomic parameters of wheat, including germination count, plant height, fertile tillers, 1000-grains weight, and grain and total yields (grain plus straws), water use efficiency were recorded. Grain protein was determined by using Kjeldahl's method (AACC, 1983). To measure root length, five plants were dug-out from the field, roots were separated from the soil and other residues by gentle washing under a flow of water, and the root length was measured (Tennant, 1975). Water use efficiency (WUE) was calculated by dividing the grain yields with the total volume of water used by the crop:

Water-use efficiency (kg/mm) = [Grain yield / (Irrigation + Rainfall)]

Soil collection and analysis

Composite soil samples were collected from 0–20 cm depths prior to establishing the experiment (2009) and after the crop harvest in 2011. Soil samples were air-dried and ground to pass through a 2-mm sieve. Soil chemical properties were determined; such as *p*H by the glass electrode method, electrical conductivity of the saturation paste by the electrical conductivity method, total N by the micro Kjeldhal method, 0.5 *M* $NaHCO_3$ extracted P by the method of Olsen & Sommers (1982), exchangeable K by the flame photometric method, and soil organic matter content by the method described by Ryan & Estefan (2001). Soil bulk density was measured using the standard core method. The volumetric water content of soil was determined gravimetrically. Soil penetration resistance was measured with a standard cone penetrometer.

Statistical analysis

Data were analyzed statistically using SAS (SAS Institute, 2008). The effects of tillage and mulch, soil depth and their interaction were evaluated by the least significant difference (LSD) test at $P \leq 0.05$ unless otherwise mentioned.

Results and discussion

Tillage and mulch effects on soil physical properties

Tillage had significant effects on soil bulk density (pb), penetration resistance and volumetric water (θv) content (Fig. 1) and (Table 1). The bulk density remained constant over time under all tillage treatments. In the first growing season (2009–2010), the pb

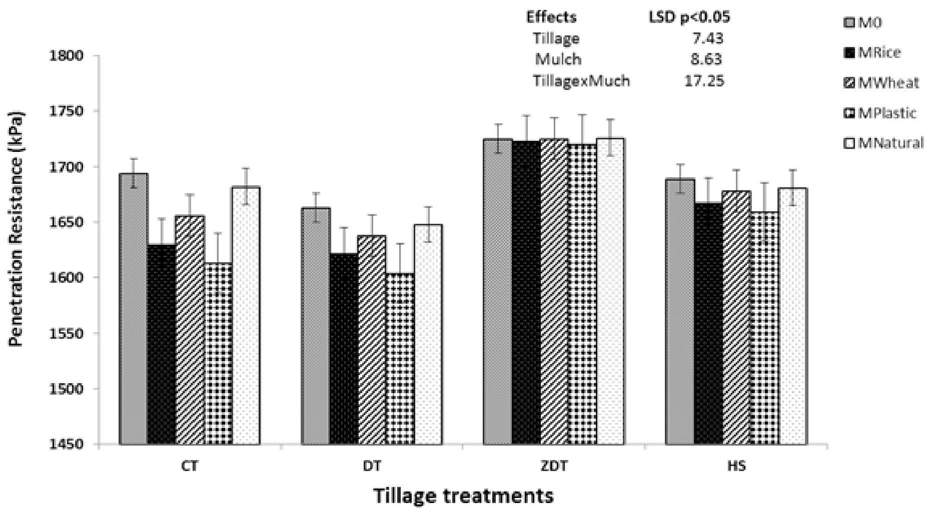

Fig. 1. Tillage and mulch effect on soil penetration resistance (data were combined over 2009–2010 and 2010–2011 growing seasons).

TABLE 1
Tillage effects on bulk density and volumetric water conent at different depths of soil

Tillage System	*Soil depth (cm)*	*Bulk density (g cm⁻³)* 2009-10	2010-11	2009-11	*Volumetric water (mm cm⁻¹)* 2009-10	2010-11	2009-11
$CT_{Initial}$	0-10	1.40C[ø]	—	—	1.8	—	—
CT	0-10	1.48C[§]	1.48C	1.48C	1.3C	1.3C	1.3C
DT	0-10	1.40D	1.40D	1.40D	0.8D	0.8D	0.8D
ZDT	0-10	1.59A	1.59A	1.59A	2.2A	2.2A	2.2A
HS	0-10	1.57B	1.57B	1.57B	1.8B	1.7B	1.8B
			Tillage × Soil depth				
$CT_{Initial}$	0-5	1.44	—	—	1.0	—	—
	5-10	1.51	—	—	1.5	—	—
DT	0-5	1.36	1.36	1.36	0.6	0.6	0.6
	5-10	1.44	1.44	1.44	1.0	0.9	1.0
ZDT	0-5	1.56	1.56	1.56	2.0	2.0	2.0
	5-10	1.63	1.63	1.63	2.4	2.4	2.4
HS	0-5	1.52	1.52	1.53	1.6	1.6	1.6
	5-10	1.61	1.61	1.61	1.9	1.9	1.9
LSD*Pd" 0.05*							
Soil depth		0.04	0.04	0.03	0.2	0.2	0.2
Tillage x Soil depth		ns	ns	ns	ns	ns	ns

CT = Conventional tillage, DT = Deep tillage, ZDT = Zone disc tiller (zero tillage drill), HS = Happy seeder (zero tillage drill) and ns = Non-significant. [ø]Means separated by upper case letter in each column are not significantly different at $P \leq 0.05$.

under DT was decreased by 5%, 10% and 12% as compared to CT, HS and ZDT. Similar tillage effects on pb were also observed in the second year of study. Averaged across years, the bulk density was noted significantly lower in DT than in other tillage systems. In both the years of study, soil penetration resistance was noted highest in ZDT, intermediate in HS and CT, and lowest in DT. Average across years, the ZDT had 5% higher soil penetration resistance than DT (Fig. 1). However, the ZDT had 41% and 64% more volumetric water content in both the years (2009–10 and 2010–11) than in CT and DT, respectively (Table 1). Irrespective of tillage operations, the soil bulk density, penetration resistance and volumetric water content significantly increased with soil depth. However, tillage and its interaction with soil depth did not exert any significant effects on bulk density and volumetric water content.

In contrast, mulch had non-significant effects on bulk density and volumetric water content while significant on penetration resistance in both growing seasons (Table 2) and (Fig. 1). Mulch interaction with soil depth did not exert any significant effects on

TABLE 2

Mulch effects on bulk density and volumetric water content at different depths of soil

Mulch	*Soil depth (cm)*	*Bulk density (g cm^{-3})* 2009–10	2010–11	2009–11	*Volumetric water (mm cm^{-1})* 2009–10	2010–11	2009–11
M_0	0–10	1.52A[Ø]	1.52A	1.52A	1.7A	1.7A	1.7A
M_{Rice}	0–10	1.51A	1.51A	1.50A	1.5A	1.5A	1.5A
M_{Wheat}	0–10	1.51A	1.51A	1.51A	1.4A	1.4A	1.4A
$M_{Plastic}$	0–10	1.51A	1.51A	1.51A	1.5A	1.5A	1.5A
$M_{Natural}$	0–10	1.52A	1.52A	1.52A	1.4A	1.4A	1.4A
Mulch × Soil depth interaction							
M_0	0-5	1.48	1.48	1.48	1.5	1.5	1.5
	5-10	1.56	1.56	1.56	1.9	1.9	1.9
M_{Rice}	0-5	1.47	1.47	1.47	1.3	1.3	1.3
	5-10	1.55	1.55	1.55	1.7	1.7	1.7
M_{Wheat}	0-5	1.47	1.47	1.47	1.3	1.3	1.3
	5-10	1.55	1.55	1.55	1.6	1.7	1.6
$M_{Plastic}$	0-5	1.47	1.47	1.47	1.3	1.3	1.3
	5-10	1.54	1.54	1.54	1.7	1.7	1.7
$M_{Natural}$	0-5	1.48	1.48	1.48	1.3	1.3	1.3
	5-10	1.55	1.55	1.55	1.6	1.6	1.6
LSD $P \leq 0.05$							
Soil Depth		0.04	0.04	0.03	0.3	0.3	0.3
Mulch x Soil depth		ns	ns	ns	ns	ns	ns

CT = Conventional tillage, DT = Deep tillage, ZDT = Zone disc tiller (zero tillage drill), HS = Happy seeder (zero tillage drill) and ns = Non-significant. [Ø]Means separated by upper case letter in each column are not significantly different among mulch at $P \leq 0.05$.

soil bulk density and volumetric water content. Moreover, tillage interaction with mulch had non-significant effects on bulk density and volumetric water content while significant on penetration resistance. In both the growing seasons, no mulch had 3% greater penetration resistance than other mulches (Fig. 1).

In deep tillage, significantly lower values of soil bulk density, penetration resistance, and volumetric water contents were due to greater soil mixing and inversion by plowing. In deep tillage, lower values of soil bulk density and penetration resistance reduce the ability of soil to hold moisture content due to exposure of large surface area of soil to the sunlight (Osunbitan *et al.*, 2005). In contrast, ZDT had significantly higher values of bulk density, penetration resistance and volumetric water content than other tillage systems due to lack of soil disturbance, crop residues deposition on soil surface as mulch, and less evaporation (Alvarez & Steinbach, 2009; Fuentes *et al*., 2009). In NT, wheat production along with crop residues had positive effect on soil physical properties (Mohanty *et al*., 2007). Soil surface without any residues/materials lacks soil moisture content due to evaporation, and these soils had high soil penetration resistance compared with other soils that have residues/materials (Pervaiz *et al*., 2009).

Tillage and mulch effects on wheat yields

Tillage and mulch had significant effects on yield parameters of wheat (Table 4–6). In first year (2009–2010), DT and HS had significantly 3% higher germination count over others (Table 4) while in 2010–2011 trend was same (Table 5). Average across years, germination count of DT and HS was significantly higher than other tillage treatments (Table 6). In 2009–2010 growing season, tillage systems had non-significant effect on plant height (Table 4).

During second year of study, DT and HS had significantly higher plant height over others (Table 5). The DT had 3% higher plant height than CT and ZDT. Plant height of DT and HS was at par with each other. Averaged across years, CT and ZDT had significantly lower plant height than DT and HS. In 2009–2010 growing season, the HS produced 3%, 8% and 9% more fertile tillers than in DT, ZDT and CT, respectively. During 2010–11, HS and DT produced 7–8% more fertile tillers than in CT and ZDT. Averaged across year, HS produced highest number of fertile tillers over others. In both growing seasons, DT had 15%, 30% and 40% longest root length of wheat compared with CT, HS and ZDT.

In the 2009–2010 growing season, wheat grain yield was significantly higher (5.2 Mg ha^{-1}) in HS followed by DT (5.1 Mg ha^{-1}) as compared with CT and ZDT. HS and DT was 6% higher grain yields than ZDT and CT. In contrast, wheat grain yield was significantly higher (6.1 Mg ha^{-1}) in HS and DT as compared with CT and ZDT during 2010–2011 growing season. Average across the year, the trend was same (Table 6). In both the growing seasons, water-use efficiency was significantly higher in HS and DT than other treatments. HS and DT was 7% higher than ZDT and CT. Deep tillage in both the growing seasons gave 2% higher grain protein than zone disc tiller and happy seeder. Maximum grain protein contents were observed in deep tillage and minimum was observed in zero tillage systems (Happy seeder and zone disc tiller) during both growing seasons.

Mulch significantly influenced the yield of irrigated wheat in both the growing seasons (Table 4–6). Mulch had significant effect on germination count in both the growing seasons. Average across years, the maximum germination count was recorded at $M_{Plastic}$ that were 3%, 7%, 10% and 16% greater than M_{Rice}, $M_{Natural}$, M_{Whaet} and M_0, respectively. In both years of study, maximum plant height of wheat was noted in $M_{Plastic}$ and M_{Rice} that were 4%, 4% and 3% greater than the plant height of M_0, M_{Wheat} and $M_{Natural}$, respectively. Averaged across years, the highest number of fertile tillers was recorded at $M_{Plastic}$ that were 16%, 10%, 7% and 3% greater than in M_0, M_{Wheat}, $M_{Natural}$ and M_{Rice}, respectively. In first year 2009–10, mulch had non-significant effect on 1000-grain weight while in 2010–11 $M_{Plastic}$ produced 3% greater 1000-grain weight than M_0. However, the longest root length was measured in $M_{Plastic}$ that were

TABLE 3

Tillage and mulch interaction on soil bulk density and volume metric water content average across soil depth over time

Tillage System	*Mulch*	*Bulk density (g cm^{-3})* 2009–10	2010–11	2009–11	*Volumetric water (mm cm^{-1})* 2009–10	2010–11	2009–11
CT	M_0	1.49	1.49	1.49	1.4	1.4	1.4
	M_{Rice}	1.47	1.47	1.47	1.3	1.3	1.3
	M_{Wheat}	1.48	1.48	1.48	1.2	1.2	1.2
	$M_{Plastic}$	1.47	1.47	1.47	1.3	1.3	1.3
	$M_{Natural}$	1.48	1.48	1.48	1.2	1.2	1.2
DT	M_0	1.41	1.41	1.41	0.8	0.8	0.8
	M_{Rice}	1.40	1.40	1.40	0.8	0.8	0.8
	M_{Wheat}	1.40	1.40	1.40	0.7	0.7	0.7
	$M_{Plastic}$	1.40	1.40	1.40	0.8	0.8	0.8
	$M_{Natural}$	1.41	1.41	1.41	0.7	0.7	0.7
ZDT	M_0	1.60	1.60	1.60	2.4	2.4	2.4
	M_{Rice}	1.59	1.59	1.59	2.2	2.2	2.2
	M_{Wheat}	1.59	1.59	1.59	2.1	2.1	2.1
	$M_{Plastic}$	1.59	1.59	1.59	2.2	2.2	2.2
	$M_{Natural}$	1.59	1.59	1.59	2.1	2.2	2.1
HS	M_0	1.58	1.58	1.58	1.9	1.9	1.9
	M_{Rice}	1.57	1.57	1.57	1.7	1.7	1.7
	M_{Wheat}	1.57	1.57	1.57	1.7	1.7	1.7
	$M_{Plastic}$	1.56	1.56	1.56	1.8	1.8	1.8
	$M_{Natural}$	1.57	1.57	1.57	1.7	1.7	1.7
LSD $P \leq 0.05$							
Tillage x Mulch		ns	ns	ns	ns	ns	ns

CT = Conventional tillage, DT = Deep tillage, ZDT = Zone disc tiller (zero tillage drill), HS = Happy seeder (zero tillage drill) and ns = Non-significant

22%, 11%, 9% and 2% greater than M_0, $M_{Natural}$, M_{Wheat} and M_{Rice}, respectively in both years. Total yield in $M_{Plastic}$ and M_{Rice} were 5–17% greater than $M_{Natural}$, M_{Wheat} and M_0, respectively.

Wheat grain yield in $M_{Plastic}$, M_{Rice} and $M_{Natural}$ was 16% higher than M_{Wheat} and M_0 in first year of study. In 2010–11, higher grain yield was recorded in $M_{Plastic}$ and M_{Rice} that was 7, 10 and 15% higher than $M_{Natural}$, M_{Wheat} and M_0, respectively. Water-use efficiency of wheat in $M_{Plastic,}$ M_{Rice} and $M_{Natural}$ were 17 and 18% higher than M_{Wheat} and M_0 during 2009–10. In second year of study, $M_{Plastic}$ and M_{Rice} had maximum WUE that was 7, 9, 14% greater than $M_{Natural}$, M_{Wheat} and M_0, respectively. During both the growing seasons (2009–10 and 2010–11),

TABLE 4

Tillage and mulch interaction on germination, fertile tillers, plant height, 1000-garin weight, root length, total and grain yields, water use efficiency and protein content of irrigated wheat (data of 2009–2010 growing season)

Tillage trts.	*Mulch* (m^{-2})	*Germination* (*cm*)	*Plant height* (m^{-2})	*Tiller grain wt. (g)*	*1000-length* (*cm*)	*Root yield*	*Total yield* ($Mg\ ha^{-1}$)	*Grain*	*WUE* ($kg\ mm^{-1}$)	*Protein* (*%*)
	M_0	131eø	100.7b	223e	44.8a	12.7e	1.2b	4.5b	10.5b	12.1e
	M_{Rice}	143b	102.9ab	250b	46.1a	16.1b	13.5a	5.4a	12.8a	12.4b
	M_{Wheat}	135d	100.7b	228d	45.4a	15c	11.4b	4.5b	10.7b	12.2d
	$M_{Plastic}$	146a	105a	258a	45.8a	16.5a	13.6a	5.4a	12.9a	12.5a
	$M_{Natural}$	141c	101.5b	242c	46.5a	14.7d	12.9ab	5.3a	12.6a	12.3c
Tillage × Mulch interaction										
CT	M_0	130	100.3	210	43.9	13.8	10.4	4.1	9.7	12.1
	M_{Rice}	141	102.1	242	46.1	17.8	13.4	5.3	12.5	12.4
	M_{Wheat}	132	100.5	222	45.3	15.6	11.4	4.5	10.6	12.2
	$M_{Plastic}$	143	103.4	250	45.6	18.3	13	5.1	12.4	12.5
	$M_{Natural}$	137	101.2	231	46.2	15.1	13.2	5.2	12.2	12.3
	Mean	137B§	101.5A	231D	45.4A	16.1B	12.3A	4.8C	11.5B	12.3B
DT	M_0	131	100.5	230	45.5	15	11.4	4.5	10.7	12.1
	M_{Rice}	145	103.1	250	46.2 `	20.5	13.6	5.5	12.9	12.5
	M_{Wheat}	136	101.3	233	45.5	19.6	11.4	4.5	10.7	12.3
	$M_{Plastic}$	148	106.5	260	46.3	21.1	13.8	5.5	13.1	12.6
	$M_{Natural}$	144	102.3	248	45.2	19.4	13.5	5.4	12.8	12.4
	Mean	141A	102.7A	244B	45.7A	19.1A	12.7A	5.1AB	12A	12.4A
ZDT	M_0	128	101.4	222	44.4	10	11.2	4.5	10.6	12
	M_{Rice}	141	102.2	240	46.2	12.1	13.2	5.3	12.6	12.4
	M_{Wheat}	133	100.4	218	45.2	11.1	11	4.4	10.4	12.1

	$M_{Plastic}$	145	103.5	248	45.3	12.3	13.3	5.3	12.7	12.5
	$M_{Natural}$	141	101.2	235	48.6	11.2	13.2	5.2	12.4	12.3
	Mean	138B	101.7A	233C	45.9A	11.4D	12.4A	4.9BC	11.7B	12.2C
HS	M_0	133	100.5	230	45.5	11.8	11.8	4.7	11	12.1
	M_{Rice}	145	104.2	268	46.2	14.2	13.9	5.6	13.2	12.4
	M_{Wheat}	137	100.7	240	45.6	13.5	11.9	4.7	11.2	12.2
	M-$_{Plastic}$	148	106.5	275	46.2	14.3	14.1	5.6	13.4	12.5
	$M_{Natural}$	143	101.3	253	46	13.1	11.8	5.5	13.1	12.3
	Mean	141A	102.6A	253A	45.9A	13.4C	12.7A	5.2A	12.4A	12.2C
LSD $P \leq 0.05$										
Tillage x Mulch		ns	ns	3	ns	0.19	ns	ns	ns	ns

CT = Conventional tillage, DT = Deep tillage, ZDT = Zone disc tiller (zero tillage drill), HS = Happy seeder (zero tillage drill), WUE = Water-use efficiency, and ns = Non-significant. [Ø]Means separated by lower case letter in each column are not significantly different among Mulch at $P \leq 0.05$. [§]Means separated by upper case letter in each column are not significantly different among tillage treatments at $P \leq 0.05$.

TABLE 5

Tillage and mulch interaction on germination, fertile tillers, plant height, 1000-garin weight, root length, total and grain yields, water use efficiency and protein content of irrigated wheat (data of 2010 to 2011 growing season)

Tillage trts.	*Mulch*	*Germination* *(m^{-2})*	*Plant height (cm)*	*Tiller* *(m^{-2})*	*1000-grain wt. (g)*	*Root length (cm)*	*Total yield* *(Mg ha^{-1})*	*Grain yield* *(Mg ha^{-1})*	*WUE* *(kg mm^{-1})*	*Protein* *(%)*
	M_0	118e[Ø]	100.9c	238e	47.1b	12.8e	13.5b	5.4d	12d	12.1e
	M_{Rice}	147b	103.1ab	279b	48.4ab	16.2b	15.8a	6.3a	14a	12.4b
	M_{Wheat}	126d	101.5bc	262d	47.5ab	15c	14.4ab	5.7c	12.7c	12.2d
	$M_{Plastic}$	156a	104.1a	289a	48.6a	16.6a	15.9a	6.4a	14.1a	12.5a
	$M_{Natural}$	139c	102.1bc	269c	47.6ab	14.7d	14.8ab	5.9b	13.1b	12.3c
				Tillage × Mulch interaction						
CT	M_0	115	100.1	232	46.8	14	12.9	5.1	11.3	12.1
	M_{Rice}	142	100.3	268	48.3	17.9	15.4	6	13.4	12.4

	M_{Wheat}	122	100.3	250	47.4	15.7	14.3	5.6	12.6	12.2
	$M_{Plastic}$	150	102.5	283	48.5	18.5	15.4	6.1	13.6	12.5
	$M_{Natural}$	133	100.6	254	47.5	15.3	14.7	5.8	13	12.3
	Mean	132B§	100.8B	257B	47.7A	16.3B	14.5A	5.7B	12.8B	12.3B
DT	M_0	122	101.6	243	47.2	15.1	14.1	5.6	12.5	12.2
	M_{Rice}	152	104.9	290	48.5	20.4	16.1	6.4	14.3	12.5
	M_{Wheat}	131	102.6	276	47.5	20	14.5	5.8	12.9	12.3
	$M_{Plastic}$	163	105.3	294	48.6	21	16.1	6.5	14.4	12.6
	$M_{Natural}$	143	103.2	285	47.7	19.2	15	6	13.4	12.4
	Mean	142A	103.5A	278A	47.9A	19A	15.1A	6.1A	13.5A	12.4A
ZDT	M_0	112	100.2	230	47.2	10	12.8	5.1	11.4	12.1
	M_{Rice}	141	102.7	266	48.3	12.2	15.6	6.2	14	12.4
	M_{Wheat}	120	100.4	246	47.4	11.2	13.8	5.5	12.3	12.2
	$M_{Plastic}$	151	103.5	284	48.5	12.4	15.7	6.3	14	12.5
	$M_{Natural}$	136	101.6	253	47.5	11.2	14.4	5.7	12.7	12.3
	Mean	132B	101.7B	256C	47.8A	11.4D	14.5A	5.8B	12.9B	12.2C
HS	M_0	123	101.7	245	47.2	11.9	14.1	5.6	12.5	12.1
	M_{Rice}	152	104.6	291	48.4	14.2	16.2	6.5	14.4	12.4
	M_{Wheat}	129	102.7	276	47.5	13.6	14.8	5.9	13.1	12.2
	$M\text{-}_{Plastic}$	161	105.4	295	48.6	14.4	16.3	6.5	14.6	12.5
	$M_{Natural}$	145	103.2	282	47.7	13.2	14.9	6	13.3	12.3
	Mean	142A	103.5A	278A	47.9A	13.4C	15.3A	6.1A	13.6A	12.2C
LSD $P \leq 0.05$										
Tillage x Mulch		ns	ns	3	ns	0.21	ns	ns	ns	ns

CT = Conventional tillage, DT = Deep tillage, ZDT = Zone disc tiller (zero tillage drill), HS = Happy seeder (zero tillage drill), WUE = Water-use efficiency, and ns = Non-significant. ØMeans separated by lower case letter in each column are not significantly different among Mulch at *Pd"0.05*.
§Means separated by upper case letter in each column are not significantly different among tillage treatments at $P \leq 0.05$.

TABLE 6

Tillage and mulch interaction on germination, fertile tillers, plant height, 1000-garin weight, root length, total and grain yields, water use efficiency and protein content of irrigated wheat (combined over 2009-2010 and 2010-2011 growing seasons)

Tillage trts.	*Mulch*	*Germination (m^{-2})*	*Plant height (cm)*	*Tiller (m^{-2})*	*1000-grain wt. (g)*	*Root length (cm)*	*Total yield (Mg ha^{-1})*	*Grain yield (Mg ha^{-1})*	*WUE (kg mm^{-1})*	*Protein (%)*
	M_0	124e[ø]	100.8c	230e	46b	12.7e	12.3c	4.9d	11.2d	12.1e
	M_{Rice}	145b	103b	264b	47.3a	16.1b	14.7a	5.9a	13.4a	12.4b
	M_{Wheat}	130d	101.1c	245d	46.4ab	15c	12.9bc	5.1c	11.7c	12.2d
	$M_{Plastic}$	151a	104.6a	274a	47.2a	16.5a	14.7a	5.9a	13.5a	12.5a
	$M_{Natural}$	140c	101.8bc	255c	47.1a	14.7d	13.9ab	5.6b	12.8b	12.3c
Tillage × Mulch interaction										
CT	M_0	123	100.2	221	45.4	13.9	11.7	4.6	10.5	12.1
	M_{Rice}	141	101.2	255	47.2	17.8	14.4	5.7	12.9	12.4
	M_{Wheat}	127	100.4	236	46.4	15.7	12.9	5.1	11.6	12.2
	$M_{Plastic}$	147	103	267	47.1	18.4	14.2	5.6	13	12.5
	$M_{Natural}$	135	100.9	243	46.9	15.2	14	5.5	12.6	12.3
	Mean	135B[§]	101.1B	244C	46.6A	16.2B	13.4A	5.3B	12.1C	12.3B
DT	M_0	127	101.1	237	46.4	15.1	12.8	5.1	11.6	12.1
	M_{Rice}	149	104	270	47.4	20.4	14.9	6	13.6	12.5
	M_{Wheat}	134	102	254	46.5	19.6	13	5.2	11.8	12.3
	$M_{Plastic}$	156	106	277	47.5	21.1	15	6	13.8	12.6
	$M_{Natural}$	144	102.8	267	46.5	19.3	14.3	5.7	13.1	12.4
	Mean	142A	103.1A	261B	46.8A	19.1A	14A	5.6A	12.8B	12.4A
ZDT	M_0	120	100.8	226	45.8	10	12	4.8	11	12.1
	M_{Rice}	141	102.5	253	47.3	12.1	14.4	5.8	13.3	12.4
	M_{Wheat}	127	100.4	232	46.3	11.1	12.4	5	11.4	12.2
	$M_{Plastic}$	148	103.5	266	46.9	12.4	14.5	5.8	13.3	12.5
	$M_{Natural}$	139	101.4	244	48.1	11.2	13.8	5.5	12.5	12.3
	Mean	135B	101.7B	244C	46.9A	11.4D	13.4A	5.4B	12.3C	12.2C

HS	M_0	128	101.1	237	46.4	11.9	13	5.2	11.8	12.1
	M_{Rice}	149	104.4	280	47.3	14.2	15.1	6.1	13.8	12.4
	M_{Wheat}	133	101.7	258	46.6	13.5	13.5	5.3	12.2	12.2
	$M_{-Plastic}$	154	106	285	47.4	14.4	15.2	6.1	13.8	12.5
	$M_{Natural}$	144	102.3	267	46.9	13.2	13.4	5.8	13.2	12.3
	Mean	142A	103.1A	266A	46.9A	13.4C	12.9A	5.7A	13A	12.2C
LSD $P \leq 0.05$										
Tillage x Mulch		ns	ns	9	ns	0.15	ns	ns	ns	ns

CT = Conventional tillage, DT = Deep tillage, ZDT = Zone disk tiller (zero tillage drill), HS = Happy seeder (zero tillage drill), WUE = Water-use efficiency, NUE = Nutrient-use efficiency and ns = Non-significant. ºMeans separated by lower case letter in each column are not significantly different among Nitrogen fertilization rates at $P \leq 0.05$. §Means separated by upper case letter in each column are not significantly different among tillage treatments at $P \leq 0.05$.

plastic mulch gave maximum grain protein while lower was recorded at no mulch.

In both the years (2009–2010 and 2010–2011), tillage × mulch interaction significantly influenced the wheat number of fertile tillers and root length (Table 4 and 5). However, $M_{Plastic}$ under HS produced significantly higher growth and yield of wheat followed by DT over other tillage ´ mulch combination. Significantly higher germination count of wheat was observed in deep tillage and happy seeder. In DT, higher germination count was due to less mean weight diameter that made fine root bed and deep surface area for moisture storage that is helpful for germination (Ozpinar & Cay, 2006).

Morris *et al*. (2009) observed that moisture evaporation was decreased, if seedling row was covered with straw in the case of HS. Zone disc tiller gave lower germination count due to soil surface was not covered by rice straw that decreased seed germination (Tessir *et al.*, 1991). Deep tillage had higher plant height that was associated with better seedbed preparation, higher soil porosity and greater water and nutrient availability (Khan *et al.*, 2001). Hemmat & Eskandari, (2006) and Lupwayi *et al*. (2006) observed higher plant height in the zero tillage than conventional tillage due to high moisture availability and nutrient concentrations greater in zero tillage at upper soil surface and decreased with increased in soil depth than conventional tillage. In contrast, the lower plant height of wheat under CT was due to subsurface soil compaction, which may have hindered root growth and affected water and nutrient uptakes. Similarly, higher percentage of fertile tillers in DT and HS than in CT and ZDT was due to greater water and nutrient availability to plants (Mrabet, 2002; Lopez-Fando & Pardo, 2009).

Deep tillage having significantly longer root lengths of wheat than in HS and ZDT was due to transitional soil compaction and higher values of soil bulk density (Beulter & Centurion, 2004). It is suggested that no-till having shorter root length than in CT was due to sub-surface soil compaction (Lopez-Bellido *et al*., 2007a,b).] Significantly higher total and grain yields in happy seeder and deep tillage than in CT were reported in several studies (Sip *et al*., 2009). Deep tillage gave higher grain yield due to finer and loose soil structure, which positively influences the seedling emergence and establishment to support higher crop yields (Rashidi & Keshavarzpour, 2007). In contrast, soils under HS and ZDT were cooler and moist than CT and DT. Cooler soil temperatures and higher moisture content often improve crop water-use efficiency. Soil water storage in DT was more due to large surface area (Hong-lingl *et al.*, 2008). Happy seeder has higher WUE than all other tillage systems (Su *et al*, 2007).

Mrabet (2002) reported similar findings that WUE of wheat in zero tillage and DT were due to high water storage. Moreover, significant difference of wheat grain yields between two growing seasons was due to the change in air temperatures, amount of rainfall and relative humidity. In 2010–2011 growing seasons, the weather was more favorable to irrigated wheat growth and WUE compared to the weather conditions in 2009–2010 growing seasons. Cociu & Alionte, (2011) reported that deep tillage had longer roots length that increased the nutrient use efficiency which increased the grain protein content.

Significantly higher germination counts were recorded in $M_{Plastic}$ than the other mulch materials due to improve soil water content and thermal conditions (Yan-Jun *et al*., 2006). Rahman *et al.* (2005) suggested that the earlier seedling emergence in $M_{Plastic}$ than straw mulch was due to high soil temperature, and conserve soil moisture from evaporation that helped the plant in early growth stages while straw mulch lowered soil temperature and higher moisture contents might be effect on seedling emergence. Similarly, in both years of study, $M_{Plastic}$ produced the higher plant height due to moisture availability and longer root lengths (Feng-Min *et al.*, 2004). Feng-Min *et al.*, 2004; Zhong-Kui *et al.*, 2005 and Yong-Shan *et al*., 2007 suggested that higher number of fertile tillers in $M_{Plastic}$ due to higher water use efficiency and nutrient availability effected on crop yield and yield parameters including total number of fertile tillers than no mulch. Rahman *et al*. (2005) and Yan-Jun *et al.* (2006) reported that mulch materials had non-significant effect on 1000-grain weight due to favorable climatic conditions that inhibit the treatments effect.

During both the growing seasons, longer root length of wheat was noted in $M_{Plastic}$ than other mulch materials due to lower soil bulk density and higher soil moisture, which was suitable for root growth (Hassan *et al*., 2005). Plastic mulch gave higher biological and grain yield due to higher yield attributes, soil moisture condition that favored plant establishment and plant population, which ultimately enhanced the crop yield. Most of the studies (Feng-Min *et al*., 2004; Zhong-kui *et al.*, 2005; Rahman *et al.*, 2005; Yong-shan *et al.*, 2007; Yan-Jun *et al.*, 2006) reported that $M_{Plastic}$ gave higher yield due to favorable soil conditions that favored plant establishment and population, which ultimately enhanced the crop yield. Similarly, Shangning & Unger (2001) and Palada *et al*. (2003) reported that $M_{Plastic}$ had higher WUE due to less water evaporation than bare soil that had no mulch materials. Mulch materials affected the grain quality, and higher grain protein content was noted in $M_{Plastic}$ due to favorable soil conditions that enhanced the roots for water and nutrients uptake (Hiltbrunner & Liegdens, 2008).

Significant interaction of tillage × mulch on fertile tillers and root length on the growth and yields of irrigated wheat suggested that $M_{Plastic}$ under HS performed best, followed by DT compared with other tillage × mulch combinations, since HS provides a higher amount of soil moisture to wheat, plastic mulch at 4 t ha^{-1} was enough to produce high yields.

Conclusion

In rice-wheat cropping system, during winter water is unavailable that causes hindrance in the growth and development of wheat crop. Zero tillage and mulch are important conservation agricultural practices for timely cultivation and saving water. Polythene mulch compared with other mulches, showed good potential for saving water, growth and yield in wheat under the sub-tropical soil and climatic conditions as in the present study. Happy seeder and deep tillage along with plastic mulch have positive impact on soil physical properties, root growth, water use efficiency and yield parameters by creating a favorable soil environment. Soil physical properties are normally helpful for ZT when wheat is planted after rice (Hobbs, Sayre & Oritz-Monasterio, 1998). Application of mulch also showed positive effects on grain production by delaying water stress.

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