EFFECT OF NITROGEN FERTILIZATION UNDER PLASTIC AND STRAW MULCHED CONDITIONS ON CROP YIELD AND WATER USE EFFICIENCY IN MAIZE-WHEAT ROTATION

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Abstract. Field experiments were conducted to find out the best optimization strategy for nitrogen and mulching for high yield and water use efficiency (WUE) of maize and wheat. Three nitrogen practices (250 kg Nha^{-1} for maize and 120 kg Nha^{-1} for wheat in single split, 200 kg Nha^{-1} for maize and 100 kg Nha^{-1} for wheat in two and three splits) and two mulches (plastic film and straw mulch) were tested. Maximum maize grain yield was recorded in T_5 (plastic film + nitrogen in three splits) which was 75.6 and 81.4% higher over control in 2014 and 2015 respectively. T_6 (straw mulch + nitrogen in three splits) increased wheat grain yield by 40.7% and 46.9% in 2014 and 2015 respectively. The highest WUE of maize (11.0 kg ha^{-1} mm^{-1} in 2014 and 12.4 kg ha^{-1} mm^{-1} in 2015) and wheat (8.0 kg ha^{-1} mm^{-1} in 2014 and 9.0 kg ha^{-1} mm^{-1} 2015) were recorded in T_5 and T_6 plots respectively. T_6 increased soil water contents and storage by increasing soil active carbon and decreasing bulk density. In conclusion, nitrogen (200 kg ha^{-1} for maize and 100 kg ha^{-1} for wheat) applied in three splits under straw mulched conditions is preferred optimization.
Keywords: *mulch, nitrogen management, soil water storage, total water use, water use efficiency*

Introduction

In regions with sufficient nutrients and water inputs, nutrient and water use efficiency (WUE) of maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) are still low because of suboptimal management (Vitousek et al., 2009) which results in their increased losses (Liu et al., 2014a). Wheat and maize are important cereals that account for ~70% of the world cereal production but limited water and nutrients availability are significantly affecting their yields especially in arid and semi-arid regions. However, food production will need to be doubled to feed the growing world population of 7.5 billion in 2017 which is expected to be 9.8 billion in 2050 (UN, 2017). Thus, use of limited natural resources (e.g. nutrient, water and land) will be under increasing pressure, and improving efficient use of water and nutrients for major cropping systems is a high priority (Green et al., 2010). Low productivity in semi-arid regions (like Pakistan) is due to poor soil water retention and low water-holding capacity caused by low soil organic matter (SOM) and coarse texture (Ahmad et al., 2014). To maintain normal water supply for crops with high water demand (i.e., maize) is a major challenge. Therefore, shortage in water availability is threatening the sustainability and production of major crops (Farooq and Nawaz, 2014).

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The irrigation and fertilization are the two major factors around the world to obtain high grain yields. Heavy rates of nitrogen are applied to wheat and maize crops (100-200 and 200-350 kg ha^{-1}, respectively) to support productive agriculture (Khan et al., 2007) because of poor N contents and inherently low organic carbon of agricultural soils in Pakistan. Scheduled application of nitrogen with irrigation events can enhance nitrogen availability to plants because undue N and water use in agriculture degrades environment as well as potentially threaten the sustainability of the system (Fang et al., 2010). Practices effective in conserving soil water include using suitable mulches, adding organic materials, and growing cover crops. Mulching has good potential in improving crop production by increasing soil water storage (Qureshi et al., 2010). Both straw and plastic mulching can play an important role in increasing crop and water productivity. Under warmer climate of Pakistan, plastic film mulch is more beneficial than straw mulch for improving water holding capacity and WUE (Jabran et al., 2015). Pervaiz et al. (2009) concluded that mulching significantly increased soil water and SOM content and decreased soil bulk density and soil strength. Use of rice husk vis-a-vis polyethylene mulch has a great potential of water saving with comparable growth and yield of wheat in the sub-tropical climatic and soil conditions (Chakraborty et al., 2008).

The amount of water used by plants is low in many cases even if the mulches are applied well. The reason for low water use by plants might be the poor fertility status of soils especially N (Li et al., 2000, 2009). There are various studies on effect of nitrogen fertilizers in many arid to semi-arid regions of the world, but most of the studies focuses on effect of nitrogen fertilizers on crop growth (Liu et al., 2010), its effect on crop yield and quality (Meng et al., 2012), groundwater pollution, its accumulation in soil and effects on the environment (Huai et al., 2009), but not on effect of nitrogen under mulched conditions on water use efficiency of crops. Crop yield and quality are determined by the management of nitrogen in any cropping system. Understanding the fate of applied nitrogen is vital for designing any optimal strategy for nitrogen management.

Mulches act as a barrier affecting the heat and energy transfer between atmosphere and soil and thus affect the hydrothermal properties of soil. Therefore, covering the soil with mulch may affect the fate and movement of nitrogen fertilizer in the plant–soil system and the management strategies of nitrogen for mulched and unmulched cropping systems should be different (Kettering et al., 2013). Soil chemical and biological processes such as C and N mineralization are significantly affected by mulching due to changes in soil temperature (Kader et al., 2017). Differences in water and N input levels, soil characteristics, climatic conditions (temperature and rainfall) and crop species lead to contrasting effects of mulching. Effects of mulching on crop yields and WUE can differ because of differences in water regime and environmental factors which require a quantitative and systematic assessment under site-specific conditions. Therefore, interactive effects between N fertilizer and mulches are important to understand as many soil processes and properties are affected by mulch.

This led to made us hypothesize that yield and WUE of maize and wheat crops could be improved by managing rate and timing of nitrogen under different mulched conditions. Therefore, present study was conducted with the aim to find out the best optimization strategy for nitrogen and soil surface mulching to obtain high yield and WUE of maize and wheat crops. The findings achieved will be used to optimize nitrogen fertilizers under mulched conditions to improve grain yield and WUE of maize

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and wheat crops in study area and areas with similar climatic conditions and cropping system.

Materials and methods

Experimental site

The field experiments using maize-wheat rotation were conducted for two years (2014 and 2015) at experimental station of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Punjab, Pakistan (31° N, 73° E). The climate of Faisalabad is subtropical and semi-arid, with the mean maximum temperature of 41 °C and the minimum of 27 °C during the summer. In winter these temperatures are 21 and 6 °C, respectively. The average annual precipitation is 380 mm, of which about half is received during July and August. *Table 1* represents the meteorological conditions of the maize and wheat growing seasons during 2014-15 and 2015-16. The soil is derived from alluvial deposits mixed with loess and classified as a, well-drained Hafizabad loam, a mixed, semi-active, isohyperthermic Typic Calciargids (Soil Survey Staff, 2014). Soil properties at the experimental site are summarized in *Table 2*.

Table 1. *Meteorological conditions of maize and wheat growing seasons at experimental site in Faisalabad, Pakistan. (Source: Agricultural Meteorological Cell, Department of Agronomy, University of Agriculture Faisalabad, Pakistan)*

Months	Mean temperature (°C)				Total rainfall (mm)	
	Maximum		Minimum			
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
August	37.1	35.9	27.3	26.7	4.8	48.4
September	33.9	35.4	24.5	24.4	140.2	75.2
October	31.3	32.2	19.1	19.1	3.6	14.5
November	26.3	27.1	11.5	12.1	10.0	8.8
December	18.5	21.8	5.9	7.2	0.0	0.0
January	16.6	17.3	6.9	7.7	12.2	13.1
February	22.0	23.3	11.1	9.3	20.5	7.8
March	24.5	26.8	13.6	15.6	67.9	66.7
April	33.2	34.3	20.7	20.2	32.8	5.6

Temperatures are monthly averages and rainfalls are monthly total

Treatments and experimental design

The crop varieties used were ‘Syngenta-8611’ and ‘AARI-2011’ for maize and wheat, respectively. Seven treatments were tested including nitrogen and mulch omission plots (T_0) and three nitrogen management practices and two mulched conditions. The treatments for the experiments for both crops were as follows:

T_0 = Control (No mulch, no nitrogen)
T_1 = Plastic film + nitrogen in single split (N_1)
T_2 = Straw mulch + nitrogen in single split (N_1)
T_3 = Plastic film + nitrogen in two splits (N_2)
T_4 = Straw mulch + nitrogen in two splits (N_2)

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T_5 = Plastic film + nitrogen in three splits (N_3)
T_6 = Straw mulch + nitrogen in three splits (N_3)

The nitrogen management details for each treatment are given in *Table 3*. The plots were arranged in a randomized complete block (RCB) design with three replications using a plot size of 5.5 × 13.5 m.

Table 2. *Physico-chemical properties of soil used for study in Faisalabad, Pakistan*

Soil properties	Value
Sand (%)	40±2.3
Silt (%)	37.5±1.0
Clay (%)	22.5±1.8
Textural class	Loam
ECe (dS m^{-1})	1.48±0.06
pH	8.05±0.04
Field capacity (cm^3/cm^3)	0.29±0.03
Bulk density (Mg m^{-3})	1.41±0.06
Soil organic matter (%)	0.72±0.14
Total nitrogen (%)	0.03±0.01
Available phosphorus (mg kg^{-1})	6.1±1.3
Extractable potassium (mg kg^{-1})*	168.6±6.4

*Extracted with 1 N ammonium acetate (NH_4OAc). Values are shown as mean ± standard deviation (n = 3)

Recommended rates of phosphorus (150 kg ha^{-1} for maize and 85 kg ha^{-1} for wheat) and potassium (150 kg ha^{-1} for maize and 65 kg ha^{-1} for wheat) were applied as basal dressing. While nitrogen was applied as per treatment as side dressing. For two splits nitrogen was applied to maize at sowing and 12-leaf stage (V12) and for three splits nitrogen was applied at sowing, 4-leaf stage (V4) and 12-leaf stage (V12). For wheat nitrogen was applied at sowing and crown root stage in two splits and at sowing, crown root stage and tillering stage in three splits. *Table 4* presents the details on sowing dates, plant populations, and levels of irrigation and fertilizers. After 7-10 days of seedling emergence, mulches were applied in between the crop rows. It allowed plants to grow normally and rainwater to enter the soil. Rice straw (C 53.3%, N 0.63% and C/N 84.6) was applied at the rate of 5 Mg ha^{-1}. White plastic film with 60 cm width and 0.008 mm thickness was used. Plastic film was stable and not decomposed after crop harvest.

Data collection and statistical analysis

Soil volumetric water contents (SWv, %) in 0-160 cm depth at 20 cm intervals were measured at sowing and harvesting and during growing seasons at every 7 days with Time Domain Reflectometry (TDR, Model 6050X1 Trase System, Soil Moisture Equipment Corp. California, USA) between crop rows in each plot (Topp et al., 1980). Soil water storage (SWS, mm) in 0-160 cm soil depth was calculated using following relationship:

$$\text{SWS (mm)} = \text{SWv (\%)} \times l \text{ (mm)}$$

where ‘l’ is soil depth.

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Table 3. *The rates of nitrogen applied for each nitrogen treatment to maize and wheat crops*

Treatments	Maize	Wheat
N_1	250 kg ha^{-1} (basal)	120 kg ha^{-1} (basal)
N_2	200 kg ha^{-1} (50:50)	100 kg ha^{-1} (50:50)
N_3	200 kg ha^{-1} (40:30:30)	100 kg ha^{-1} (40:30:30)

Bracket values indicate percent of total nitrogen applied per split

Plant height was measured with a meter rod from base to tip of the top most fully opened leaf of plants from each plot selected randomly. The mean plant height was expressed in cm. Formula reported by Dwyer and Stewart (1986) was used to measure the leaf area index (LAI):

$$\text{LAI} = \text{Leaf length} \times \text{leaf width} \times \text{A}$$

where 'A' is a factor with values of 0.80 and 0.75 for wheat and maize crops, respectively. LAI was recorded at silking stage for maize and booting stage for wheat by measuring the length and width of plant leaves from each plot selected randomly. After harvesting total biomass for each plot was measured in kg by using the spring balance having 20 kg capacity with division 0.2 g and precision of +0.3% (C.K. 6202, Carl Kammerling International, UK). The straw yield was reported at 0% moisture for both crops and expressed in Mg ha^{-1}. Grain yield of both crops was noted and converted into Mg ha^{-1} for each experimental unit. Grain yield was expressed at 14% moisture content for maize and 13% moisture for wheat according to grain quality standards for commercial trade. Following formula was used to calculate total water use (TWU) for both crops (Ram et al., 2013):

$$\text{TWU (mm)} = \text{I} + \text{P} + \Delta\text{W} + \text{CR} - \text{D} - \text{R}$$

where TWU is the total water use during both crops; P is the total precipitation; I is the amount of irrigation applied; ΔW is the change in soil water content from sowing to harvesting in 0 to 160 cm depth; R is the surface runoff; D is the drainage; CR is the capillary rise to the root zone (Zhang et al., 2005; Su et al., 2007). Drainage and capillary rise were considered as negligible and not taken in the calculations. The drainage was considered negligible based on the assumption that irrigation water applied was equal to the soil field capacity. The WUE was calculated using following formula:

$$\text{WUE}\left(\text{kg ha}^{-1}\text{mm}^{-1}\right) = \frac{\text{Grain yield}\left(\text{kg ha}^{-1}\right)}{\text{Total water use}\left(\text{mm}\right)}$$

Core samples with 50 mm internal diameter were also taken from each plot for bulk density determination. Cores were placed in oven at 105 °C for 24 h and bulk density was calculated by dividing the oven dried mass to the volume of core (Blake and Hartge, 1986). Soil samples from 0-15 cm and 15-30 cm were also taken for active carbon concentrations. Biologically active carbon was determined by spectrophotometer after extraction with 0.02 M potassium permanganate (Weil et al., 2003).

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ANOVA (analysis of variance) techniques were used to statistically analyze the collected data for field trials according to RCB design. Tukey's HSD (Honestly significant difference) test at $P \leq 0.05$ was used for mean comparison (Steel et al., 1997). For statistical analysis, the software packages IBM SPSS statistics 21 was used.

Table 4. *Sowing methods, plant populations, irrigation and fertilizers rate of maize-wheat crops for different treatments from 2014 to 2016*

Crops	Treatments	Sowing date		Sowing method	Plant population (10^4 ha^{-1})	Irrigation (mm)	Fertilizer rate (kg ha^{-1})		
		2014	2015				N	P_2O_5**	K_2O**
Maize	T_0	Aug. 8	Aug. 11	Direct	300	490	0	150	100
	T_1	Aug. 8	Aug. 11	Direct	300	490	250*	150	100
	T_2	Aug. 8	Aug. 11	Direct	300	490	250*	150	100
	T_3	Aug. 8	Aug. 11	Direct	300	490	200	150	100
	T_4	Aug. 8	Aug. 11	Direct	300	490	200	150	100
	T_5	Aug. 8	Aug. 11	Direct	300	490	200	150	100
	T_6	Aug. 8	Aug. 11	Direct	300	490	200	150	100
Wheat	T_0	Dec. 10	Dec. 14	Direct	6.0	300	0	85	65
	T_1	Dec. 10	Dec. 14	Direct	6.0	300	120*	85	65
	T_2	Dec. 10	Dec. 14	Direct	6.0	300	120*	85	65
	T_3	Dec. 10	Dec. 14	Direct	6.0	300	100	85	65
	T_4	Dec. 10	Dec. 14	Direct	6.0	300	100	85	65
	T_5	Dec. 10	Dec. 14	Direct	6.0	300	100	85	65
	T_6	Dec. 10	Dec. 14	Direct	6.0	300	100	85	65

*Conventional farmer's rate. **Recommended by Punjab Agriculture Department, Govt. of Punjab, Pakistan

Results

Plant height and leaf area index

Maximum plant height of maize was recorded for treatment T_5 which showed statistical similar response with T_6 during 2014 while it was different from rest of treatments in 2015 (*Table 5*). For wheat, maximum plant height was recorded in treatment T_6. Minimum plant height was recorded in T_0 during both years for both crops. Treatments' effect was also significant on leaf area index (LAI) of both crops. Treatment T_6 produced maximum LAI of maize during 2014 while it was maximum in T_5 during 2015 (*Table 5*). The differences between treatments T_4, T_5 and T_6 were not statistically significant during both years. The LAI of wheat was higher in treatment T_6 than all other treatments followed by T_4, but the differences were not significant with T_4 in 2015. T_0 always produced minimum LAI of both crops in both growing seasons.

Straw yield and grain yield

Treatment T_5 produced maximum straw yield of maize during both years. The differences among treatments were small (*Table 6*). The straw yield of wheat was

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higher in treatment T_6 than all other treatments followed by T_4 during 2014 and T_2 during 2015 but the differences were not significant. Except control (T_0) all treatments differences were not significant during 2014. *Table 6* shows the significance of grain yield of maize and wheat among treatments. Maximum grain yield of maize was recorded for treatment T_5 which showed statistical similar response with T_6 in 2015. Second lowest grain yield was recorded for treatment T_1 during both years. T_5 increased grain yield by 75.6 and 81.4% over that of T_0 during 2014 and 2015 respectively. T_6 increased grain yield of wheat by 40.7% in 2014 while 46.9% in 2015.

Table 5. *Plant height and leaf area index of maize and wheat crops under different treatments*

Treatments	Plant height (cm)				Leaf area index (LAI)			
	Maize		Wheat		Maize		Wheat	
	2014	2015	2014	2015	2014	2015	2014	2015
T_0	165.2 e	166.7 d	80.5 f	78.6 d	3.0 d	3.0 c	1.4 d	1.4 e
T_1	171.8 d	168.4 cd	84.3 e	94.4 ab	3.4 bc	3.4 b	1.6 cd	1.6 de
T_2	178.9 c	175.3 bcd	91.3 cd	92.7 ab	3.4 bc	3.3 b	2.0 b	2.1 bc
T_3	173.1 d	173.0 bcd	88.7 d	88.1 bc	3.3 c	3.4 b	1.7 c	1.7 cde
T_4	186.6 b	177.2 bc	95.1 ab	86.1 c	3.6 ab	3.5 ab	2.2 b	2.3 ab
T_5	190.9 a	191.1 a	92.3 bc	91.0 bc	3.6 abc	3.7 a	2.0 b	2.0 bcd
T_6	180.9 c	182.8 ab	96.3 a	98.6 a	3.8 a	3.6 ab	2.4 a	2.5 a
HSD	**4.0**	**10.1**	2.9	6.7	**0.3**	**0.3**	**0.3**	**0.4**

In single column different letters show statistical significance and same letters show non-significance at *P* = 0.05. Values are shown as mean ± standard deviation (n = 3)

Table 6. *Straw yield and grain yield of maize and wheat crops under different treatments*

Treatments	Straw yield (Mg ha^{-1})				Grain yield (Mg ha^{-1})			
	Maize		Wheat		Maize		Wheat	
	2014	2015	2014	2015	2014	2015	2014	2015
T_0	12.2 c	12.6 c	7.6 b	7.4 c	4.0 d	4.0 d	2.5 d	2.4 c
T_1	14.9 b	15.6 ab	8.1 ab	8.1 abc	5.6 c	5.6 c	2.9 c	2.9 b
T_2	14.6 b	16.7 ab	8.6 ab	9.6 ab	5.8 c	6.0 bc	3.0 bc	3.1 ab
T_3	16.9 a	17.1 a	7.9 ab	7.9 bc	6.0 c	6.5 ab	3.1 bc	3.2 ab
T_4	16.2 a	14.8 b	9.4 a	8.7 abc	6.9 ab	6.7 ab	3.3 ab	3.3 ab
T_5	17.1 a	17.5 a	8.9 ab	8.8 abc	7.1 a	7.2 a	3.2 abc	3.2 ab
T_6	17.0 a	17.0 a	9.5 a	9.7 a	6.7 b	6.8 ab	3.5 a	3.5 a
HSD	**0.9**	**2.1**	**1.8**	**1.8**	**0.4**	**0.8**	**0.4**	**0.5**

In single column different letters show statistical significance and same letters show non-significance at *P* = 0.05. Values are shown as mean ± standard deviation (n = 3)

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Total water use and water use efficiency

Effect of different treatments on total water use by maize was significant in both years (*Table 7*). Maximum water use by maize and wheat was recorded in control (T_0) treatment during both years. T_6 and T_5 showed minimum water use by maize and wheat crops respectively in both years. WUE differed significantly in both growing seasons. In 2014 WUE of maize ranged from 6.49 kg ha^{-1} mm^{-1} in T_0 to 11 kg ha^{-1} mm^{-1} in T_5 and from 6.61 kg ha^{-1} mm^{-1} in T_0 to 12.42 kg ha^{-1} mm^{-1} in T_5 in 2015. WUE of maize increased by 77.7% and 87.8% in T_5 as compared to that of T_0 in 2014 and 2015, respectively. The data also show that WUE of wheat increased significantly from 6.68 kg ha^{-1} mm^{-1} in T_0 to 8 kg ha^{-1} mm^{-1} in T_6 in 2014 and from 6.02 kg ha^{-1} mm^{-1} in T_0 to 8.96 kg ha^{-1} mm^{-1} in T_6 in 2015. T_6 increased WUE of wheat by 41.8 and 48.8% over that of T_0 in 2014 and 2015 respectively (*Table 7*).

Table 7. *Total water use and water use efficiency of maize and wheat crops under different treatments*

Treatments	Total water use (mm)				WUE (kg ha^{-1} mm^{-1})			
	Maize		Wheat		Maize		Wheat	
	2014	2015	2014	2015	2014	2015	2014	2015
T_0	652.0 a	598.4 a	440.1 a	400.1 a	6.2 e	6.6 d	5.6 d	6.0 c
T_1	651.2 ab	581.3 b	439.5 ab	398.6 ab	8.7 d	9.6 c	6.7 c	7.3 b
T_2	649.8 bc	573.6 d	438.8 bc	397.6 bc	8.9 cd	10.5 bc	6.9 bc	7.8 ab
T_3	648.2 cd	580.0 bc	438.1 cd	397.1 bcd	9.2 c	11.3 ab	7.0 bc	8.0 ab
T_4	647.7 d	573.3 d	438.5 bc	397.4 bc	10.7 ab	11.6 ab	7.5 ab	8.4 ab
T_5	644.8 e	578.4 c	437.2 de	396.1 cd	11.0 a	12.4 a	7.2 abc	8.0 ab
T_6	644.7 e	572.1 d	436.7 e	395.3 d	10.4 b	11.9 a	8.0 a	9.0 a
HSD	**1.8**	**2.2**	**1.2**	**2.0**	**0.5**	**1.4**	**0.8**	**1.3**

In single column different letters show statistical significance and same letters show non-significance at *P* = 0.05. Values are shown as mean ± standard deviation (n = 3). WUE = water use efficiency

Soil water contents and soil water storage

The soil water contents showed significant variation in each soil layer after harvesting under different treatments in both growing seasons (*Fig. 1*). In 2014 growing season of maize T_5 treatment significantly increased the soil water contents in all soil layers while in 2015 growing season T_6 treatment increased the soil water significantly in the upper 100 cm soil depth. In 120-160 cm soil layers soil water contents in T_6 were lower than that at sowing. For both growing seasons of wheat, soil water contents under T_6 treatment were significantly higher than that under all treatments in each soil layer. For both crops soil water contents were comparatively higher after 2nd growing season compared with after 1st growing season.

The soil water storage (SWS) showed slightly different pattern in both growing seasons (*Fig. 2*). In 2014 SWS under T_6 was higher throughout the growing season of maize except in middle of season where SWS was comparatively lower. In wheat season SWS in T_6 treatment was initially lower but it remained higher for rest of season. In 2015, SWS in T_6 treatment was higher throughout the maize growing season. In

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wheat season SWS in T_6 treatment was lower in start and middle of growing season while it was higher during late stages of growing season. SWS was comparatively lower in T_0 for both crops except 2014 growing season of wheat in which SWS was lower in T_2 at the end of season.

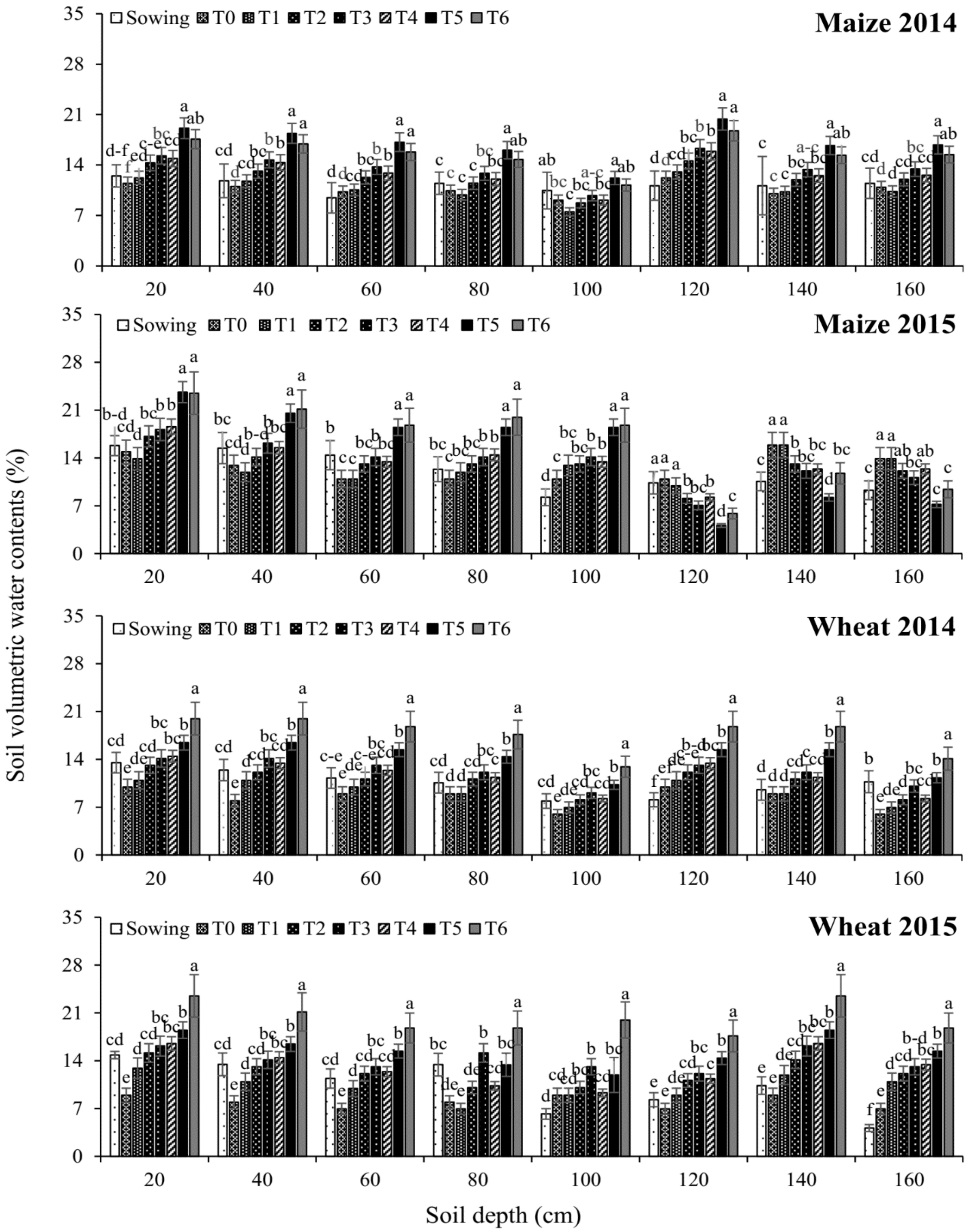

Figure 1. *Soil water contents before sowing and harvesting of maize-wheat crops under different treatments. Bars represent standard deviation (n = 3). Column with different letters within same depth are statistically significant at P = 0.05*

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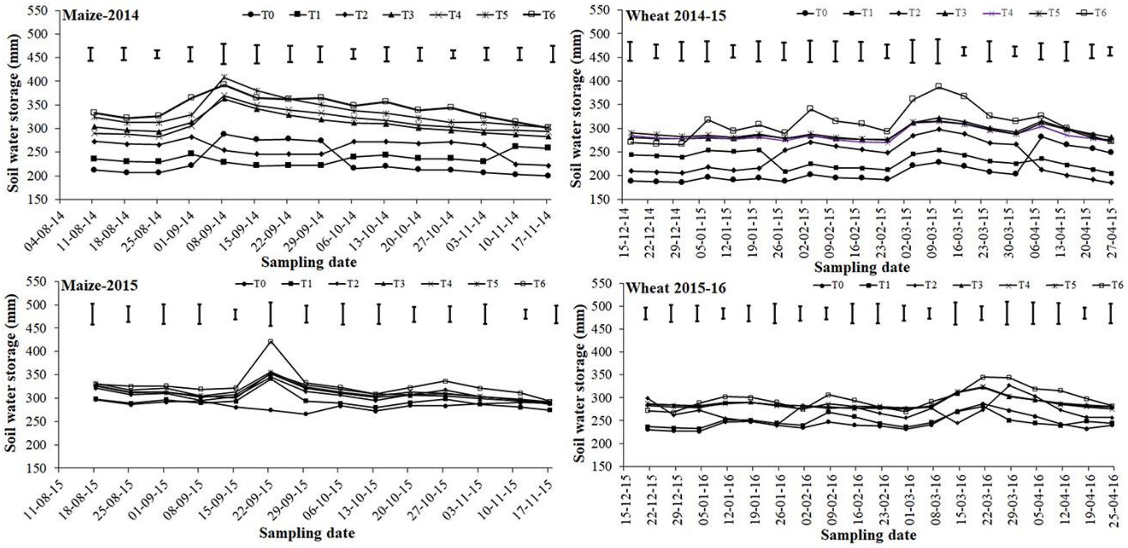

Figure 2. *Soil water storage under different treatment in maize and wheat growing seasons. Bars represent $HSD_{0.05}$ values*

Soil active carbon and bulk density

Figure 3 shows that mulches significantly decreased the soil bulk density in upper and lower soil layers. Treatment T_6 resulted in lower bulk density in both soil layers after harvest of maize and wheat.

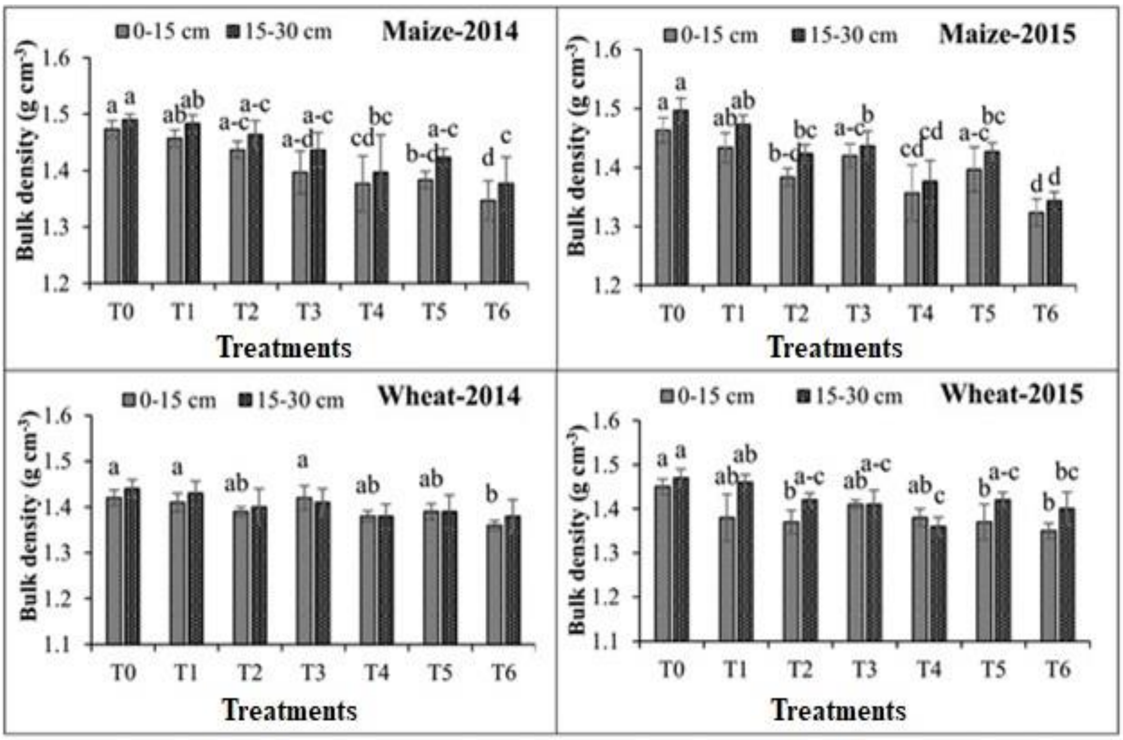

Figure 3. *Soil bulk density under different treatments after maize and wheat harvest. Bars represent standard deviation (n = 3). Column with different letters within same year and depth are statistically significant at P = 0.05*

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Upper soil layer (0-15 cm) exhibited lower bulk density than that of lower soil layer (15-30 cm). Active carbon content decreased with increase in soil depth during both years after harvest of both crops (*Fig. 4*). Significantly higher active carbon contents were recorded in T_6 followed by T_4. However, difference between T_6 and T_4 was not significant in both soil layers in both growing seasons. In surface as well as sub-surface soil layers T_0 resulted in higher bulk density and lower active carbon contents during both years.

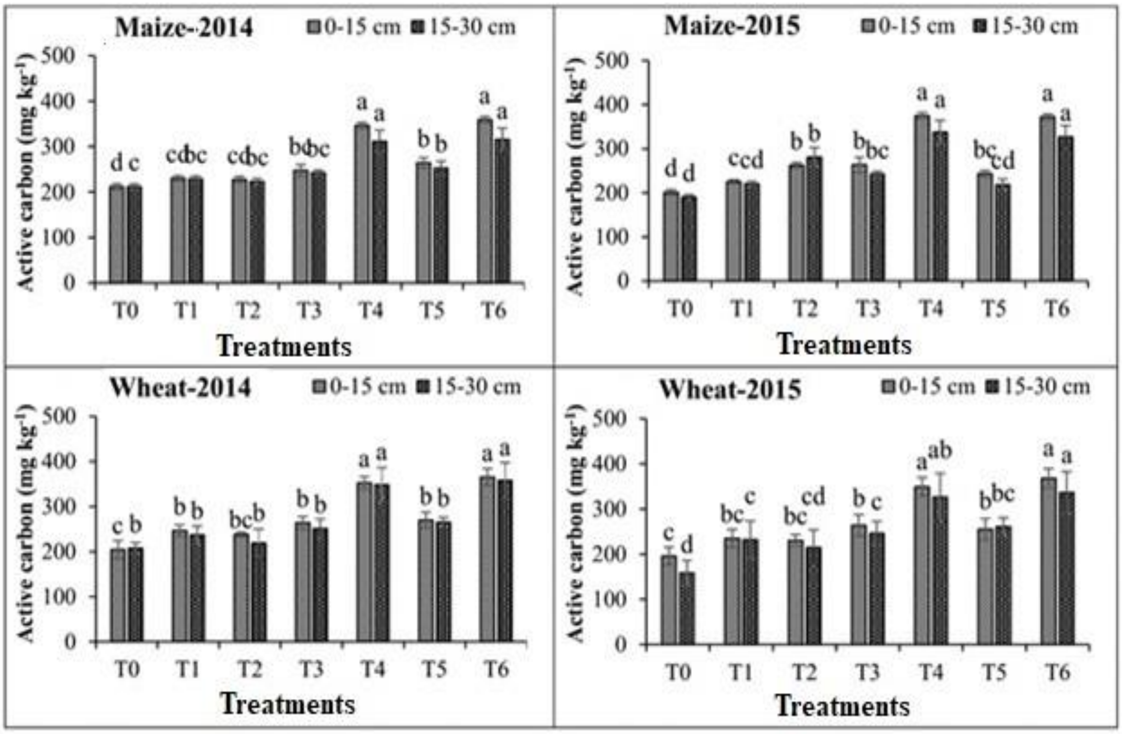

Figure 4. *Soil active carbon content under different treatments after maize and wheat harvest. Bars represent standard deviation (n = 3). Column with different letters within same year and depth are statistically significant at P = 0.05*

Discussion

If nutrients status of soil especially nitrogen is poor the plant water use may be low and mulches effects may not be ideal even if the mulches are properly applied. Plants use nitrogen as an essential macronutrient to produce large number of complex macromolecules like proteins, amino acids and nucleic acids that play a vital role for their life cycles (Mengel and Kirkby, 2001). For improved crop yield and WUE, a proper and balanced supply of nitrogen from soil is essentially required which helps plants for better root and shoot growth (Ali and Talukder, 2008). A huge gap exists between nitrogen supply and demand by plants as almost all of soils in the world are deficient in nitrogen. In many conventional and low input farming systems nitrogen supply is still limited which is reducing the crop production. Therefore, nitrogen fertilization has been termed as main priority for supplying nutrients. This is particularly true for maize and wheat which are major consumers of nitrogen fertilizers.

Although increased crop yield is the main objective of nitrogen fertilizers and have never been termed as water conservation practice, it has very important role in

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increasing the amount of water use by plants. In our study N fertilization and mulching significantly increased the yield of maize-wheat crops (*Table 6*). Mulching and N fertilizer application conserved the soil water which significantly increased the WUE, and this was the main reason of increased crop yield. Mulching materials, especially T_5 and T_6 treatments, showed a higher potential for improving maize and wheat yield respectively as compared to unmulched treatment. Levels of nitrogen fertilizer affect the sensitivity of maize and wheat crops to water stress as reported in previous studies (Gheysari et al., 2009) and increase in nitrogen inputs increased the WUE of maize (Paolo and Rinaldi, 2008). In our study, applying N fertilizer significantly increased WUE, but the difference was significant between mulched and unmulched treatments. Liu et al. (2014b) reported a significant negative correlation between WUE and level of nitrogen fertilizer. Mulching treatments, including the T_5 and T_6 treatments, significantly increased the WUE of maize and wheat respectively compared to the unmulched treatment which might be attributed to the decrease in evaporation and the increased water retention due to surface application of mulches, i.e. straw or plastic film (Li et al., 2013). Interaction effect of mulches and nitrogen was more significant for maize-wheat yield and WUE in second year (*Table 6*).

The results of present studies clearly highlight the importance of nitrogen management for both maize and wheat crops to improve their growth and yield and to conserve water in soil. In addition to improving the growth and yield of maize and wheat, reduction of water evaporation from soil surface by the combined use of mulches and nitrogen might be the major reasons of improved WUE of both maize and wheat. A significant relationship exists between mulching and nitrogen that affect the crop yield and WUE (Liu et al., 2017) which might be the reason of improved yield and WUE of maize and wheat crops in present study. Coupling effects of mulching and nitrogen were significant on WUE because mulching improves the nitrogen uptake by altering the water use by maize and wheat crops (Liu et al., 2016). The interaction effect of mulches and nitrogen becomes more significant with time which supports that long-term field experiments are needed to determine this effect on yield and WUE of maize and wheat crops (Dong et al., 2014).

A significant correlation was found between soil active carbon and WUE of both maize and wheat crops in our study (*Fig. 5*). The soil active carbon contents were linearly correlated with WUE of maize (r = 0.71, $P < 0.01$ in 2014 and r = 0.59, $P < 0.05$ in 2015) and wheat (r = 0.87, $P < 0.01$ in 2014 and r = 0.89, $P < 0.01$ in 2015). This explains the significance of mulching in improving WUE. Improvement in WUE by active carbon is due to improvement in soil quality by increasing organic carbon (Shehzadi et al., 2017). The results indicate that application of straw mulch significantly improved the soil properties as compared to plastic film in both maize and wheat crops under similar nitrogen treatment. Improved soil fertility and soil properties have been well documented by the application of straw mulches that in turn affect crop growth and yield (Mulumba and Lal, 2008; Saroa and Lal, 2003). Soil organic matter increases by the application of straw mulch (Saroa and Lal, 2003) and this increase in soil organic matter improves aggregate stability of soil (Mulumba and Lal, 2008) and soil porosity and as a result water infiltration rate is also improved (Edwards et al., 2000). Nzeyimana et al. (2017) reported that straw mulch significantly decreased the soil bulk density and improved the organic carbon and soil aggregate stability. In the surface soil layer, significant increase in soil organic matter and reduction in bulk density have been

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widely reported (Singh et al., 2007; Yadvinder-Singh et al., 2009) and similar results have also been obtained in current study.

Soil organic carbon increased by straw mulch in surface soil layer is an energy source for microorganisms in soil (Tebrugge and During, 1999) which improves soil porosity with a decrease in bulk density through bioturbation (Mulumba and Lal, 2008). Soil aeration and root growth is improved by increased soil porosity which in result in improved crop development (Six et al., 2000) and nutrients and water uptake is also improved. The results are in agreement with those of Nawaz et al. (2017) who reported the beneficial role of mulches in improving soil organic carbon and total soil porosity with a decrease in soil bulk density compared with no mulch. Treatments T_5 and T_6 conserved more soil water during both growing seasons of maize and wheat crops. This increase in soil water storage is explained by increase in active carbon contents in soil which increased the water holding capacity of soil. This shows that mulching has good potential in increasing soil water storage and soil organic carbon. Increase in soil water contents with increase in soil organic carbon has also been reported by Minasny and Mcbratney (2018) and Qureshi et al. (2010).

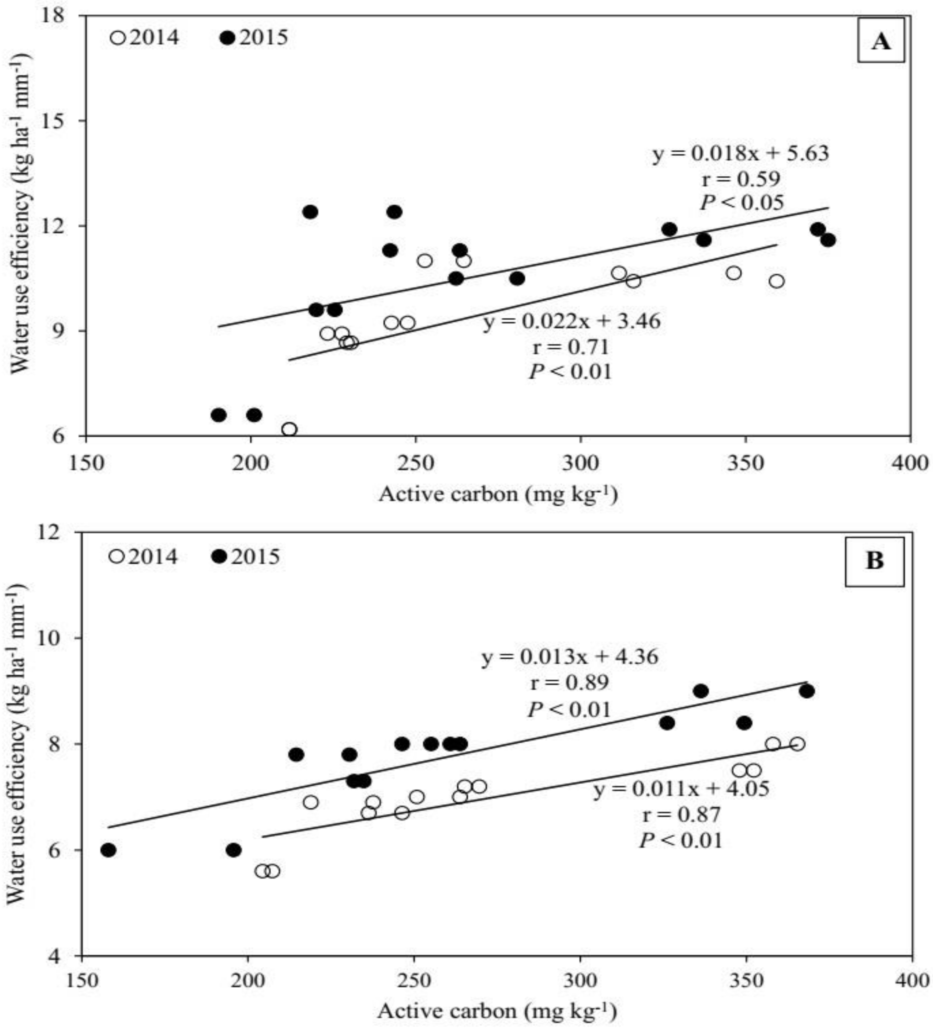

Figure 5. *Correlation between soil active carbon in 0-30 cm soil layer and water use efficiency of maize (A) and wheat (B) in two growing seasons*

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The findings clearly show that overall mulches performed well in terms of WUE and soil carbon with addition of nitrogen. Apparently, plastic and rice straw mulches have positive effects and results of current study indicate that use of these mulches can increase maize and wheat yield significantly. However, high labor cost, unavailability of proper straw mulch and difficulties in collection and recycling of plastic film residues are some side-effects of mulching. Therefore, site specific conditions and these side-effects must be included in guidelines for recommending mulch practices.

Conclusion

Nitrogen applied in three splits under plastic film for maize and under straw mulch for wheat significantly improved growth and yield of respective crops. Nitrogen fertilization under mulched conditions significantly decreased the total water use and increased the WUE in both crops. The effects of mulching were more pronounced with increased splits of nitrogen. The results of experiments contribute to our knowledge of soil surface mulching and N fertilization effects on crop growth and WUE. Nitrogen (200 kg ha^{-1} for maize and 100 kg ha^{-1} for wheat) should be applied in three splits for both maize and wheat crops under mulched conditions. Farmer's nitrogen application rates (250 kg ha^{-1} for maize and 120 kg ha^{-1} for wheat) are overuse and this rate can be decreased by mulching. Therefore, mulching should be practiced considering the nitrogen inputs and crop type. In addition, these findings may be helpful to optimize management practices (mulches and nitrogen) to improve crop production and at the same time improve soil quality in semi-arid cropping system.

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