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Mulching Effects on Water Productivity, Maize Yield and Soil Properties in Bed and Flat Sowing Methods

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Authors' contributions

This work was carried out in collaboration between all authors. Author SSHS and SBA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SHHS, AM and AN managed the analyses of the study. Authors AN, AW and AM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted to investigate the impact of mulching on water productivity, soil properties and maize yield (*Zea mays* L.) in bed and flat sowing methods at Research Area of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Wheat straw mulch was applied @ 8 t ha^{-1}. Randomized complete block design with split plot arrangement was used. Four treatments with four replicates were used. A measured amount of irrigation was ensured using cut throat flume as and when required. The bed sowing with mulch interaction enhanced water productivity from 34 to 115% compared with other combinations. This interaction also improved soil chemical and physical fertility by increasing total nitrogen from 24 to 62% and decreasing bulk density from 4.4 to 11.0%, respectively compared with other interactions. The soil

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structure of beds was improved by 6.0% lower bulk density, 15.1% higher infiltration rate and 35% higher soil organic carbon as compared with flat sowing. In this short term study, the improved soil structure of beds with wheat straw mulch resulted in enhanced grain yield and water productivity in comparison to flat sowing with wheat straw mulch. Long term studies may be required to detect further mineralization effects of wheat straw on soil physical and chemical properties in relation to water productivity and crops yield.

Keywords: Mulching; bed sowing; water productivity; soil properties; maize growth and yield.

1. INTRODUCTION

Maize is the third most important cereal crop in the world after wheat and rice. However, its productivity is higher than wheat and rice. Globally, its average production in 2003 was 4.47 t ha^{-1} as compared to 2.67 and 3.84 t ha^{-1} for wheat and rice, respectively [1]. It is cultivated throughout the world and is important for countries like Pakistan because of increasing population and limited available food supplies. It is gaining a more important position in the cropping system due to higher yield potential, short growing period, high value for food, forage and feed for livestock, poultry and cheaper source of raw material for agro-based industry. Water scarcity is the biggest problem faced by the world generally and Pakistan specifically [2]. There is an uncertainty about water supply for future generations [3]. By the year 2050, the global shortage of 640 billion cubic meters water is forecasted annually. This issue is gaining importance in scientific and political agendas because the irrigation sector is the largest consumptive user of water. It accounts for 71% of the freshwater use across the world [4]. Therefore, it is necessary for irrigation management practices to shift from emphasizing production per unit area towards maximizing the production per unit of water consumed [5].

Mulching is a desirable management practice to combat the problem of water scarcity. It regulates farm environment and enhances crop production by affecting soil temperature, leaching, evapotranspiration, soil organic carbon content and nutrient loss due to run off [6,7]. It also increases yield by improving soil physical conditions [8,7]. Wheat straw mulch reduced evaporation by 50% under winter wheat, and saved about 80 mm of water during a wheat growth season [9]. Under arid and semi-arid environment in Pakistan, there is a need to evaluate different types of mulches with high soil water storage that could provide more water for crop production. In addition to mulching, planting patterns also influence growth and yield of maize and saves considerable quantity of water and improves the fertilizer use efficiency [10]. Similarly, the beds due to improved soil physical condition enhanced the 10% grain yield compared with flat sowing [11]. There was also noted water saving of 26 to 42% in beds as compared to flat sowing using various crops [12]. Under the prevailing conditions, there is need to search out such strategies that could improve water productivity, soil health and yield. In this context, this study was planned with the objective to evaluate wheat straw mulching effects on water productivity, maize yield and soil properties in bed and flat sowing methods.

2. MATERIALS AND METHODS

This Study was conducted at the Research Area of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Before sowing, composite soil samples were taken at random from the experimental field. The soil samples were air-dried, ground, well mixed and passed through a 2 mm sieve and analyzed for basic soil characteristics and mulching material (wheat straw) was also analyzed for nitrogen, phosphorous, potassium and organic carbon before applying onto the experimental plots (Table 1).

Field was prepared using rotavator, and after applying fertilizer, beds were prepared with the help of a bed planter. Other specifications like climate, experimental design, etc of the experiment are listed in Table 2.

The following four (4) treatment combinations were tested to meet the objective of the study:

1. Wheat straw @ 0 t ha^{-1} × bed sowing (M_o × B),
2. Wheat straw @ 8 t ha^{-1} × bed sowing (M_{wst} × B),
3. Wheat straw @ 0 t ha^{-1} × flat sowing (M_0 × F),
4. Wheat straw @ 8 t ha^{-1} × flat sowing (M_{wst} × F).

Table 1. Basic soil analysis and wheat straw characterization

Basic analysis	N	P	K	OC	pH	EC_e	Sand	Silt	Clay	T. Class
Units	g kg^{-1}	mg kg^{-1}		%	-	d S m^{-1}	%			-
Soil	0.33	9.1	114.6	0.42	7.3	1.49	40	38.5	21.5	Loam
Wheat	g kg^{-1}			-	-	-	-	-	-	-
Straw	7.2	3.7	33.2	41.3	-	-	-	-	-	-

OC = organic carbon, ECe = Electrical conductivity of soil extract

Table 2. Experiment specifications

Specifications	
Crop	Maize
Statistical design	Randomized complete Block split plot
Main plot	Sowing methods
Sub plot	Mulching material, i.e. wheat straw @ 8 t ha^{-1}
Plot size (m^2)	55
Maize Hybrid	Pioneer-3062
Sowing method	Chokka (Two seeds per hole)
Row to row distance (cm)	45
Plant to plant distance (cm)	20
Seed rate (kg ha^{-1})	25
NPK (kg ha^{-1})	300-150-125
Climate	Semi-arid

The doses of 300 kg N, 150 kg P_2O_5 and 125 kg K_2O as urea, triple super phosphate and murate of potash, respectively were used for growing of maize. The nitrogen dose was applied in three splits; one at the time of sowing, one at knee height and one at tasseling stage. The one only dose of P_2O_5 and K_2O was applied at the time of sowing. The Standard analytical methods of soil and plant analysis described by [13] for nitrogen, phosphorous and potassium were followed. Soil texture was determined by Bouyoucos hydrometer method [14]. Soil organic carbon was determined following the method described by [15]. Soil bulk density from 0-10 cm depth was determined by following the method of [16]. Infiltration rate was measured with double ring infiltrometer [17]. Eight irrigations were applied up to maturity of the crop. First irrigation was applied 15 days after sowing while subsequent were given as per requirement. Measured amount of irrigation water to each plot was applied by using a cut throat flume. Flood and furrow irrigation methods were used in flat and bed sowing respectively. At maturity, agronomical parameters like plant height, 100 grain weight, grain and biological yield were determined. The water productivity was calculated by the following formula:

$$WP = \frac{GY}{TWA}$$

Where WP is the water productivity in kg m^{-3}, GY is the grain yield in kg/ha, TWA is total water applied in m^3.

After harvesting the crop, disturbed and undisturbed soil samples were also taken from the root zone depth of 10 cm for nitrogen, phosphorous, potassium and organic carbon analysis, and soil bulk density, respectively. In-situ field infiltration rate was also determined in each experimental unit. All the soil and plant data was analyzed statistically using RCBD Split plot design. The means were compared by LSD (least significant difference) test at p≤ 0.05 [18].

3. RESULTS AND DISCUSSION

3.1 Impact of Wheat Straw Mulch and Sowing Methods on Soil Properties

Wheat straw mulch and sowing methods alone with interaction had variable effects on soil properties (Table 3). Simple effect of wheat straw mulch showed no significance on bulk density (ρ_b) statistically but on infiltration rate (IR), the effect was significant. It depicted decrease in ρ_b by 2.9% and increase in IR by 20% compared with no mulch. Bed sowing showed significant improvement in decreasing ρ_b and increasing IR by 7.7 and 14.6%, respectively compared with flat sowing. Wheat straw mulch and sowing methods also showed significant effect on soil ρ_b and IR with interaction. The M_{wst} × B interaction proved best in reducing ρ_b from 4.4 to 11.0% and rising IR from 15.6 to 36.8%, respectively compared with all other interactions. While the soil nitrogen, potassium and organic carbon concentrations were also significantly influenced by mulching materials and sowing methods with interaction, however the phosphorous concentration remained at par in all interactions. Mulching and bed sowing alone enhanced the concentrations of total nitrogen (32 and 25%), available phosphorous (19 and 14%), extractable potassium (13 and 4%) and soil organic carbon (18 and 35%) compared with no mulch and flat sowing method, respectively. The M_{wst} × B interaction improved the soil chemical fertility by rising soil organic carbon contents from 17 to 59%, total nitrogen from 24 to 62%, available phosphorous from 6 to 23%, and extractable potassium from 3 to 17% compared with other interactions (M_o × F, M_{wst} × F and M_o × B).

3.2 Impact of Wheat Straw Mulch and Sowing Methods on Maize Growth, Yield and Water Productivity

Wheat straw mulch and sowing methods also showed variable effects on maize growth, yield and water productivity in alone and with interaction (Table 4). Plant growth is generally measured in terms of plant height. Simple and integrated effects of mulching and sowing methods were significant on plant height. Mulching increased the plant height by 7.7% compared to no mulch. However, bed sowing increased 5% plant height from 191 cm in flat sowing method to 201 cm in case of bed sowing method. The $M_{w.st}$ × B combination produced maximum plant height (208 cm) and the M_o × F interaction yielded least plant height (184.0 cm). This combination ($M_{w.st}$ × B) increased the plant height from almost 5 to 13 % compared with all other interactions. The range of 100 grain weight (100 GW) was from 31.0 to 35.1 g under different combinations. The $M_{w.st}$ × B interaction enhanced the 100 GW from 5 to 13 % compared with all other combinations. Wheat straw mulch and bed sowing also enhanced 100 GW alone by 7.0 and 6.3%, respectively compared with no mulch and flat sowing, respectively. Alone effect of mulching on grain and biological yield was at par, however in interaction with bed sowing depicted pronounced effects in comparison with no mulch + flat sowing interaction. The $M_{w.st}$ × B interaction showed maximum grain (10.89 t ha^{-1}) and biological yield (26.49 t ha^{-1}) and enhanced grain yield from 15 to 22% and biological yield from 5 to 12% compared with other interactions (M_o × F, M_{wst} × F and M_o × B). Bed sowing also showed 3.1% higher biological yield than flat sowing. Mulching and sowing methods had significant effect on water productivity alone and in interaction. Averaged across mulching, bed and flat sowing produced 2.03 and 1.17 kg grains per meter cube, respectively. Mulching increased water productivity by 27% compared with no mulch alone and in interaction with bed sowing, it enhanced water productivity from 34 to 115% compared with M_o x F, M_{wst} x F and M_o x B interactions.

4. DISCUSSION

Significant increase in IR with an associated decrease in ρ_b is most probably due to the beneficial effects of organic matter (wheat straw applied @ 8 t ha^{-1}). The organic matter due to its lower bulk density and ability to increase aggregation resulted in better IR and lower ρ_b [19,20]. The changes in ρ_b reflected changes in IR because of close relations between ρ_b and IR

Table 3. Soil properties

Treatments	SOC g kg^{-1}	N g kg^{-1}	P mg kg^{-1}	K mg kg^{-1}	BD Mg m^{-3}	IR mm hr^{-1}
M_o	4.0b	0.31b	9.6	112.0b	1.40	40b
M_{wst}	4.7a	0.41a	11.4	126.6a	1.36	48a
LSD	0.40	0.03	NS	2.96	NS	2.4
B	5.0a	0.40a	10.6	121.4	1.31b	47a
F	3.7b	0.32b	9.3	117.2	1.42a	41b
LSD	0.56	0.02	NS	NS	0.030	3.8
M_o × B	4.6b	0.36b	9.1	114.5b	1.35c	43b
M_{wst} × B	5.4a	0.47a	11.2	128.4a	1.29d	52a
M_o × F	3.4d	0.29c	8.1	109.5c	1.45a	38c
M_{wst} × F	4.0c	0.38b	10.6	124.9a	1.40b	45b
LSD	0.47	0.031	NS	2.74	0.032	4.88

M_o (No mulch), M_{wst} (wheat straw mulch), B (bed sowing method), F (flat sowing method), SOC (total organic carbon), N (total nitrogen), P (available phosphorus), K (extractable potassium), BD (bulk density from 0-10 cm soil depth), IR (infiltration rate)

Table 4. Maize growth, yield and water productivity

Treatments	Plant height cm	100-GW g	Grain yield t ha^{-1}	Biolo. Yield t ha^{-1}	WUE kg m^{-3}	TWA (mm)
M_o	188.2b	32.5	9.19	23.80	1.41b	531.1 a
M_{wst}	202.5a	34.8	10.04	25.87	1.79a	444.6 b
LSD	2.48	ns	ns	ns	0.029	50.7
B	200.1a	34.5a	10.18a	26.2a	2.03a	353.3 b
F	190.6b	32.8b	9.05b	24.5b	1.17b	622.4 a
LSD	5.89	0.85	0.72	0.94	0.55	124.2
M_o × B	192.3c	33.3b	9.46b	23.92c	1.73b	392.0 c
M_{wst} × B	207.8a	35.7a	10.89a	26.49a	2.32a	314.6 d
M_o × F	184.0d	31.7c	8.91b	23.68c	1.08d	670.2 a
M_{wst} × F	197.2b	33.9b	9.19b	25.25b	1.26c	574.6 b
LSD	2.93	1.44	1.38	0.75	0.084	85.6

M_o (No mulch), M_{wst} (wheat straw mulch), B (bed sowing method), F (flat sowing method), 100-GW (100 grain weight), Biolo. Yield (biological yield), WUE (water use efficiency), TWA (total water applied)

[21,22]. The higher concentrations of N, P and K were due to organic matter addition from wheat straw which is a major source of nutrients in soil [23]. Bed sowing depicted better soil physical health by decreasing ρ_b and increasing IR and soil organic carbon compared with flat sowing. The differences arose presumably because there was less structural disruption of aggregates and settlement in the unsaturated condition of the raised beds compared to the saturated condition of the basins. Fahong also supported our results by concluding that bed planting decreased the soil surface exposed to flooding by 40%, which eliminated surface soil crusting on the top of the bed where the crop was planted [11]. In addition, Hassan noted that the cumulative infiltration was 2.8 times higher in raised beds than in basins and 10 times higher than in furrows [24]. Almost 35% higher organic carbon contents under raised beds (12 inches high) compared with flat were most probably due to carbon addition through the highly proliferating roots in response to decreased ρ_b with an associated increase in total porosity. Hassan also reported the same for raised beds [24]. Higher available P and extractable K concentrations in beds were due to the chemical fertilizers addition as the beds were made after mixing the fertilizer with soil.

Bed sowing produced significantly taller plants with greater biomass and grain yields; it was most probably due to better nutrient availability, good soil conditions and weed control in beds [7,25]. Mulching further improved the soil environment of beds by increasing soil organic carbon and decreasing bulk density, resultantly M_{wst} × B interaction enhanced the growth and yield of maize. Our results are in accordance with the findings of Ahmad who reported improvement in maize growth and yield and attributed it to better nutrition of the plants under mulched bed sowing method [26]. In contrast, significantly lower 100 GW along with decreased grain and biological yield in flat sowing with no mulch combination (M_o × F) was most probably due to poor soil environment resulted from compaction because of increased bulk density with an associated decrease in porosity and thereby affected water and nutrient uptake by the crop [21]. This explanation was further confirmed by lowered water productivity compared with other interactions (M_o × F, M_{wst} × F and M_o × B). Enhanced water productivity in M_{wst} × B interaction, is most probably due to less application of water in furrows among beds which is a divider in crop water productivity calculations [24] and less evaporation from the surface of beds owing to lesser exposure to sun light under mulch [9]. Hsamar and Saxena also reported saving of 2 irrigations compared with flat sowing, resulting increased water productivity under beds [27].

Mulching and sowing methods had variable effects on soil properties and maize growth and yield. Simple effect of mulching showed at par significance on maize growth and yield attributes, bulk density and soil available phosphorous. However interactive effect of wheat straw mulch and bed sowing on soil properties and maize production was more pronounced. Along with this, the main effect of sowing methods on soil and plant parameters was consistent.

5. CONCLUSION

This short term study suggested wheat straw mulch and bed sowing combination best in improving the soil health of beds and maize productivity. Long term studies may be required to see further mineralization effects of wheat straw on soil physico-chemical properties in relation to water productivity and crops yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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