

Effect of Deficit Irrigation and Mulch on Soil Physical Properties, Growth and Yield of Maize

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Abstract A field experiment was conducted to study the effect of deficit irrigation and mulch levels on soil physical properties and growth and yield of maize crop. The experiment comprised of two irrigation levels, i.e. I_1 : 558.8 mm and I_2 : 711.2 mm while two mulch levels, i.e. M_0 : no mulch and M_{15} : 15 Mg ha⁻¹. Soil samples were collected from 0-10, 10-20, and 20-30 cm depths before sowing and at crop harvest. The samples were analyzed for soil physical, i.e. bulk density, field saturated hydraulic conductivity (mm hr⁻¹), and infiltration rate (mm hr⁻¹) and chemical parameters, i.e. SOC concentration, soil NPK and plant NPK. The results of this study showed that the maximum increase in plant height (11.39 %), biological yield (29.56 %) and grain yield (35.5 %) was observed with treatment combination $I_2 \times M_{15}$ as compared to control. In case of soil physical properties, the maximum mean value of infiltration rate and hydraulic conductivity was observed 19.4 and 88.33 mm hr⁻¹ with treatment combination $I_2 \times M_{15}$, respectively while minimum mean value of infiltration rate and hydraulic conductivity was recorded 12.4 and 32.56 mm hr⁻¹ with treatment combination $I_1 \times M_0$, respectively. Soil bulk density decreased by increasing the mulch rate and minimum value of 1.44 Mg m⁻³ observed at 0-10 cm depth with treatment combination $I_2 \times M_{15}$. In case of soil chemical properties, the treatment combination $I_2 \times M_{15}$ showed highest value of SOC, soil nitrogen, phosphorus and potassium that was 0.55 g kg⁻¹, 0.64 g kg⁻¹, 15.48 ppm and 144.67 ppm, respectively.

Keywords Maize, Soil Prosperities, Irrigation, Mulching, Yield

1. Introduction

Maize (*Zea mays* L.) is an important cereal crop of Pakistan and it has third position in the cereals after wheat and rice. In the Khayber Pakhtunkhwa second most

important crop is maize. According to Agric. Statistics of Pakistan maize growing area is 941.6 thousands ha and total maize production is 1664.4 thousand tones and yield is 1768 kg ha⁻¹ [1].

Deficit irrigation is a technique in which irrigation is done during drought sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought tolerant phenological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant droughtstress and consequently in production loss, deficit irrigation (DI) maximizes irrigation water productivity, which is the main limiting factor [2]. In other words, DI aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields [3].

The task of increasing food production with less water, particularly in countries with limited water, land resources has become a big challenge for the coming decades due to the serious water shortages [4]. Therefore, to increase the water use efficiency, better techniques are needed. Usually the purpose of irrigation scheduling is to attain an optimum water supply for productivity, with soil water content being controlled near field capacity. The costs of irrigation and increasing worldwide shortages of water are important for developing methods of irrigation that maximize the water use efficiency and minimize water use [5]. Irrigation scheduling is the decision to maximize profit in order to, when and how much water applied to a field. Its aim is to maximize irrigation efficiencies by the application of exact amount of water needed to refill the soil water to the appropriate level, thus save energy and water. By reducing the drainage requirements, the water-logging problems can be minimized and control the salinity problems in root zone through controlled leaching [6, 7].

Water requirement for maize is 600-700 mm for optimum

growth and yield depending on the climatic conditions [8]. At any growth stage water deficiency reduces growth and production of the maize crop [9]. Water stress affects maize yield as much as all other environmental factors combined. It decreases leaf area [10] and plant height [11] by reducing cell division and leaf expansion [12]. A lot of studies have been conducted on maize water requirement and effect of water stress in temperate and semi-arid regions [13]. When the crop is subjected to drought, it causes, lower yield in maize with high dose of nitrogen [14, 15]. Variable supply of water is either due to water shortage or failure in the supply of water at critical crop growth stages in many irrigated areas of the world [16].

Traditional irrigation development model aims at providing sufficient water to crops to avoid water deficits at all stages, so as to achieve maximum yields [17]. Adoption of deficit irrigation requires the knowledge of the response of different crops to water deficit at various growth stages. Reduced yield as the result of deficit irrigation, especially under water limiting situations, may be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation [18].

High sensitivity of maize to water stress means that under water limiting conditions it is difficult to implement irrigation management strategies without incurring significant yield losses [19]. The limited supplies particularly affect field maize due to its relative high water requirements and because it covers large area than any other irrigated crop in the region. Farmers with limited water often have to choose among options such as fully irrigating a portion of the field area or deficit-irrigating a larger crop area or changing to crops that require less water, or investing in more efficient irrigation systems [20].

Water stress on maize has been shown to reduce plant height, leaf area index and root growth [21]. It is clear from the literature that termination of irrigation in maize causes significant yield losses. However, the effects of moderate water stress on maize yield, which in practice is more likely to occur in the region as a consequence of an increased interval between irrigations, have been less studied. This type of water deficit in some cases could result in water savings by reducing irrigation water use for little cost in yield [22].

Mulch is one of the management practices which improve the water use efficiency of soil. Any material dispersed on the surface of soil to protect it from solar radiation, evaporation or raindrops is called mulch. Mulching can affect the soil temperature and soil water content [23] and directly affect on the grain yield of crops [24]. Straw mulching systems can conserve soil water and decrease temperature because they increase residue accumulation and reduce soil disturbance on the soil surface [25, 26].

When maintained at sufficient levels, mulches can reduce the rate of evaporation and runoff of water, it increase penetration of rain fall and entrap snow and therefore soil water conservation is higher, compared to other soil in which mulch is not applied. In semi-arid areas where soil

temperature conducive for maize growth, presence of mulch during a growing season may increase the crop yields by conserving the soil water [27]. Mulched maize yield was 17 % more than un-mulched maize, when wheat stubble was removed at maize planting [28].

Mulch can decrease soil temperature and retain better root growth in maize in case of coarse textured soil and grain yield was more in loamy sand than sandy loam soil mulching has potential for increasing soil water storage [28]. Mulch directly influences the grain yield of crops. Soil biota increase under mulched soil environment thereby improving nutrient cycling and organic matter build up over a period of several years [29]. A number of researchers have evaluated the positive effects of irrigation and mulching management under rain-fed farming systems [26].

Keeping in view the above facts, this study has designed objectives to examine the effect of deficit irrigation and mulching material on the growth and yield of maize and to observe the influence of mulching material on soil physical and chemical properties.

2. Materials and Methods

The study was carried out under field condition at the Research Area, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad during 2011, to study the 'Effect of deficit irrigation and mulch on soil physical properties and growth and yield of maize.

Before sowing the crop, composite soil samples were taken at random from the experimental field. The soil samples were air-dried, ground, well mixed and passed through 2mm sieve and analyzed for different physical and chemical characteristics.

2.1. Treatments

There were two irrigation and two mulch levels.

i. Irrigation levels:

I_1 = Irrigation depth 558.8 mm

I_2 = Irrigation depth 711.2 mm

ii. Mulch level:

M_0 = Control (no mulch)

M_{15} = Mulch applied @ 15 Mg ha⁻¹

A field experiment was conducted following a randomized complete block design with split plot arrangements. Each treatment was repeated thrice. Irrigation levels were maintained in the main plots, while mulch levels in the subplots of 5 m x 5 m size. A basal dose of N, P₂O₅ and K₂O was applied at the rate of 250, 150, 125 kg ha⁻¹, in the form of urea, DAP and SOP, respectively. All of the phosphorus and potash were incorporated at sowing time while N was applied in three splits. Hybrid maize variety "Pioneer-3062" was sown by dibble method keeping row-to-row distance at 70 cm and plant-to-plant distance at 20 cm. Deficit irrigation

was used according to treatment plan, as and when required during the whole season of crop growth. Wheat straw mulch was applied after the complete germination of maize crop.

Soil physical parameters, i.e. bulk density, infiltration rate, hydraulic conductivity and soil strength and chemical parameters, i.e. N, P, K and SOC concentration were determined at the crop harvest. Yield and yield characteristics of maize, i.e. total biomass, grain yield, plant height, 1000-grain weight, cob length, number of rows per cob and number of grains per cob were recorded. At maturity, plant samples were analyzed for N, P and K concentrations. The data obtained was subjected to statistical analysis by using standard procedures and LSD test was applied to compare the effectiveness of treatments [30].

2.2. Observations

2.2.1. Soil Parameters

- i. Bulk density (Mg m^{-3})
- ii. Soil organic carbon concentration (g kg^{-1})
- iii. Infiltration rate (mm hr^{-1})
- iv. Hydraulic conductivity (mm hr^{-1})
- v. Soil strength (kPa)
- vi. N, P and K concentration in soil

2.2.2. Plant Parameters

- i. Plant height (cm)
- ii. Biological yield (Mg ha^{-1})
- iii. Grain yield (Mg ha^{-1})
- iv. 1000-grain weight (g)
- v. Cob length (cm)
- vi. Number of rows per cob
- vii. Number of grains per row
- viii. N, P and K uptake in plants

2.2.3. Water use efficiency (WUE)

$$\text{WUE} = \text{Total biomass (kg ha}^{-1}) / \text{Total water applied in mm}$$

2.3. Analytical Methods

Soil and plant samples were analyzed according to analytical method described by US Salinity Lab. Staff [31], unless otherwise mentioned.

2.3.1. Soil Analysis

2.3.1.1. Particle size analysis

Percentage of sand, silt and clay was determined by Bouyoucos hydrometer methods. Soil (40 g) was soaked over-night with 1 % sodium hexameta-phosphate solution plus distilled water. Then this was dispersed with electrical stirrer, transferred to 1-L graduated cylinder, silt and clay particles (%) was determined by using Bouyoucos hydrometer. Textural class was determined by the International triangle [32].

2.3.1.2. pH of saturated soil paste (pH_s)

Saturated paste of soil (300 g) was prepared by adding distilled water (Method 2, p. 84). The saturated paste was allowed to stand as such for overnight and pH_s was measured by the model HM – 12 pH meter, by calibrating it with buffer solution of pH 4, 7 and 9.2.

2.3.1.3. Electrical conductivity of saturated soil extracts (EC_e)

Clear extract of saturated soil paste was obtained by a vacuum pump. The EC_e (dS m^{-1}) was measured by using Jenway Conductivity meter Model-4070 (Method 21a, 21c, p. 102).

2.3.1.4. Total soluble salts (TSS)

The EC_e (dS m^{-1}) was converted into TSS ($\text{mmol}_c \text{L}^{-1}$) in soil following the graph [32].

2.3.1.5. Saturation percentage

A portion of saturated soil paste was transferred to a tarred soil can with lid, weighed and dried to a constant weight at 105°C , cooled and weighed again (Method -2, 26-27, p. 107).

$$\text{Water content (\%)} = (\text{Loss in mass on drying} / \text{Mass of oven dry soil}) \times 100$$

2.3.1.6. Water Soluble Ions

a) Calcium and Magnesium

Soil extract was titrated against 0.01 normal EDTA (Ethylene diamine tetra acetic acid) using Eriochrome Black T indicator in the presence of $\text{NH}_4\text{Cl-NH}_4\text{OH}$ buffer solution (Method 7, p. 94).

a. Sodium and Potassium

Soluble sodium and potassium ions were determined by using Corning Flame photometer-410 after calibrating with standard solutions of Na and K (Method 10a and 11a, p. 96-97).

b. Carbonates and Bicarbonates

Soil carbonates and bicarbonates were determined by titrating the soil extract against 0.01 N H_2SO_4 using phenolphthalein and methyl orange indicators, respectively to colorless and pinkish yellow end point (Method 12, p. 98).

c. Chloride

After carbonates and bicarbonates titration, chloride were determined by titrating the soil extract against 0.005 AgNO_3 solution using K_2CrO_4 as an indicator to brick red end point (Method 13, p. 99).

d. Sulphates

Sulphates were determined by difference method by the following formula:

$$\text{SO}_4\text{-2 meq L}^{-1} = (\text{TSS in meq L}^{-1}) - (\text{CO}_3\text{-2} + \text{HCO}_3\text{-1} + \text{Cl in meq L}^{-1})$$

2.3.1.7. Organic carbon concentration of soil

Soil organic carbon was determined following the method described by Walkley and Black [33]. One-gram air-dry soil

sample were taken in a 500 mL beaker and added 10 mL 1 N Potassium dichromate solution. Afterward added 20 mL concentrated sulfuric acid, swirled the beaker to mix the suspension and then allow it to stand for 30 minutes. To it added 200 mL de-ionized water, 10 mL concentrated Orthophosphoric acid, allowed the mixture to cool and added 10-15 drops of Diphenyl amine indicator. Then the contents were titrated with 0.5 M Ferrous ammonium sulphate solution, until the color changed from violet blue to green. Two blank reading were obtained by following above procedure except adding soil.

Calculations

$$\% \text{ Oxidizable organic carbon} = [(V_{\text{blank}} - V_{\text{sample}}) \times 0.3 \times M] / [\text{Weight of soil (g)}]$$

$$\% \text{ Total organic carbon (w/w)} = 1.33 \times \% \text{ Oxidizable organic carbon}$$

M = Molarity of ferrous ammonium sulphate solution

V_{blank} = Volume of ferrous ammonium sulphate solution used for blank (mL)

V_{sample} = Volume of ferrous ammonium sulphate solution with soil sample (mL)

2.3.1.8. Soil bulk density

Soil bulk density of 0-30 cm depth was determined. The core sampler was pressed in the soil far enough depth to fill the core. Carefully removed the sampler and trimmed the soil extending out of the core with a sharp knife. Soil was oven dried at 105 °C to a constant weight, cooled and weighed. Soil volume was taken equal to inner volume of core sampler [34].

$$\text{Bulk density} = (\text{mass of oven-dry soil}) / (\text{Volume of soil including pore spaces})$$

2.3.1.9. Infiltration rate

Infiltration rate was measured with double ring infiltrometer. The inner and outer rings were driven 10 cm in to the soil by means of driving plate and impact absorbing hammer. The inner and outer rings were filled with water. The water flows vertically through the inner ring into the soil was noted until constant rate was obtained [36].

2.3.1.10. Field saturated hydraulic conductivity

A uniform debris free well hole was made with help of auger and sizing auger. The Guelph Permeameter (Model 2800 KI) was assembled and installed in the well hole. Three steady-state readings were taken from two depths (5.0 cm and 10.0 cm at constant lead). Field saturated hydraulic conductivity was calculated from the following formula:

$$K_{fs} = (0.0041)(X)(R_2) - (0.0054)(X)(R_1)$$

Where R_1 = the steady-state rate of fall of water in the reservoir when the first head H_1 of water is established, in cm/s.

H_1 = the first head of water established in the well hole, in cm.

H_2 = the second head of water established in the well hole, in

cm.

R_2 = the steady-state rate of fall of water in the reservoir when the second head of water is established, in cm/s.

X = Reservoir constant, corresponds to the cross sectional area of the combined reservoir expressed in cm^2

2.3.1.11. Soil strength

Soil strength was measured with Cone penetrometer. The penetrometer was operated by placing the core on the soil surface with the shaft oriented vertically. The cone was then pressed into the soil until it just becomes buried (i.e. soil surface was level with the base of cone). Then reading was noted. Soil sample for water content were also taken, and then correlated to force applied. Each plot was repeated three times.

2.3.1.12. Total nitrogen

Ten gram of soil was added in 40 mL of concentrated H_2SO_4 plus 10 g of digestion mixture ($\text{K}_2\text{SO}_4:\text{FeSO}_4:\text{CuSO}_4$, 10:1:0:5) and then digested the material using the Kjeldahl digestion method. Ten mL of aliquot was taken from 250 mL of digested material and distillation was carried out with micro Kjeldahl apparatus. The NH_3 evolved was absorbed in a receiver containing 4 % Boric acid solution and mixed indicator (Bromocresol green and methyl red). After distillation, the contents of receiver were titrated against 0.1 N H_2SO_4 [37] and N was calculated by the following formula:

$$\% \text{ N} = \frac{0.0014 \times (\text{Acid used for sample titration} - \text{Blank})}{\text{Wt. of sample}} \times 100$$

2.3.1.13. Extractable phosphorus

Five gram of soil sample was extracted with the sodium bicarbonate solution while shaking on mechanical shaker. Then 2 mL of aliquot was taken and put in 50 mL flask, add 8 mL of color developing reagent and make the volume up to the mark (Ascorbic acid, Ammonium molybdate, Potassium antimony tartrate and sulphuric acid). After 30 minutes reading was recorded on ANA-703 Spectrophotometer at a wavelength of 880 nm [37].

2.3.1.14. Extractable potassium

Extraction was made by ammonium acetate solution and extractable K was determined by PEP-70 Flame photometer after standardizing with K standard solutions (Method 58a: p. 132).

2.3.2. Plant Analysis

At maturity, the harvesting was done on an area of 1 m^2 per plot. The fresh weight was determined in the field; an aliquot was randomly taken for the determination of dry matter and for nitrogen analysis. The samples of grains and straws were kept at 65 °C for 48 hrs in an electric oven and then their weight was obtained. The concentration of N, P and K in grain and straw were analyzed as under:

2.3.2.1. Digestion

The plant samples were digested by following method of Moore and Chapman (1986). For this purpose digestion mixture was prepared. Added 0.42 g Se and 14 g of $\text{Li}_2\text{SO}_4 \cdot \text{H}_2\text{O}$ to 350 mL of 100 % pure H_2O_2 . Mixed well and added 420 mL of concentrated H_2SO_4 with care. Cooled the mixture during addition of the acid. Weighed 0.4 g of dry ground plant sample into a suitable Kjeldahl flask. Added 4.4 mL of digestion mixture. Digested at low heat until the initial reaction subsides avoiding loss of H_2SO_4 fumes. Continued the digestion until a clear and almost colorless solution is obtained. For most of the samples this requires about 2 hours. Then diluted the sample five folds.

2.3.2.2. Nitrogen determination

Dried and powdered plant material (1 g) was digested using 30 mL of H_2SO_4 and 8 g of digestion mixture. Ten mL aliquot from 100 mL digested material was taken from the distillation in the micro Kjeldahl apparatus. Nitrogen evaluated as ammonia was collected in a receiver containing Boric acid (4 %) solution and mixed indicator (Bromocresol green and methyl red) and titrated against 0.1 N H_2SO_4 to pink end point [37].

2.3.2.3. Phosphorus determination

Plant samples were digested in an acid mixture of HNO_3 and HClO_4 . Then phosphorus was determined by developing color with reagent (Ammonium molybdate, Ammonium vanadate and Nitric acid). The phosphorus was determined with an ANA-730 Spectrophotometer at 470 nm after calibrating with P standards (Method 61: p. 134).

2.3.2.4. Potassium determination

Potassium was determined by Corning Flame photometer-410 after calibrating the instrument with K standards (Method 58: p. 132).

2.4. Agronomic Parameters

2.4.1. Plant height (cm)

Plant height was measured with a meter tape at 10 random sites in each plot and their average was calculated.

2.4.2. Grain yield (Mg ha^{-1})

The cobs were removed from the plants from each plot, unsheathed, sun-dried for one week, shelled and weighed and then converted on hectare basis.

2.4.3. 1000-grain weight (g)

One thousand grains were taken at random from the grain lot of each plot and weighed with the help of electronic balance.

2.4.4. Cob length (cm)

Ten cobs were taken from each plot, their length was measured using measuring tape and average was calculated.

2.4.5. Number of rows per cob

Ten cobs were taken at random from each plot and number of grain rows counted and their average was calculated.

2.4.6. Number of grains per cob

Ten cobs were taken at random from each plot and counted the number of grains per row and average was calculated accordingly.

2.5. Statistical Analysis

Statistical analysis of the data was carried out using RCBD split plot design. The comparisons among treatment means were made according to appropriate test [30].

3. Results

3.1. Agronomic Parameters

3.1.1. Effect of irrigation and mulch on plant height (cm) of maize

Plant growth is generally measured in term of plant height. The data shows that the irrigation had significant effect on plant height shown in Table-2. As regards the irrigation, mean maximum value of plant height (229.38 cm) was observed in I_2 and minimum (222.92 cm) was in case of treatment I_1 . The mulch also had significant effect on plant height as shown in Table-3 and the mean maximum value of plant height (235.20 cm) was found in treatment M_{15} where straw was applied @ 15 Mg ha^{-1} and minimum (217.90 cm) was in M_0 (control).

The data presented in Fig. 1 revealed that the combined effect of irrigation and mulch had non significant effect on plant height yet treatment $I_2 \times M_{15}$ being the most effective. The mean maximum value of plant height (240.18 cm) was observed with treatment combination $I_2 \times M_{15}$ followed by $230.23 \text{ Mg ha}^{-1}$ in case of $I_1 \times M_{15}$ and minimum value of plant height (215.60 cm) was observed in $I_1 \times M_0$ combination.

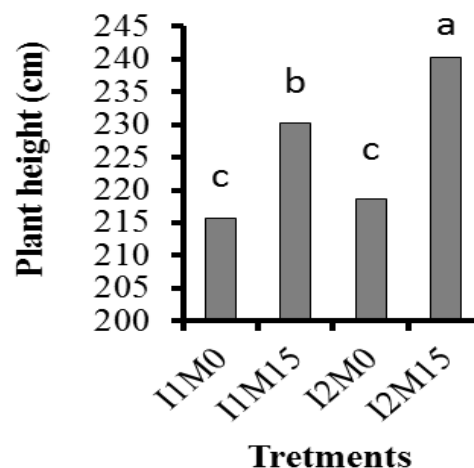


Figure 1. Effect of irrigation and mulch on plant height (cm) of maize at the time of harvest

Table 1. Effect of irrigation on agronomic parameters in maize

	Plant height (cm)	Biological yield (Mg/ha)	Grain yield(Mg/ha)	No.of rows/cob	Grains/row	Cob length (cm)	1000-grain weight (g)
I1	222.92 B	9.73 B	2.7 B	14.9 A	36 B	14.4 A	271.5 B
I2	229.38 A	12.75 A	3.8 A	15.3 A	38 A	14.8 A	307.0 A
LS D	8.253	1.030	0.653	1.652	2.303	1.742	12.364

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 2. Effect of mulch on agronomic parameters in maize

	Plant height (cm)	Biological yield (Mg/ha)	Grain yield (Mg/ha)	No. of rows/cob	Grains/row	Cob length (cm)	1000-grain weight (g)
M ₀	216.80 B	10.20 B	2.5 B	14.3 B	35 B	14.5 A	272.0 B
M ₁₅	239.49 A	12.28 A	4.0 A	16 A	39 A	14.7 A	306.5 A
LS D	11.282	1.376	0.789	1.776	2.776	0.845	11.748

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

3.1.2. NE ffect of irrigation and mulch on biological yield (Mg ha⁻¹) in maize

The data related to biological yield of maize are shown in Table 2 and 3. This revealed that irrigation and mulch rates had significant effect on biological yield of maize crop. As regard irrigation levels, the mean maximum value of biological yield was 12.75 Mg ha⁻¹ recorded in case of treatment I₂ and minimum (9.73 Mg ha⁻¹) was found in treatment I₁. In case of mulch rates, the mean maximum value (12.28 Mg ha⁻¹) was found in treatment M₁₅ and minimum (10.20 Mg ha⁻¹) was recorded in M₀, i.e. control.

The interactive effects between irrigation and mulch was significant (Fig. 2) and mean maximum value of biological yield (14.13 Mg ha⁻¹) was observed with treatment combination I₂ x M₁₅ followed by 11.36 Mg ha⁻¹ in case of I₂ x M₀ and minimum value of biological yield (9.03 Mg ha⁻¹) was observed in I₁ x M₀ treatment combination.

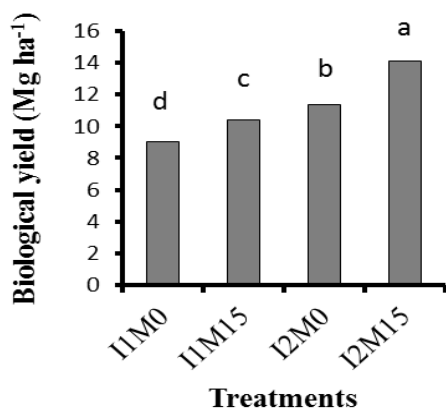


Figure 2. Effect of irrigation and mulch on biological yield (Mg ha-1) in maize

3.1.3. Effect of irrigation and mulch on grain yield (Mg ha⁻¹) of maize

Data presented in Table 1 and 2 shows that irrigation and mulch rates had significant effect on grain yield of maize crop. Regarding the irrigation effect on grain yield, the mean

maximum value (3.81 Mg ha⁻¹) of grain yield was recorded in case of treatment I₂ and minimum (2.77 Mg ha⁻¹) was found in treatment I₁. In case of mulch rates, the mean maximum value (4.00 Mg ha⁻¹) of grain yield was observed in treatment M₁₅ and minimum (2.59 Mg ha⁻¹) was found in case of treatment M₀.

It is revealed from the data that the interactive effects between irrigation and mulch was significant (Fig. 3) and mean maximum value of grain yield 4.75 Mg ha⁻¹ was observed with treatment combination I₂ x M₁₅. Next to this, treatment combinations I₁ x M₁₅, I₂ x M₀ and I₁ x M₀ showed grain yields of 3.25, 2.88 and 2.3 Mg ha⁻¹, respectively.

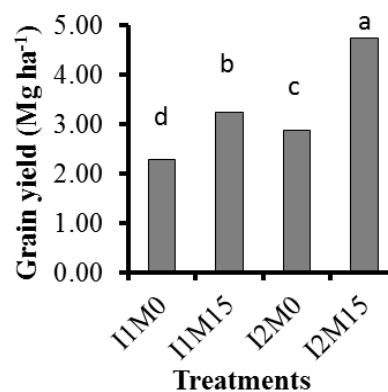


Figure 3. Effect of irrigation and mulch on grain yield (Mg ha-1) of maize

3.1.4. Effect of irrigation and mulch on number of rows per cob in maize

Data regarding to the effect of irrigation and mulch rates on number of rows per cob in maize crop is presented in Table 1 and 2. Statistical analysis (ANOVA) revealed that the mulch had significant effect on the number of rows per cob in maize. But in case of irrigation and their interaction showed non significant effect on number of rows per cob. In case of irrigation, the mean maximum value (15.38) of number of rows per cob was observed in treatment I₂ and minimum (14.98) was in case of treatment I₁. As regards mulch, the mean maximum value of 16.00 number of rows

per cob was observed in M_{15} treatment and minimum of 14.36 rows per cob was in case of control. Interaction of irrigation and mulch shows that treatment combination $I_2 \times M_{15}$ showed maximum number of rows per cob, that was 16 (18.71 % more over control) and minimum 14 (4.56 % less than control) was in treatment combination $I_1 \times M_0$ (Fig. 4).

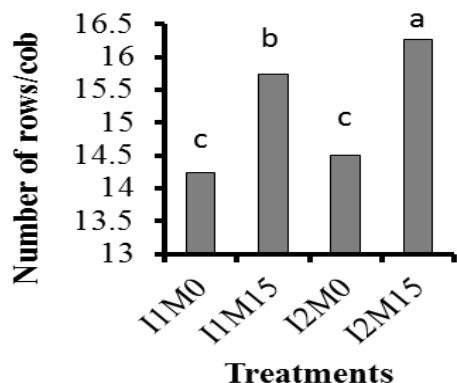


Figure 4. Effect of irrigation and mulch on number of rows per cob in maize

3.1.5. Effect of irrigation and mulch on number of grains per row in maize

It evident from data listed in Table 2 and 3 that the effect of irrigation and mulch rates on number of grains per row in maize crop was significant. Statistical analysis (ANOVA) revealed that the mulch had significantly affected the number of grains per rows. But mulch and their interaction is statistically non-significant. As regards irrigation levels, the mean maximum value of 38 number of grains per row was observed in treatment I_2 and minimum, i.e. 36 was noted in I_2 treatment. In case of mulch, the mean maximum value of 39 grains per row was observed in M_{15} treatment and minimum of 35 grains per row was observed in case of treatment M_0 .

Interaction of irrigation and mulch showed that treatment combination $I_3 \times M_3$ showed maximum number of 40 grains per row (Fig. 5) that was 34.15 % more as compare to control. Next to this, treatment combinations $I_1 \times M_{15}$, $I_2 \times M_0$ and $I_1 \times M_2$ showed 38, 36 and 34 number of grains per row, respectively.

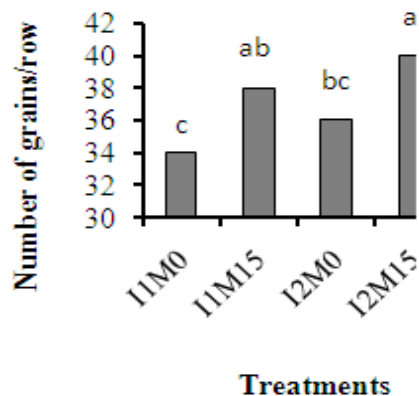


Figure 5. Effect of irrigation and mulch on number of grains per row in maize

3.1.6. Effect of irrigation and mulch on cob length (cm) in maize

The data pertaining to the effect of irrigation and mulch on cob length are given in Table 1 and 2. The data shows that both the irrigation and mulch had non-significant effect on cob length. As regards the irrigation levels, mean maximum values of 14.8 cm cob length was measured in treatment I_2 , followed by I_1 treatment which showed 14.4 cm cob length. The mean values show that there is no significant effect on cob length under different irrigation levels. As regards the mulch, the mean maximum value of 14.7 cm cob length was observed in case of treatment M_{15} and minimum of 14.5 cm cob length was noted in case of control treatment M_0 .

The interactive effects between irrigation and mulch was statistically non significant but there was mean maximum value of 14.96 cm cob length in treatment combination $I_2 \times M_{15}$ (Fig. 6) and minimum (14.13 cm) was found in $I_1 \times M_1$ treatment combination.

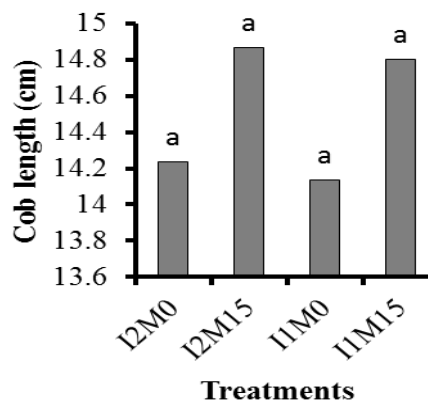


Figure 6. Effect of irrigation and mulch on cob length (cm) in maize

3.1.7. Effect of irrigation and mulch on 1000-grain weight (g) in maize

Data regarding effect of irrigation and mulch on 1000-grain weight is given in Table 1. Statistically both irrigation levels and mulch rates had significant effect on 1000-grain weight of maize crop. As regards irrigation, the mean maximum value, i.e. 307.0 g 1000-grain weight was observed in treatment I_2 and minimum of 271.50 g was in treatment I_1 . In case of mulch, the maximum value, i.e. 306.50 g 1000-grain weight was observed in treatment M_{15} and minimum of 272.0 g was observed in M_0 treatment. Due to the application of mulch the 1000-grain weight was increased and in case of M_{15} , 1000-grain weight increased 9.6 % over control.

The data related to the interaction effect of irrigation and mulch is graphically shown in Fig. 7. The interactive effects between irrigation and mulch was statistically non significant on 1000-grain weight of maize crop. Mean maximum value of 332.33 g of 1000-grain weight was noted in treatment combination $I_2 \times M_{15}$ (Fig. 7) followed by 281.67 g in case of $I_2 \times M_0$ and minimum (262.33 g) was found in $I_1 \times M_0$ treatment combination.

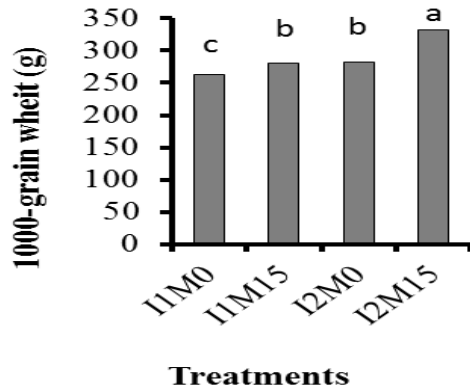


Figure 7. Effect of irrigation and mulch on 1000-grain weight (g) in maize

3.2. Water Use Efficiency and Soil Physical Parameters

3.2.1. Effect of irrigation and mulch on water use efficiency (kg/ha/mm) in maize

Data regarding the effect of irrigation and mulch on water use efficiency are given in Table 3 and 4, which revealed that irrigation and mulch had significant effect on water use efficiency of maize crop. As regard irrigation levels, the mean maximum value of 2.68 kg ha⁻¹ mm⁻¹ water use efficiency was recorded in treatment I₁ and minimum of 20.8 kg ha⁻¹ mm⁻¹ was in I₂ treatment. As regard mulch rates, the mean maximum value of 24.3 kg ha⁻¹ mm⁻¹ water use efficiency was measured in case of treatment M₁₅ and minimum of 23.3 kg ha⁻¹ mm⁻¹ water use efficiency was noted in treatment M₀. Mulch reduced the evaporation losses and improved WUE.

It is revealed from the data presented in Fig. 8 that the interactive effects between irrigation and mulch was significant on WUE and treatment combination I₁ x M₁₅ showed mean maximum value of water use efficiency 28.4 kg ha⁻¹ mm⁻¹ (40.87 % more over control). Next to this, treatment combinations I₁ x M₁, I₂ x M₀ and I₂ x M₁₅ showed 25.1, 21.5 and 20.16 kg ha⁻¹ mm⁻¹, respectively.

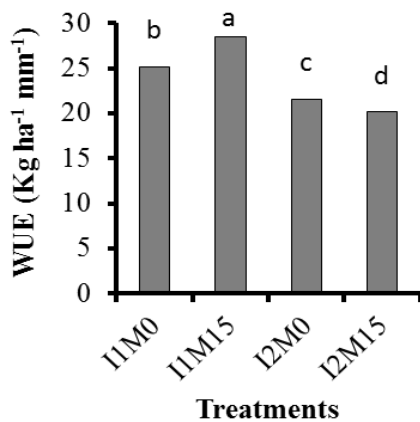


Figure 8. Effect of irrigation and mulch on water use efficiency (kg/ha/mm) in maize

3.2.2. Effect of irrigation and mulch on infiltration rate (mm hr⁻¹) at maize harvest

Data regarding the effect of irrigation and mulch on infiltration rate of soil at harvest of maize crop is presented in Table 3 and 4. Statistical analysis (ANOVA) revealed that the mulch had significantly affected the infiltration rate while irrigation effect was non significant. As regard irrigation, the mean maximum value of 16.3 mm hr⁻¹ infiltration rate was observed in treatment I₂ and minimum of 15.5 mm hr⁻¹ was noted in I₁ treatment. In case of mulch, the mean maximum value of 19.4 mm hr⁻¹ was observed in treatment M₁₅ (57.02 % more over control) and minimum of 12.4 mm hr⁻¹ was noted in case of M₀, i.e. control.

As regard the interactive effects between irrigation and mulch, the mean maximum value of infiltration rate (19.80 mm hr⁻¹) was observed in treatment combination I₂ x M₁₅ (Fig. 9). The treatment combinations viz. I₁ x M₁₅ and I₂ x M₁ gave the increase in infiltration rate by 41.6 and 17.6 % over control, respectively.

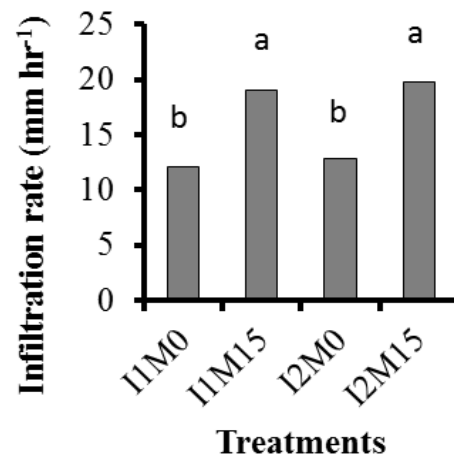


Figure 9. Effect of irrigation and mulch on infiltration rate (mm hr⁻¹) at maize harvest

3.2.3. Effect of irrigation and mulch on field saturated hydraulic conductivity (mm hr⁻¹) at maize harvest

The data pertaining to effect of irrigation and mulch on field saturated hydraulic conductivity of soil at harvest of maize crop are presented in Table 3 and 4. The data showed that both irrigation and mulch had significant effect on field saturated hydraulic conductivity. In case of irrigation, mean maximum value of 64.5 mm hr⁻¹ hydraulic conductivity was observed in treatment I₂ (35.04 % more over control) and minimum of 45.6 mm hr⁻¹ was noted in I₁ treatment. In case of mulch, the mean maximum value 73.5 mm hr⁻¹ of hydraulic conductivity was observed in treatment M₁₅ (76.53 % more over control) and minimum of 36.6 mm hr⁻¹ was noted in treatment M₀.

Table 3. Effect of irrigation on WUE and soil physical quality parameters

	WUE kg/ha/mm	Infiltration rate (mm hr ⁻¹)	Hydraulic conductivity (mm hr ⁻¹)	Soil strength (kPa)
I ₁	23.38 B	15.5 A	45.6 B	981.3 A
I ₂	26.3 A	16.3 A	64.5 A	960.5 B
LSD	3.303	2.613	14.384	25.423

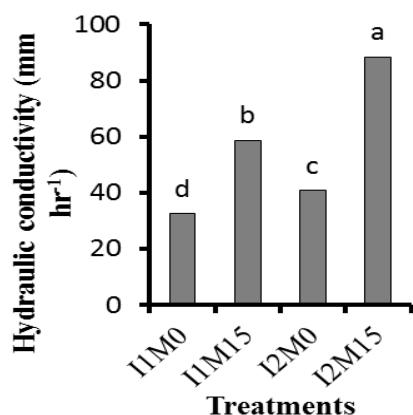
Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$

Table 4. Effect of mulch on WUE and soil physical quality parameters

	WUE kg/ha/mm	Infiltration rate (mm hr ⁻¹)	Hydraulic conductivity (mm hr ⁻¹)	Soil strength (kPa)
M ₀	23.3 B	12.4 B	36.6 B	1060.7 A
M ₁₅	24.3 A	19.4 A	73.5 A	881.2 B
LSD	2.776	2.346	13.928	22.532

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

The data presented in Fig. 10 showed that interactive effects between irrigation and mulch have non-significant effect on K_{fs} . The mean maximum value of field saturated hydraulic conductivity 88.33 mm hr⁻¹ was observed in treatment combination I₂ x M₁₅ followed by 58.70 mm hr⁻¹ in case of I₁ x M₂ and minimum value of field saturated hydraulic conductivity (32.56 mm hr⁻¹) was observed in treatment combination I₁ x M₀.

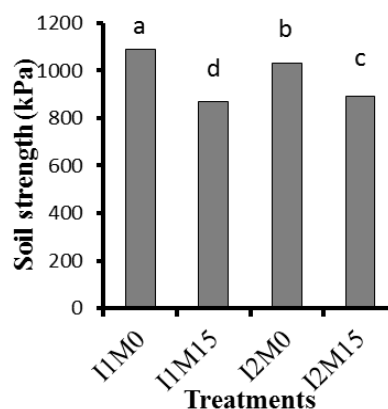
**Figure 10.** Effect of irrigation and mulch on field saturated hydraulic conductivity (mm hr⁻¹) at maize harvest

3.2.4. Effect of irrigation and mulch on soil strength (kPa)

The data regarding the soil strength as affected by irrigation and mulching at harvest of maize is presented in Table 4 and 5. There is significant effect of mulching on soil strength due to lower soil bulk density which lowers the penetration resistance in the soil. As regard irrigation, mean maximum value (981.3 kPa) of soil strength was observed in treatment I₁ and minimum (960.5 kPa) was noted in treatment I₂. In case of mulch application, the mean maximum value (1060.7 kPa) of soil strength was observed in M₀ and minimum (881.2 kPa) was found in treatment M₁₅.

Data given in Fig. 11 revealed that at the harvest of maize

crop less penetration resistance was observed with treatment combination I₂ x M₁₅ (891.3 kPa). More penetration resistance was observed in treatment combination I₁ x M₀ due to less moisture contents. Due to lower water contents soil become compact and hard.

**Figure 11.** Effect of irrigation and mulch on soil strength (kPa)

3.2.5. Effect of irrigation and mulch on soil bulk density (Mg m⁻³) at maize harvest

Data related to effect of irrigation and mulch on soil bulk density at 0-10 cm depth after harvesting of maize crop are given in Table 5 and 6. Statistical analysis clearly indicated that the irrigation had significant effect on bulk density of soil. As regard irrigation levels, the mean maximum value of 1.54 Mg m⁻³ soil bulk density was observed in treatment I₁ and minimum of 1.45 Mg m⁻³ soil bulk density was in case of treatment I₂. In case of mulch rates, the mean maximum value 1.51 Mg m⁻³ of soil bulk density was observed in M₀ and minimum (1.48 Mg m⁻³) was noted in M₁₅ treatment.

The interactive effects between irrigation and mulch on soil bulk density was found statistically non significant. Mean maximum value of soil bulk density 1.56 Mg m⁻³ was observed in case of treatment combination I₁ x M₀ followed

by 1.53 Mg m⁻³ in case of treatment combination I₁ x M₁₅ and minimum value of soil bulk density 1.44 Mg m⁻³ was observed in case of I₂ x M₁₅ combination. The data regarding interaction of irrigation and mulch is presented graphically in Fig. 12.

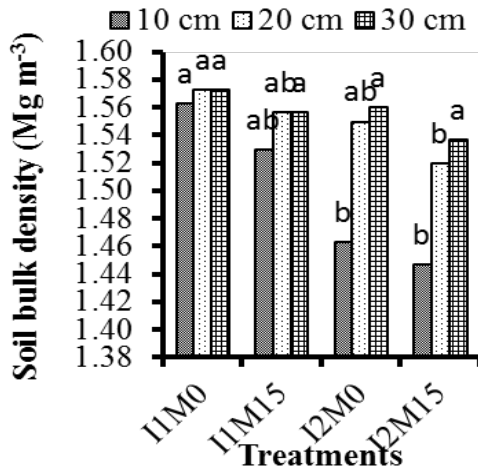


Figure 12. Effect of irrigation and mulch on soil bulk density (Mg m⁻³) at maize harvest

At 10-20 cm depth, effect of both irrigation and mulch on soil bulk density was found statistically non significant. As regard the irrigation, the mean maximum value of 1.56 Mg m⁻³ soil bulk density was observed in treatment I₁ and minimum of 1.53 Mg m⁻³ was found in treatment I₂. In case of mulch rates, the mean maximum value (1.56 Mg m⁻³) of soil bulk density was reported in M₀ and minimum (1.53 Mg m⁻³) was noted in treatment M₁₅.

In case of interaction, the mean maximum value of soil bulk density 1.57 Mg m⁻³ was observed in case of treatment combination I₁ x M₀ and minimum value of soil bulk density 1.52 Mg m⁻³ was observed in case of I₂ x M₁₅ combination. Bulk density reduced due to mulch because of decomposition on mulch soil improved by aggregation and soil porosity increased. So due to porosity, bulk density at soil surface reduced. Irrigation had no effect on bulk density.

At 20-30 cm depth, effect of irrigation on soil bulk density was found statistically non significant and effect of mulch was significant. As regard irrigation, the mean maximum value of 1.56 Mg m⁻³ soil bulk density was observed in treatment I₁ and minimum 1.55 Mg m⁻³ was noted in treatment I₂. In case of mulch rates, the mean maximum value (1.56 Mg m⁻³) of soil bulk density was reported in treatment M₀ and minimum (1.54 Mg m⁻³) of soil bulk density was observed in treatment M₁₅.

In case of interaction, the mean maximum value of soil bulk density 1.57 Mg m⁻³ was observed in case of treatment combination I₁ x M₀ followed by 1.56 Mg m⁻³ in case of treatment combination I₂ x M₀ and minimum value of soil bulk density 1.53 Mg m⁻³ was observed in case of I₂ x M₁₅ combination. Mulching increased organic matter contents and soil moisture leading to appropriate environment for root penetration.

Table 5. Effect of irrigation and mulch on soil bulk density

Irrigation level	Bulk density (Mg m ⁻³)		
	0-10 (cm)	10-20 (cm)	20-30 (cm)
I ₁	1.54 A	1.56 A	1.56 A
I ₂	1.45 B	1.53 A	1.55 A
LSD	0.0703	0.0563	0.0236

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 6. Effect of irrigation and mulch on soil bulk density

Mulch rates	Bulk density (Mg m ⁻³)		
	0-10 (cm)	10-20 (cm)	20-30 (cm)
M ₀	1.51 A	1.56 A	1.56 A
M ₁₅	1.48 A	1.53 A	1.54 A
LSD	0.0876	0.0283	0.0283

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

3.3.1. Effect of irrigation and mulch on soil organic carbon concentration (g kg⁻¹) at harvest of maize

The data pertaining to the effect of irrigation and mulch on soil organic carbon concentration at harvest of maize is given in Table 7 and 8. As regard irrigation, there was non significant effect on SOC concentration. The mean maximum value 5.70 g kg⁻¹ of SOC was observed in treatment I₂ and minimum 5.01 g kg⁻¹ was noted in I₁ treatment. At the harvest of maize crop, statistically more SOC concentration was observed with treatment M₁₅ (5.96 g kg⁻¹) and least with treatment M₀ (4.83 g kg⁻¹).

The interactive effect of irrigation level with mulch at 0-10 cm depth of soil organic carbon was found statistically non significant. However, the mean maximum SOC concentration at maize harvest (6.5 g kg⁻¹) was observed in treatment combination I₂ x M₁₅ while I₁ x M₁₅ showed 5.43 g kg⁻¹ and was second best treatment. Minimum SOC concentration of 4.76 g kg⁻¹ was observed in case of I₁ x M₀ at 0-10 cm depth (Fig. 13).

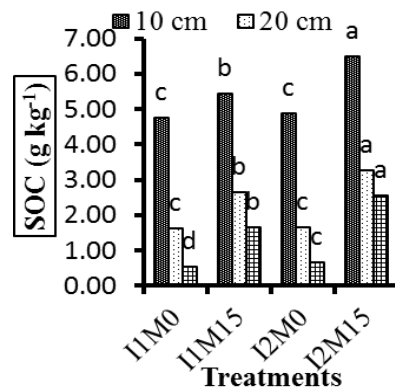


Figure 13. Effect of irrigation and mulch on soil organic carbon concentration (g kg⁻¹) at harvest of maize

Mulch was found significant for SOC concentration at 10-20 cm depth and the mean maximum value (2.95 g kg⁻¹)

of SOC concentration was measured in treatment M_{15} and minimum (1.64 g kg^{-1}) was observed in treatment M_0 . As regard irrigation, there was non significant effect on SOC concentration yet the mean maximum value (2.45 g kg^{-1}) of SOC was observed in treatment I_2 and minimum (2.14 g kg^{-1}) was noted in I_1 treatment.

Interaction of mulch and irrigation levels also showed non significant effect on SOC at 10-20 cm depth. The $I_2 \times M_{15}$ proved to be the best treatment combination regarding SOC concentration, yielding mean maximum SOC concentration that showed 3.26 g kg^{-1} . It was followed in descending order by treatment combinations $I_1 \times M_{15}$, $I_2 \times M_0$ and $I_1 \times M_0$ which increased SOC concentration (g kg^{-1}) by 2.65, 1.65 and 1.63 g kg^{-1} , respectively at 10-20 cm depth (Fig. 13).

At 20-30 cm depth, effect of irrigation levels and mulch was significant on SOC concentration. As regard irrigation levels, the mean maximum value of 1.61 g kg^{-1} SOC was observed in treatment I_2 and minimum 1.10 g kg^{-1} was noted in treatment I_1 .

In case of mulch, the mean maximum value of 2.10 g kg^{-1} SOC was measured in treatment M_3 and minimum (0.61 g kg^{-1}) was noted in M_0 treatment.

The interactive effect of irrigation levels with mulch was also significant. The SOC concentration at 20-30 cm was greater with $I_2 \times M_{15}$ treatment combination. Treatment combination $I_2 \times M_{15}$ gave mean maximum value of soil organic carbon of 2.55 g kg^{-1} . Minimum SOC was found in treatment combination $I_1 \times M_0$, i.e. 0.55 g kg^{-1} (Fig. 13).

Table 7. Effect of irrigation on soil organic carbon concentration

Irrigation level	Soil organic carbon (g kg^{-1})		
	0-10 (cm)	10-20 (cm)	20-30 (cm)
I_1	5.1000 B	2.1400 B	1.1017 A
I_2	5.7000 A	2.9683 A	2.1000 B
LSD	1.8303	0.8313	0.3683

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 8. Effect of mulch on soil organic carbon concentration

Mulch rates	Soil organic carbon (g kg^{-1})		
	0-10 (cm)	10-20 (cm)	20-30 (cm)
M_0	4.833 B	1.6400 B	0.6117 B
M_{15}	5.9667 A	2.9683 A	2.1000 A
LSD	1.576	0.7193	0.1634

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 9. Effect of irrigation on soil macronutrient (NPK) status

Irrigation level	N in soil (g kg^{-1})	P in soil (ppm)	K in soil (ppm)
I_1	0.50 B	14.53 A	131.00 B
I_2	0.55 A	14.33 A	135.50 A
LSD	0.1303	0.3664	1.8303

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 10. Effect of mulch on soil macronutrient (NPK) status

Mulch rates	N in soil (g kg^{-1})	P in soil (ppm)	K in soil (ppm)
M_0	0.46 B	13.39 B	126.33 B
M_{15}	0.58 A	15.46 A	140.17 A
LSD	0.1576	0.7762	2.7376

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$

3.3.2. Effect of irrigation and mulch on soil nitrogen (g kg^{-1})

The data related to effect of irrigation and mulch on N concentration is shown in Table 9 and 10 and there was significant effect of mulching on nutrient status. As regard irrigation, the mean maximum value 0.55 g kg^{-1} of soil nitrogen was observed in treatment I_2 and minimum 0.50 g kg^{-1} was in treatment I_1 . In case of mulch, the mean maximum value 0.58 g kg^{-1} of soil nitrogen was reported in treatment M_{15} and minimum 0.46 g kg^{-1} was noted in treatment M_0 . Due to mulching nitrogen losses reduced and also its amount increased within the soil because of decomposition of straw mulch.

There was also significant effect of their interaction on soil nitrogen. The mean maximum value 0.64 g kg^{-1} of soil nitrogen was found in that treatment combination $I_2 \times M_{15}$ where straw was applied @ 15 Mg ha^{-1} and that is 50 % more than control and minimum value of soil nitrogen 0.46 g kg^{-1} was observed in case of $I_1 \times M_0$ (Fig 14).

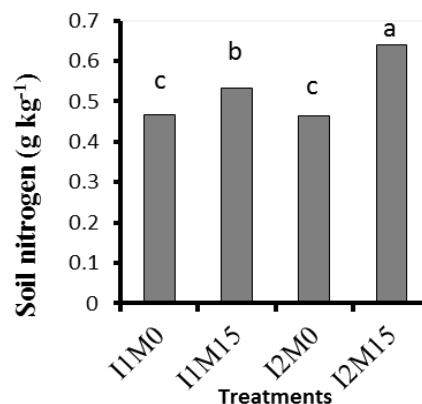


Figure 14. Effect of irrigation and mulch on soil nitrogen (g kg^{-1})

3.3.3. Effect of irrigation and mulch on soil phosphorus (ppm)

The data related to effect of irrigation and mulch on phosphorus concentration is given in Table 9 and 10. As regard irrigation, the mean maximum value 14.53 ppm of soil phosphorus was observed in treatment I_2 and minimum 14.32 ppm was found in treatment I_1 . In case of mulch, the mean maximum value 15.46 ppm of soil phosphorus was observed in case of treatment M_{15} and minimum 13.35 ppm was in M_0 , i.e. control treatment.

In case of interaction, the mean maximum value of soil phosphorus was found in treatment combination $I_2 \times M_{15}$ that was 15.48 ppm (14.54% more over control) and minimum

was found in treatment combination $I_1 \times M_0$ that was 13.22 ppm (Fig. 15).

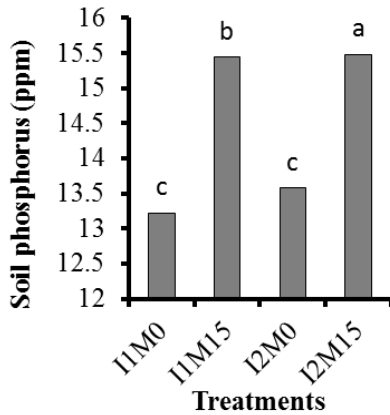


Figure 15. Effect of irrigation and mulch on soil phosphorus (ppm)

3.3.4. Effect of irrigation and mulch on soil potassium (ppm)

The data related to effect of irrigation and mulch on potassium concentration is presented in Table 10 and 11. As regard irrigation, the mean maximum value 135.50 ppm of soil potassium was observed in treatment I_2 and minimum 131.08 ppm was noted in treatment I_1 . In case of mulch, the mean maximum value 140.17 ppm of soil potassium was observed in treatment M_{15} and minimum 126.33 ppm of soil potassium was found in M_0 treatment.

But in case of interaction, irrigation and mulch had significant effect on soil potassium concentration and data is shown graphically in Fig. 16. Mean maximum value of soil potassium was found in treatment combination $I_2 \times M_{15}$ that was 144.67 ppm (13.55 % more over control) and minimum value was 126.33 ppm soil potassium found in treatment combination $I_1 \times M_0$.

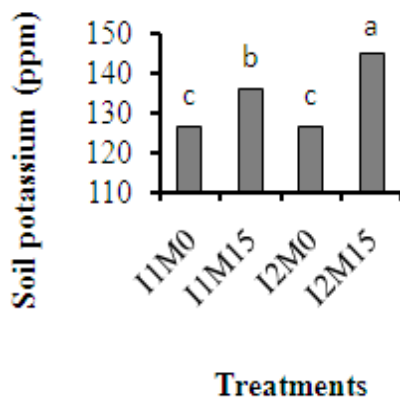


Figure 16. Effect of irrigation and mulch on soil potassium (ppm)

3.3.5. Effect of irrigation and mulch on nitrogen uptake by maize

The data related to effect of irrigation and mulch on N, P and K uptake by maize plant is listed in Table 11 and 12. Mulch and irrigation has significant effect on nitrogen uptake by maize plant. Interaction of irrigation and mulch also was significant on nitrogen uptake by plant. As regard

irrigation, the mean maximum value 91.71 kg ha⁻¹ of N uptake by maize crop was observed in treatment I_2 and minimum 71.87 kg ha⁻¹ of N uptake by maize crop was noted in treatment I_1 . In case of mulch, the mean maximum value 88.79 kg ha⁻¹ of N uptake by maize crop observed in M_{15} treatment and minimum 74.79 kg ha⁻¹ was found in case of treatment M_0 .

In case of interaction, the mean maximum value of N uptake was found in treatment combination $I_2 \times M_{15}$ that was 105 kg ha⁻¹ which was 15.68 % more over control. Next to this treatment combinations $I_2 \times M_0$ and $I_1 \times M_{15}$ showed 78.28 and 72.44 kg ha⁻¹, respectively and minimum nitrogen uptake in case of $I_1 \times M_0$ that is 71.32 kg ha⁻¹ (Fig. 17).

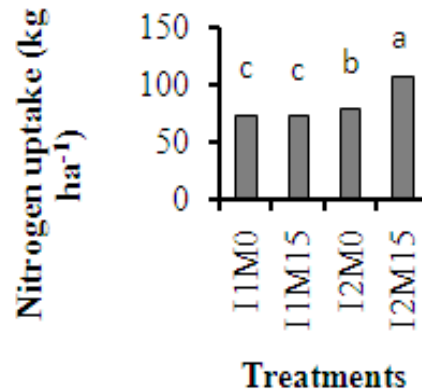


Figure 17. Effect of irrigation and mulch on nitrogen uptake by maize

Table 11. Effect of irrigation on NPK uptake by maize crop

Irrigation level	N uptake (kg ha ⁻¹)	P uptake (kg ha ⁻¹)	K uptake (kg ha ⁻¹)
I_1	71.87 B	31.01 A	131.48 B
I_2	91.71 A	31.61 A	137.58 A
LSD	4.433	1.648	2.303

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

Table 12. Effect of mulch on NPK uptake by maize crop

Mulch rates	N uptake (kg ha ⁻¹)	P uptake (kg ha ⁻¹)	K uptake (kg ha ⁻¹)
M_0	74.79 B	28.05 B	129.53 B
M_{15}	88.79 A	34.58 A	139.53 A
LSD	4.984	1.646	2.776

Means with in columns for each treatment followed by the same letter are not significantly different at $\alpha = 0.05$.

3.3.6 Effect of irrigation and mulch on phosphorus uptake by maize

The data presented in Table 11 and 12 revealed that there was non significant effect of irrigation and significant effect of mulch on phosphorus uptake. The mean maximum value of 31.61 kg ha⁻¹ P uptake by maize crop was observed in treatment I_2 and minimum of 31.01 kg ha⁻¹ P uptake by maize crop was in noted treatment I_1 . In case of mulch, the mean maximum value of 34.58 kg ha⁻¹ P uptake by maize crop

observed in treatment M_{15} and minimum 28.05 kg ha^{-1} was noted in treatment M_0 .

In case of interaction of irrigation and mulch, there was non significant effect on P uptake. The mean maximum value 34.17 kg ha^{-1} of P uptake by maize was observed in treatment combination $I_2 \times M_{15}$ and minimum 27.58 kg ha^{-1} was observed in treatment combination $I_1 \times M_0$ of control (Fig.18).

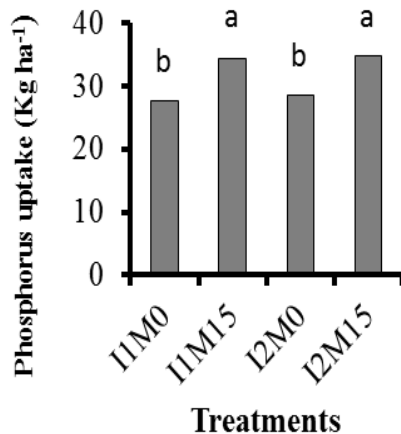


Figure 18. Effect of irrigation and mulch on phosphorus uptake by maize

3.3.7. Effect of irrigation and mulch on potassium uptake by maize

The data presented in Table 11 and 12 revealed that both mulch and irrigation has significant effect on K uptake by maize crop and their interactions were also significant. As regard irrigation, the mean maximum value $137.58 \text{ kg ha}^{-1}$ of K uptake by maize crop was observed in treatment I_2 and minimum $131.48 \text{ kg ha}^{-1}$ of K uptake by maize crop was in treatment I_1 . In case of mulch, the mean maximum value $139.53 \text{ kg ha}^{-1}$ of K uptake by maize crop observed in case of treatment M_{15} and minimum $129.53 \text{ kg ha}^{-1}$ was noted in treatment M_0 .

In case of interaction, the mean maximum value of K uptake was found in treatment combination $I_2 \times M_{15}$ that was $144.61 \text{ kg ha}^{-1}$ while treatment combinations $I_1 \times M_0$ and $I_2 \times M_0$ showed 128.52 and $130.55 \text{ kg ha}^{-1}$ (Fig. 19), respectively.

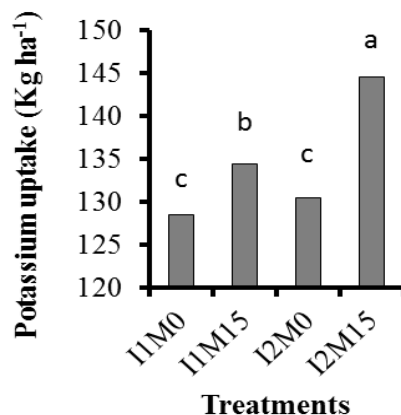


Figure 19. Effect of irrigation and mulch on potassium uptake by maize

4. Discussion

The height of maize plant was more where more irrigation depth and high mulch rates were applied because of improved availability of water contents for plant growth. These results were in agreement with those of Wicks [38] who concluded that with increasing the mulch levels the maize height enhanced. Similarly, Ahmad [39] noted that the plant height increased with increasing wheat straw rate from 1 to 4 t ha^{-1} compared with control. This showed that plant height was directly proportional to the mulching material.

Mulch enhanced the soil physical properties through aggregation. Our results are similar to those of Khurshid [42] who revealed that mulch had significantly affected the growth of crop and physical properties of soil. Similarly, Bhardwaj and Sindhwal [42] reported that the addition of mulch resulted in significant increase in soil water contents and reduced runoff. The increase in soil water was effective in ensuring better germination and higher yield.

Nutrients were available to plant roots in presence of moisture, leading to higher grain yield. Our results coincide with those of Liu [43] who reported that mulch increases the soil moisture and nutrients availability to plant roots, in turn, leading to higher grain yield. Also mulch increased grain yield by 17 % and above ground biomass by 19 % (Tolk *et al* [44] Similarly, Chaudhary *et al.* [45] examined the effect of three rates of mulches, i.e. 2, 4 and 6 tones ha^{-1} and noted that mulch application appreciably improved the grain and straw yields.

Results are in line with those of Wajid [36] who reported that plant height, number of grains per cob, number of cobs per plant, grain yield, mean grain weight and harvest index were significantly affected by the irrigation levels and mulching materials.

The number of grains per row is increased with decreasing irrigation depth and mulch rates. These results were in agreement with those of Oktem *et al.* [37] who studied the influence of deficit irrigation on drip irrigated maize in 1998 and 1999. Water was applied to maize as 100, 90, 80 and 70 % evaporation from a Class A pan (Epan). Applied irrigation water was 610-816 mm and 715-879 mm in 1998 and 1999, respectively. Number of kernels per ear, ear length and single fresh ear weight values were the highest at 100 % Epan, whereas minimum was found at 70 % Epan in both the years.

Similar findings were reported by Wajid [34] who reported that plant height, grains per cob, number of cobs per plant, grain yield, mean grain weight and harvest index were influenced significantly by the irrigation frequencies and mulching materials but had non significant effect on cob length. Similarly, Oktem *et al.* [36] who reported the influence of deficit irrigation on drip irrigated sweet corn in 1998 and 1999. Water was applied to sweet corn as 100, 90, 80 and 70 % evaporation from a Class A pan (Epan). Plant height, single fresh cob weight, ear length and number of kernels per ear values were the maximum at 100 % Epan, whereas lowest values were found at 70 % Epan, during the

both 1998 and 1999 years.

Due to presence of more moisture in higher irrigation depth and higher mulch rates and also their interaction, the size of grains increased so grain weight increased. Our results coincide with those of Khurshid *et al.* [42] who reported that mulch had significantly affected the physical properties of soil and growth of crop. The soil water contents and 1000-grain weight of maize were highest when mulch was applied at the rate of 12 Mg ha⁻¹.

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The mulching materials on the soil surface act as a shade, serve as a barrier against moisture loss from the soil. By reducing the irrigation depth and application of mulch, the evaporation losses reduced so that WUE was increased. Our findings are in line with those of Oweis *et al.* [46]. They reported that the straw mulching reduced soil evaporation by 43 mm for maize and WUE was improved by over 10 %. These results indicate that the water use efficiency increased with the decrease in irrigation depth applied. Similarly, Mulumba and Lal [32] confirmed that mulch rates significantly increased available water use efficiency by 17-36 % and soil moisture retention at low suctions from 28 to 70 %. At high suctions, no differences in soil moisture content were observed between mulch levels.

These results confirm the findings of Gurpeet *et al.* [47] who reported that increased carbon content of the soil due to mulching increased the aggregation status and infiltration rate of soil. Moreover, mulches increased infiltration rate and water in the rhizosphere, improved macro-porosity and structure of soil along with reducing runoff and evaporation losses [48].

These results corroborate the findings of Canqui and Lal [49] who reported that mulching significantly impacted hydraulic conductivity properties of soil. Mulched treatment had K_{sat} 123 times greater and retained 40 to 60 % more water between 0 and -1500 kPa than the unmulched treatment.

Our findings are in line with those of Pervaiz *et al.* [50] who concluded that mulch increase soil organic matter and soil moisture contents but decreased soil strength and bulk density compared to control.

Mulching increased organic matter contents and soil moisture leading to appropriate environment for root penetration. Similarly, Ghuman *et al.* [51] concluded that mulching decreases bulk density of the surface soil. Pervaiz *et al.* [50] also concluded that mulch increased moisture contents (17 %) and soil organic matter (1.32 g kg⁻¹), but decreased soil strength (464 kPa) and bulk density (1.35 Mg m⁻³) compared to control.

The SOC increased due to decomposition of applied mulch. Higher values of SOC concentration were observed at 0-10 cm than 10-20 cm and lowest at 20-30 cm soil depth. Our results are in line with those of Lal [32] and Khurshid *et al.* [57] who concluded that organic matter was significantly higher when more mulch was applied. Similarly Canqui and Canqui [53] conducted a study to assess the long term (10 years) impact of three levels (0, 8 and 16 Mg ha⁻¹ on a dry matter basis) of wheat (*Triticum aestivum* L.) straw applied annually on SOC concentration and physical properties of a Crosby silt loam soil (fine, mixed, active, mesic Aeric Epiaqualfs). They reported that mulching increased SOC concentration, but did not significantly change cone index and shear strength.

Due to decomposition of mulch material, organic matter increased and enhanced soil nitrogen status. Our results are in line with those of Khurshid *et al.* [42] who conducted an experiment to investigate the methods to minimize erosion hazards, reduce the cost of cultivation and increase crop productivity. A strip of ground flora effective for the control of soil erosion was allowed to grow before it was cut and spread as mulch. The mulch (4.5-5.0 tones ha⁻¹) contributed 75 kg N, 17 kg P and 144 kg K to soil and addition of mulch resulted in significant increase in infiltration rate and soil moisture and decrease in runoff. Similarly, Saroa and Lal [51] conducted a study to assess the role of aggregation to enhancing soil organic carbon (SOC) and total soil nitrogen (TSN) concentration for different mulch rates. Their results showed that mulch rates significantly increased the SOC and TSN concentration in the 0-5 cm soil layer only.

Our results are in line with those of Bhardwaj and Sindhwal [52] who conducted an experiment to investigate the methods to minimize soil erosion hazards, reduce the cost of cultivation and increase the crop productivity. A strip of ground flora for the control of soil erosion was allowed to grow before it was cut and spread as mulch. The mulch (4.5-5.0 tones ha⁻¹) contributed 75 kg N, 17 kg P and 144 kg K to soil.

Our results are similar to findings of Bu *et al.* [53] who reported that surface-applied mulches provide benefits to crop production through improving water, heat energy and nutrient status in soil, preventing soil and water loss, preventing surface soil salinity and controlling weed. Also straw mulch helps to retain soil moisture, reduce temperature, conserve soil, control weeds and increase soil fertility [53].

Due to mulching, water is conserved with in the soil and because of more water availability there was more uptake of nitrogen by crop. Plants uptake the nutrients through water and nitrogen is mobile in soil solution thus if there is more moisture within the soil then more nitrogen uptake by plants.

In the presence of water contents phosphorus availability enhanced due to more diffusion. Our results are in accordance with those of Pevaiz *et al.* [50] who reported that mulch and tillage significantly affected the N and P concentration in maize shoots, while its affect on K concentration was appreciable. Interactive effect of mulch and tillage was statistically significant in case of N (1.423 g kg⁻¹) and P (0.156 g kg⁻¹) concentration but non significant in case of K (1.767 g kg⁻¹) concentration.

. During plants uptake, potassium moves through diffusion, so due to increase in mulch rates, more water is available for movement. Our results are in line with those of Pevaiz *et al.* (2009) who reported that greater plant height (2.59 m) and grain yield (10.6 Mg ha⁻¹) were obtained from M₂ and biological yield (20.7 Mg ha⁻¹) from M₁ in combination with deep tillage. Mulch and tillage significantly affected the N and P concentration in maize shoots, while its affect on K concentration was appreciable. Interactive effect of mulch and tillage was statistically significant in case of N (1.413 g kg⁻¹) and P (0.157 g kg⁻¹) concentration but non significant in case of K (1.768 g kg⁻¹) concentration.

REFERENCES

- [1] MinfaL. Agric. Statistics of Pakistan. Ministry of Food, Agriculture & Livestock, Economic Wing, Islamabad, 2013.
- [2] M. English. Deficit irrigation. Analytical framework. Journal of Irrigation and Drainage, Vol.116, 399-412, 1990.
- [3] H. Zhang, T. Oweis, S. Garabet, M. Pala. Water use efficiency and transpiration efficiency of wheat under rainfed conditions and sup rigation practices, Water Report No. 22, Rome, Italy.2000.
- [4] A. Hess. A microcomputer plemental irrigation in a Mediterranean type environment. Plant Soil, Vol.201, 295-305, 1999.
- [5] FAO. Deficit ir scheduling program for supplementary irrigation. In: Irrigation Scheduling: From theory to practice. Proc. ICID/FAO Workshop, Rome, Italy. 1996
- [6] J. M. De Jager, J.A. Kennedy. Weather-based irrigation scheduling for various farms (commercial and small-scale). In: Irrigation Scheduling: From Theory to Practice. Proceedings ICID/FAO Workshop, Rome, Italy. 1996.
- [7] A. L. van der Westhuizen, J.G. Annandale, N. Benadé. 1996. Encouraging irrigation scheduling: A cost-benefit approach. In: Irrigation Scheduling: From theory to practice. Proc.ICID/FAO Workshop, Rome, Italy. 1996.
- [8] S. R. Reddy. Agronomy of field crops. 2nd Ed. Kalyani Publishers, India. 2006.
- [9] K. R. Paudyal, J.K. Ransom, N.P. Rajbhandari, K. Adhakari, R.V. Gerpacio, P.L. Pingali. 2001. Maize in Nepal: Production systems, constraints and priorities for research. Kathmandu: NARC, Nepal. 2001.
- [10] R. K. Pandey, J.W. Maranville, M.M. Chetima. Deficit irrigation and nitrogen effects on maize in a Sahelian environment II. Shoot growth, nitrogen uptake and water extraction. Agriculture and Water Management, Vol.46, 15-27, 2000.
- [11] C. M. T. Soler, G. Hooenboom, P.C. Sentelhas, A.P. Duarte. 2007. Impact of water stress on maize grown off-season in a subtropical environment, Journal of Agronomy and Crop Sciences, Vol.193, 247- 261, 2007.
- [12] M. M. Reymond, B. Leonardi, A. Charcosset, A. Tardieu. Combining quantitative trait loci analysis and an ecophysiological model to analyses the genetic variability of the response of leaf growth to temperature and water deficit. Plant Physiology, Vol.131, 664-675, 2003.
- [13] H. V. Eck, Effects of water deficits on yield, yield components and water use efficiency of irrigated corn. Agronomy Journal, Vol.78, 1035-1040, 1985.
- [14] S. B. Moser, B. Feil, S. Jampatong, P. Stamp. Effects of preanthesis drought, nitrogen fertilizer rate, and variety on grain yield, yield components, and harvest index of tropical maize. Agriculture and Water Management, Vol.81, 41-58, 2006.
- [15] C. A. Grant, G.A. Peterson, C.A. Campbell. Nutrient considerations for diversified cropping systems in the northern great plains, Agronomy Journal Vol.94, 186-198, 2002.
- [16] H. E. Igbadun, A.K. Tarimo, B.A. Salim, H.F. Mahoo. Evaluation of selected crop water production functions for an irrigated maize crop, Agriculture and Water Management. Vol.94, 1-10, 2007.
- [17] I. J. Lorite, Mateos, F. Orgaz, E. Freres. Assessing deficit irrigation strategies at the level of an irrigation district. Agriculture and Water Management, Vol.91, 51-60, 2007.
- [18] M. A. Ali, A. A. Hoque, Hassan, A. Khair. Effects of deficit irrigation on yield, water productivity and economic return of wheat. Agriculture and Water Management, Vol.92, 151-161, 2007.
- [19] F. R. Lamm, D.H. Rogers, H.L. Manges. Irrigation scheduling with planned soil water depletion. Journal of Irrigation and Drainage. Vol.37, 1491-1497, 1994.
- [20] C. A. Norwood. Water use and yield of limited-irrigated and dryland corn. Soil Science Society of American Journal, Vol.64, 365-370, 2000.
- [21] R. C. Akir. Effect of water stress at different development stages on vegetative and reproductive growth of corn, Field Crops Research, Vol.89, 1-6, 2004.
- [22] E. Fereres, M.A. Soriano. 2006. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany. Vol.58, 147-159, 2006.
- [23] C. L. Acharya, K.M. Hati, K.K. Bandyopadhyay, Hillel, D., C. Rosenzweig, D.S. Pawlson, K.M. Scow, M.J. Sorger, D.L.

- Sparks and J. Hatfield (eds.). *Encyclopedia of Soils in the Environment*, Elsevier Publication, USA. 2005. A. A. Ramalan, C.U.
- [24] Nwokeocha. 2000. Effects of furrow irrigation methods, mulching and soil water suction on the growth, yield and water use efficiency of tomato in the Nigerian Savanna. *Agriculture and Water Management*, Vol.45, 317-330, 2000.
- [25] R. L. Baumhardt, O.R. Jones. Residue management and tillage effects on soil-water storage and grain yield of dryland wheat and sorghum for a clay loam in Texas, *Soil and Tillage Research*, Vol.68, 71-82, 2002.
- [26] S. L. Zhang, L. Lövdahl, H. Grip, Y.A. Tong, X.Y. Yang, Q.J. Wang. Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. *Soil and Tillage Research*, Vol.102, 78-86, 2009.
- [27] R. E. Phillips, R.L. Blevins, G.W. Thamas, W.W. Frye, S.H. Phillips. No-tillage. *Agricultural Science*, Vol.208, 1108-1113, 1980.
- [28] R. H. Hoefler, G.A. Wicks, O.C. Burnside. Grain yields, soil water shortage, weed growth in a winter wheat-corn-fallow rotation, *Agronomy Journal*, Vol.73, 1066-1071, 1981.
- [29] A. R. Chaudhary. *Maize in Pakistan*. Punjab Agricultural Research Coordination Board, Pakistan, 1988.
- [30] R. G. D. Steel, J.H. Torrie, D.A. Dicky. 1997. *Principles and Procedures of Statistics- A Biometrical Approach 3rd Ed.* McGraw Hill Book International Corporation, Singapore, 1997.
- [31] U. S. Salinity Laboratory Staff. *Diagnosis and improvement of saline and alkaline soils*. USDA Hand Book No. USA. 1954
- [32] R. E. Moodie, R.W. Smith, R.A. MacGreery. *Laboratory Manual of Soil Fertility*. State College Washington, USA. 1959.
- [33] A. Walkley, I.A. Black. Estimation of soil organic carbon by chromic acid titration method. *Soil Science*, Vol.37, 29-38, 1934.
- [34] G. R. Blake, K.H. Hartage. Bulk density. In: *Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods*. A. Klute. (Ed.) *Agronomy Monograph No. 9*, USA. 1986.
- [35] S. A. Wajid. Effect of different mulching material and irrigation levels on growth and grain yield of maize. M.Sc. (Hons.) Agri. Thesis. Deptt. Agron. Univ. Agri. Faisalabad. 1990
- [36] A. Oktem. Effects of deficit irrigation on some yield characteristics of sweet corn. *Bangladesh Journal of Botany*, Vol.37, 127-131, 2008.
- [37] M. L. Jackson. *Soil chemical analysis*. Constable and Co. Ltd, London, UK. 1962.
- [38] G. A. Wicks, D.A. Crutchfield, O.C. Burnside. Influence of wheat (*Triticum aestivum*) straw mulch and metolachlor on corn (*Zea mays L.*) growth and yield. *Weed Science*, Vol.42, 141-147, 1994.
- [39] A. Ahmad, Hammad, H.M., F. Azhar, T. Khaliq, A. Wajid, W. Nasim, W. Farhad. Optimizing water and nitrogen requirement in maize (*Zea mays L.*) under semi arid conditions of Pakistan. *Pakistan Journal of Botany*, Vol.43, 2919-292, 2011.
- [40] S. P. Bhardwaj, N.S. Sindhwai. Zero tillage and weed mulch for erosion control on sloping farmland in Doon Valley, *Indian Journal of Soil Conservation*, Vol.26, 81-85, 1998.
- [41] K. Khurshid, M. Iqbal, M.S. Arif, A. Nawaz. Effect of tillage and mulch on soil physical properties and growth of maize, *International Journal of Agriculture and Biology*, Vol.8, 593-596, 2006.
- [42] J. Liu, S.A. Xu, G.Y. Zhou, H.H. Lu. Effect of transplanting multi-cropping spring maize with plastic film mulching on the ecological effect, plant growth and grain yield, *Journal of Hubei Agriculture College*, Vol.2, 100-102, 2002.
- [43] J. A. Tolk, T.A. Hawell, S.R. Evett. Effect of mulch, irrigation and soil type on water use and yield of maize, *Soil and Tillage Research*, Vol.50, 137-147, 1999.
- [44] M. A. Chaudhary, S. Ali, I. Hussain. Effect of different rates of mulches, moisture conservation and yield of corn (*Zea mays L.*) under rain-fed condition in Rawalpindi. *Pakistan Journal of Soil Science*, Vol.9, 32-36, 1994.
- [45] T. Oweis, M. Pala, J. Ryan. Stabilizing rainfed wheat yields with supplemental irrigation and nitrogen in a Mediterranean climate, *Agronomy Journal*, Vol.20, 672-681, 1998.
- [46] S. Gurpeet, S.K. Jalota, S. Yadvinder. Manuring and residue management effects on physical properties of a soil under the rice-wheat system in Punjab, India. *Soil and Tillage Research*, Vol.94, 229-238, 2007.
- [47] C. L. Acharya, C.L, O.C. Kapur. In situ soil moisture conservation for wheat through mulching in previous standing maize, *Indian Journal of Agricultural Sciences*, Vol.63, 462-466, 1993.
- [48] B. H. Canqui, R. Lal. Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage. *Soil Science Society of American Journal*, Vol.71, 1166-1173, 2007.
- [49] M. A. Pervaiz, M. Iqbal, K. Shahzad, A. Hassan. Effect of mulch on soil physical properties and N, P, K concentration in maize (*Zea mays L.*) shoots under two tillage systems, *International Journal of Agricultural Biology*, Vol.11, 119-124, 2009.
- [50] B. S. Ghuman, H.S. Sur. Tillage and residue management effects on soil properties and yields of rainfed maize and wheat in subhumid subtropical climate. *Soil and Tillage Research*, Vol.58, 1-10, 2001.
- [51] G. S. Saroa, R. Lal. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in Central Ohio, *Land Degradation and Development*, Vol.14, 481-493, 2003.
- [52] Y. S. Bu, H.L. Shao, J.C. Wang. Effects of different mulch materials on corn seeding growth and moisture contents and distributions, *Journal of Soil and Water Conservation*, Vol.16, 40-42, 2002.