INTERACTIVE EFFECTS OF MULCH, IRRIGATION AND NITROGEN ON MAIZE (*ZEA MAYS* L.) PRODUCTIVITY

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Abstract. Combined effects of mulch, irrigation and nitrogen application at optimum level played an important role in influencing crop and water use efficiency. A field experiment was conducted during main maize growing season i.e. June to October for two consecutive years i.e. 2020 and 2021 with three N levels i.e. N_1 (100 kg N ha^{-1}), N_2 (125 kg N ha^{-1}) and N_3 (150 kg N ha^{-1}) in main plots, two mulch treatments including without mulch (M1) and with mulch application at the rate of 6 t ha^{-1} (M2) in sub plots and two irrigation regimes {IW/PAN-E ratio 0.6 (I_1) and 0.9 (I_2)} in sub-sub plots. The pooled data of two years indicated that the N31I2 treatment under mulch application resulted in significant increase of plant height, hundred grain weight, crop biomass, grain yield and water use efficiency of maize by 23.1%, 14.3%, 41.3%, 46.9 %, and 31.3%, respectively, over N1I1 un-mulched treatment. The root mass density increased with increase in nitrogen level and more so under mulch application. However, the interactive effects of mulch, irrigation and nitrogen were found to be not significant for most of the plant parameters. The average soil moisture content recorded at the time of maize harvesting was also observed to be higher under mulch application by 26.6% over un-mulched plots.
Keywords: *crop residue, moisture content, biomass, maize growth, root distribution, crop productivity, water use efficiency*

Introduction

In India, maize is the third most important cereal crop after wheat and rice. In Punjab, maize occupied 144.6 thousand ha, with a production of 410.5 thousand tons and mean yield of 3582 kg ha^{-1} during 2019-20 (Anonymous, 2021). The diversification of rice with maize is being emphasized especially in areas with over-exploitation of ground water resources. In the recent past, due to lowering of the water table, increasing cost of pumping in rice and evolution of high yielding cultivars of maize, the area under maize-wheat rotation has shown increasing trends in north-western India. Mulch application along with irrigation and fertilization played an important role in improving land and crop productivity. Straw mulching can improve soil organic matter, reduces evaporation at soil surface, decreases weed growth and enhances crop and water productivity. Mulching reduces water losses through evaporation, mulch forms a blanket over the soil which breaks raindrop impact and reduces crusting and soil erosion losses (Gholami et al., 2013). The application of organic mulches improves soil and water conservation along with increasing yield by up to 50% compared to un-mulched plots (Ranjan et al., 2017). Mulch increases the water storage efficiency of soils. Mulch usage proved to be a significant factor in reducing the evapotranspiration rate throughout the year leading to overall water saving while simultaneously maintaining the same yield level (Sun et al., 2012). Meena et al. (2018), and Arora et al. (2011) concluded that straw mulching improved water productivity. The improvement in the yield was noted to be around 20%. The use of residue mulch also impacts plant canopy and results in higher water status and affects several plant growth parameters such as root proliferation, leaf area index and overall yield. Rani et al. (2019) reported that the

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use of residue mulch at the rate of 5 t ha^{-1} increased soil moisture storage by a degree of 7.7% along with a reduction in evaporative flux by 23.9%, in low rainfall years. Qamar et al. (2015) studied the effect of mulching on crop productivity using different types of mulches (straw, plastic, natural mulch) and concluded that the use of mulch improves yield and yield parameters, the highest yield was seen in plastic mulch plot. Singh and Singh (2018) reported that mulched plots showed higher soil moisture content, soil moisture storage from period of mulch application till harvest, lower maximum soil temperature, weed growth was nearly reduced by half, higher plant height, significantly higher water use efficiency and better yield. Thus, mulch application gave profound results in terms of overall plant growth, alteration of soil temperature and moisture content. Mbagatuzinde (2020) studied the effect of mulching on weed management and maize productivity and observed that using mulch increased maize yield by 27% and 24% in the year 2018 and 2019, respectively. Effect of mulch in combination with sub-surface drip irrigation produced 48% higher grain yield than conventional irrigated and un-mulched control plots.

Nitrogen (N) is a key nutrient in the production of cereal crops. It is a component in many biological compounds playing a noteworthy part in photosynthetic activity and crop yield. Its inadequacy constitutes one of the real yield constraining factors in cereal crops. Irrigation is another most essential agricultural input to achieve the optimum crop yield. Irrigation is a very important agricultural practice in achieving optimum productivity. Water deficit induces a reduction in water potential, leaf elongation, leaf photosynthesis and N metabolism and hence leads to significant influence on plant height, leaf area index (LAI), relative leaf water content (RLWC), chlorophyll content as well as nutrient uptake and hence indirectly affects the crop yield significantly. Motazedian et al. (2019) studied the effect of irrigation on sweet corn growth and grain yield as influenced by irrigation and suggested that when maize was irrigated at 70% (moderate stress) of the water requirement the yield was highest with improved water productivity as compared to 50 (severe stress) and 100% normal irrigation levels, the protein content and sugar content also show similar results. There is a lack of information regarding the interactive effects of N, irrigation regimes and mulching on maize productivity under Punjab conditions. Keeping the above facts in view, a study was conducted to investigate the interactive effect of N, irrigation and mulch on water use efficiency and maize productivity.

Materials and methods

Experimental site and treatment details

The study was conducted during main maize growing season locally named as kharif season i.e. from June to October during two consecutive years i.e. 2020 and 2021 in a sandy loam soil (basic properties mentioned in *Table 1*) at an experimental station (30° 56’ N and 75° 52’ E, latitude and longitudes and 247 meter above the mean sea level) of Punjab Agricultural University, Ludhiana, India. The climate of Ludhiana is semi-arid sub-tropical, with hot-dry summers from April to June, with humid and hot monsoon from July to September, and cold winters from November to January. The average summer and winter temperature undergoes a drastic change. Temperature varied from 40 °C in summer and as low as 0.5 °C during winters and thus, crops suffers from a hot dry spell during summers and frost during winters. The average annual rainfall received in the region is about 759 mm (Kaur et al., 2021). The climatic

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data of crop growing period for both the year is presented in *Table 2*. The research experiment design was a split-split design with three treatments (2 mulch, 2 irrigation and 3 N levels) and three replications, thus forming a total of 36 plots. In main plot treatments: three N levels (N_1:100 kg N ha^{-1}; N_2:120 kg N ha^{-1}; N_3:150 kg N ha^{-1}); in sub plot treatments: two mulch levels i.e. without mulch (M1) and with mulch at the rate of 6 t ha^{-1} (M2) and in sub-sub plot treatments: two irrigation levels based on irrigation water to open pan evaporation ratio (I_1: IW/PAN-E ratio 0.6; I_2: IW/PAN-E ratio 0.9) were studied. The maize was sown on June 10, 2020 and June 7, 2021, while the crop was harvested on September 29, 2020 and September 25, 2021, respectively, for two years. The row to row spacing was maintained at 60 cm, while the plant to plant spacing was maintained at 20 cm. The plot size was 32 m^2. Whole of the phosphorus was applied as basal dose and N was applied as per the treatment. The N was applied in three splits (i.e. at sowing, knee high stage and at pre-tasseling stage). Gravimetric method was used to determine the surface soil moisture content. These samples were oven dried (at 105 °C) till constant weight was obtained and water content was calculated on mass basis. The difference between wet and dry weights of the soil sample is expressed as soil water content on dry weight basis. The volumetric water content can be calculated by multiplying the mass water content with bulk density.

Table 1. *Soil characteristics of experimental site*

Depth (cm)	pH	EC (dS m^{-1})	OC (%)	Sand (%)	Silt (%)	Clay (%)	FC (%)	PWP (%)
0-15	7.6	0.25	0.42	62.3	21.5	16.1	21.7	11.3
15-30	7.3	0.26	0.36	62.7	18.3	19.0	18.4	10.4
30-45	7.5	0.21	0.23	60.4	19.4	20.2	19.7	12.8
45-60	7.4	0.22	0.18	58.6	20.1	21.3	20.6	13.5
60-75	7.4	0.20	0.08	58.0	19.3	22.7	21.5	14.3
75-90	7.1	0.18	0.06	56.4	19.6	24.0	22.9	13.8

Table 2. *Climatic data of the crop growing period*

Month	2020				2021				Normal value*			
	Max temp (°C)	Min temp. (°C)	Evaporation (mm)	Rain-Fall (mm)	Max. temp. (°C)	Min. temp. (°C)	Evaporation (mm)	Rain-Fall (mm)	Max temp. (°C)	Min temp. (°C)	Evapo ration (mm)	Rain-Fall (mm)
May	36.9	22.3	213.0	49.6	36.3	22.6	235.0	37.3	38.7	22.7	310.4	23.2
Jun	37.6	26.5	220.4	9.6	36.3	25.3	208.4	84.8	38.1	25.9	289.7	84.2
July	34.4	26.9	157.6	232.0	34.3	27.8	158.6	271.2	36.3	25.3	208.4	84.8
Aug	33.5	26.8	135.9	145.6	33.7	27.2	135.6	107.6	33.7	27.2	135.6	107.6
Sep	34.5	24.9	123.4	136.0	31.7	25.3	86.7	295.8	31.7	25.3	86.7	295.8

*Normal values are average of 40 years

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Agronomic data and observations

For plant height measurements, ten plants per plot were randomly selected and their height was measured from ground surface to the tip of the plant at 80 days after sowing (DAS). The soil plant analysis development (SPAD value) /chlorophyll content of the leaves were measured at 60 DAS with the SPAD meter. Chlorophyll content in leaves of the intact plants was measured with Minolta- SPAD 502 chlorophyll Meter. The SPAD 502 Chlorophyll Meter is a handheld, a convenient and non-destructive lightweight device developed by the Minolta Camera Co., Japan for calculating the amount of chlorophyll present in the leaves. For each observation third fully opened leaf from apex was selected from ten plants for each treatment by taking the precaution that midrib should not come under the sample area/sensor of the instrument. The mean value of 10 readings was recorded as SPAD value.

The relative leaf water content (RLWC) was measured using the method by Barrs and Weatherley (1962), modified later by Esparza-Rivera et al. (2006) at 70 DAS in maize. Three randomly selected plants were sampled per plot to calculate RLWC. The determination of RLWC was accomplished by cutting two discs leaf^{-1}, from the lower, medium and uppermost leaves, making 6 discs plant^{-1} and 18 discs plot^{-1}. The leaf discs were put in plastic vials and immediately weighed, providing the value of fresh weight (FW). Then the discs were made to soak in de-ionized water for four hours and weighed to achieve the turgid weight (TW). At last, the discs were oven dried at 60 °C until a constant weight is reached (dry weight i.e. DW). The RLWC was determined using following equation:

$$\text{Relative leaf water content (\%)} = \frac{\text{FW-DW}}{\text{TW-DW}} \times 100 \qquad \text{(Eq.1)}$$

The root sampling was done at 90 DAS from 0-15, 15-30, 30-45 and 45-60 cm depths by core sampler with 5 cm diameter. Sampling was done amid the plant rows, nearly 5 cm away from the plant base. The soil-root mass in the core was then collected in plastic nets and washed under running water, carefully separating the roots from soil. The washed roots were retained on the sieves and were cleaned more to eliminate any remaining organic debris, weed roots etc. with the help of forceps. After the roots were thoroughly cleaned, they were gently pressed between filter papers to soak the excess moisture. The root mass density (RMD) was calculated by weighing the oven dried roots on a precision balance.

One hundred grains per plot were manually counted and weighed precisely and presented in grams. The crop biomass was determined at harvesting and the above ground parts of the plants were dried and weighed from net area per plot. Grain yield was recorded in kg from 9 m^2 area per plot and presented in t ha^{-1}. The total water use (TWU) was calculated by adding the irrigation water applied (IW), amount of rainfall (RF) and profile water use (PWU) as given in *Equation 2*. The water use efficiency (kg ha^{-1}mm^{-1}) was measured by dividing the grain yield by the total water use for each treatment as mentioned in *Equation 3*.

$$\text{TWU} = \text{IW} + \text{RF} + \text{PWU} \qquad \text{(Eq.2)}$$

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where, TWU = total water use (mm), IW = total irrigation water applied (mm), RF = total rainfall received (mm), PWU = profile water use (mm).

$$\text{Water use efficiency} = \frac{\text{Grain yield (t ha-1)}}{\text{Total water use (mm)}} \quad \text{(Eq.3)}$$

The data was statistically analyzed using CPCS-I software according to Cochran and Cox (1957) and adapted by Cheema and Singh (1991) and it was compared at significance level of 5%.

Results and Discussion

Plant height

The data pertaining to the impact of mulch, N levels and irrigation regimes on maize plant height is presented in *Table 3*. The maximum plant height (m) in maize was observed in N3I2 (2.92 and 2.95) under mulched condition while the lowest was recorded in N1I1 (2.21 and 2.32) under un-mulched conditions during 2020 and 2021, respectively. Irrespective of nitrogen and irrigation regimes, the mean plant height (m) was observed to be 2.47 and 2.53 at M1 and 2.53 and 2.66 at M2 during 2020 and 2021, respectively. Higher plant height under mulch in comparison to un-mulched condition might be due to greater moisture and nutrient availability in mulched than un-mulched treatment. Mulching improved plant height at all stages in maize, this is because mulch improved the soil ecological environment, decreased soil temperature and increased moisture contents, promoted the growth of maize. Irrespective of N and irrigation regimes, 26.6% more soil moisture was recorded under mulching than control treatment as depicted in *Figure 1*. Maize plant height (m) was significantly increased with N addition and value at N3 (2.76 and 2.74) was found to be significantly higher than that at N1 (2.30 and 2.44) during 2020 and 2021, respectively. However, the effect of N at N3 and N2 levels were at par during both the years. Higher N applications increase the cell division, cell elongation, number and length of internodes, maintains higher auxin and protein level in plants and therefore encourages the shoot growth. Also, higher N levels increased the chlorophyll content which increased the photosynthetic rate and plant height. Irrigation regimes had no significant effect on maize plant height. Irrespective of N level and mulch conditions, maize plant height (m) at I2 (2.61 and 2.71) was higher than under I1 (2.50 and 2.57) during 2020 and 2021, respectively.

SPAD value

The data on SPAD value at 60 days after sowing (DAS) is presented in *Table 3*. The irrigation alone and the interactive effects of mulch, irrigation and nitrogen were found to be non-significant for both the years. However, the maximum SPAD was observed in N3I2 (54.0 and 55.4) under mulched condition which was significantly higher than that of N1I1 (43.2 and 41.7) under un-mulched conditions during 2020 and 2021, respectively. Irrespective of nitrogen and irrigation regimes, the mean SPAD value was observed to be 47.3 and 46.6 at M1 and 50.5 and 52.0 at M2 during 2020 and 2021, respectively. Higher SPAD value under mulch in comparison to un-mulched condition might be due to better utilization of applied N under mulched than un-mulched conditions.

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Table 3. *Effect of mulch, N levels and irrigation regimes on plant height and SPAD value*

Mulch rate	N and Irrigation levels																	
	N1			**N2**			**N3**			**N1**			**N2**			**N3**		
	I1	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**
	2020 (Plant height, m)									**2020 (SPAD value)**								
M1	2.21	2.25	2.23	2.46	2.57	2.51	2.60	2.75	2.68	43.2	44.8	44.0	45.9	49.1	47.5	49.4	51.6	50.5
M2	2.32	2.41	2.37	2.65	2.76	2.71	2.75	2.92	2.83	46.1	48.3	47.2	49.9	52.3	51.1	52.3	54.0	53.2
Mean	2.27	2.33		2.55	2.67		2.67	2.84		44.7	46.6		47.9	50.7		50.9	52.8	
Treatment means	M1= 2.47; M2= 2.53; N1 = 2.30; N2 = 2.61; N3 = 2.76; I1 = 2.50; I2 = 2.61									M1= 47.3; M2= 50.5; N1 = 45.7; N2 = 49.3; N3 = 51.9; I1 = 47.8; I2 = 50.0								
LSD (0.05)	M = 0.12; I = NS; N = 0.24; M×I×N = NS									M = 3.1; I = NS; N = 3.1; M×I×N = NS								
	2021 (Plant height, m)									**2021 (SPAD value)**								
M1	2.32	2.44	2.38	2.53	2.67	2.55	2.63	2.83	2.65	41.7	44.6	43.2	45.6	47.5	46.6	48.8	52.8	50.0
M2	2.46	2.54	2.50	2.72	2.82	2.71	2.75	2.95	2.77	47.4	50.3	48.9	51.0	53.9	52.5	53.7	55.4	54.6
Mean	2.39	2.49		2.63	2.74		2.68	2.89		44.6	47.5		48.3	50.7		51.3	54.1	
Treatment means	M1= 2.53; M2= 2.66; N1 = 2.44; N2 = 2.68; N3 = 2.74; I1 = 2.57; I2 = 2.71									M1= 46.6; M2= 52.0; N1 = 46.1; N2 = 49.5; N3 = 52.7; I1 = 48.1; I2 = 50.8								
LSD (0.05)	M = 0.15; I = NS; N = 0.16; M×I×N = NS									M = 3.7; I = NS; N = 4.2; M×I×N = NS								

M1 = Un-mulched; M2 = Mulched; I1 = IW/PAN-E = 0.6; I2 = IW/PAN-E = 0.9; N_1 = 100 kg N ha^{-1} N_2 = 125 kg N ha^{-1}; N_3 (150 kg N ha^{-1})

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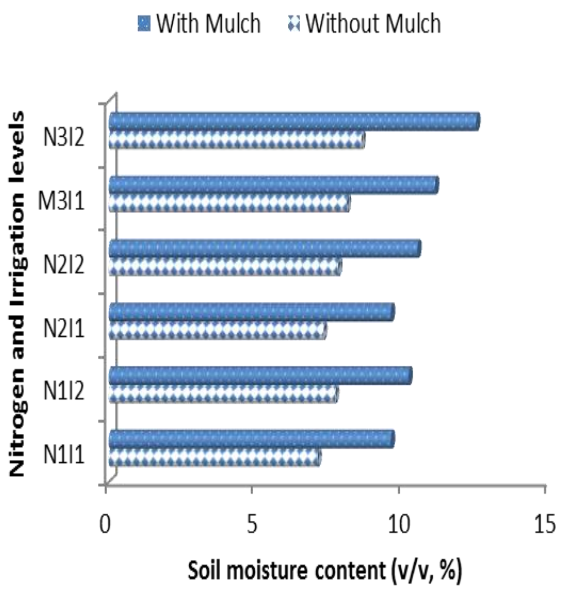

Figure 1. *Soil moisture variation at 0-15 cm depth as affected by nitrogen and irrigation regimes under mulched and un-mulch conditions*

SPAD value was found to be significantly increased with N addition and value at N3 (51.9 and 52.7) was found to be significantly higher than that at N1 (45.7 and 46.1) during 2020 and 2021, respectively. However, the effect of N at N3 and N2 levels were at par during both the years. Higher N levels increased the chlorophyll content which increased the photosynthetic rate. Irrigation regimes had no significant effect on SPAD value. Irrespective of N level and mulch conditions, maize SPAD value at I2 (50.0 and 50.8) was not significantly higher than under I1 (47.8 and 48.1) during 2020 and 2021, respectively. The higher dose of N might have produced greater values of leaf SPAD as N is considered an essential constituent of chlorophyll as reported by Schlemmer et al. (2005), Singh (2010) and Parija (2011) in maize. Munne-Bosch and Alegre (2000) observed that the SPAD value decreased with decreasing irrigation level and this decrease was correlated with relative water content in leaves. Chlorophyll decline is a negative outcome of water stress.

Relative leaf water content (RLWC)

The data regarding the effect of mulch practice and irrigation regimes on relative leaf water content (RLWC) is presented in *Table 4*. Maize RLWC (%) was found to be statistically at par under mulched (86.5 and 85.6) and un-mulched (84.4 and 83.1) treatments during 2020 and 2021, respectively. Irrespective of irrigation and mulch conditions, the RLWC increases with increase in N level and found to be 87.9% and 86.0% at N3 which was significantly higher than that under N1 82.3% and 82.2% during 2020 and 2021, respectively. The interaction effects of mulch, N and irrigation regimes were found to be non-significant. Increase in RLWC under mulching may be due to greater water extraction and uptake by plants owing to deeper and extensive rooting. Relatively more RLWC was reported under mulching may be due to greater moisture availability (Martorano et al., 2009).

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Table 4. *Effect of mulch, N levels and irrigation regimes on relative leaf water content (RLWC) and hundred grain weight*

Mulch rate	N and Irrigation levels																	
	N1			N2			N3			N1			N2			N3		
	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean	I1	I2	Mean
	2020 (RLWC, %)									2020 (Hundred grain weight, g)								
M1	79.3	82.4	81.4	84.6	85.3	85.0	86.5	87.1	86.8	37.0	37.8	37.4	39.5	40.2	39.8	40.2	41.1	40.7
M2	82.6	84.7	83.9	85.7	87.9	86.8	88.2	89.6	88.9	37.6	38.1	37.8	40.5	41.1	41.0	41.6	43.1	42.4
Mean	80.9	83.6		85.2	86.6		87.4	88.4		37.3	37.9		40.0	40.9		40.9	42.1	
Treatment means	M1= 84.4; M2= 86.5; N1 = 82.3; N2 = 85.9; N3 = 87.9; I1 = 84.5; I2 = 86.2									M1=39.3; M2= 40.4; N1 = 37.6; N2 = 40.5; N3 = 41.5; I1 = 39.4; I2 = 40.3								
LSD (0.05)	M = 2.4; I = NS; N = 2.7; M×I×N = NS									M = 0.7; I = NS; N = 1.8; M×I×N = NS								
	2021 (RLWC, %)									2021 (Hundred grain weight, g)								
M1	80.7	81.9	81.3	82.5	83.8	83.2	84.1	85.6	84.9	37.5	39.1	38.2	39.1	42.0	40.5	39.5	42.9	41.2
M2	82.6	83.5	83.1	85.6	87.4	86.5	86.7	87.4	87.1	38.9	40.5	39.7	41.3	42.9	42.1	43.1	43.8	43.4
Mean	81.7	82.7		84.1	85.6		85.4	86.5		38.2	39.8		40.2	42.4		41.3	43.3	
Treatment means	M1= 83.1; M2= 85.6; N1 = 82.2; N2 = 84.9; N3 = 86.0; I1 = 83.7; I2 = 84.9									M1= 40.0; M2= 41.7; N1 = 39.0; N2 = 41.3; N3 = 42.3; I1 = 39.9; I2 = 41.8								
LSD (0.05)	M = 2.1; I = NS; N = 2.9; M×I×N = NS									M = 1.4; I = NS; N = 1.7; M×I×N = NS								

M1 = Un-mulched; M2 = Mulched; I1 = IW/PAN-E = 0.6; I2 = IW/PAN-E = 0.9; N_1 = 100 kg N ha^{-1}; N_2 = 125 kg N ha^{-1}; N_3 (150 kg N ha^{-1})

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With increase in irrigation level RLWC increased. Irrespective of N level and mulch conditions, the RLWC (%) at I2 (86.2 and 84.9) was not significantly higher as compared to I1 (84.5 and 83.7) during 2020 and 2021, respectively. Jayasankar and Ramakrishnyya (1993) in rice and Kumar (2005) in maize also reported increased RLWC with increase in irrigation, owing to higher uptake of water.

Hundred grain weight (HGW)

The data presented in *Table 4* represents the effect of mulch practice, N levels and irrigation regimes on maize HGW. The HGW increased with increase in N levels. The HGW (g) at N3 (41.5 and 42.3) was found to be significantly higher than that at N1 (37.6 and 39.0) during 2020 and 2021, respectively. This might be attributed to proper physiological functioning of N in tissue development, cell division, enhanced plant growth and thereby increased HGW. Low N supply decreases maize HGW due to decreased supply of carbohydrates and amino compounds to the grain. The mulching practice significantly affected HGW. Irrespective of irrigation and nitrogen levels, the HGW (g) under un-mulch treatment was 39.3 and 40.0, while the same was 40.4 and 41.7 under mulch during 2020 and 2021, respectively. Irrigation regimes did not significantly affect HGW, however, higher HGW (g) was observed in I2 (40.3 and 41.8) than in I1 (39.4 and 39.9) during 2020 and 2021, respectively. Increased translocation of photosynthates to the grain under I2 might be responsible for increasing the grain mass.

Root mass density (RMD)

The *Figure 2* depicts the effect of mulch, irrigation and N on RMD of maize. The RMD sharply declined with increase in the soil depth. Mulching increased root proliferation as well as the depth to which roots penetrated and also increased the biomass of deeper root. Higher RMD may also be because of reduction in soil strength and soil bulk density under mulching and also due to improved soil moisture storage. The pooled data of two years showed that RMD (μg cm^{-3}) at 0-15, 15-30, 30-45 and 45-60 cm depths was 1.38, 0.43 0.20 and 0.07 under un mulched treatment and 1.52, 0.55, 0.32 and 0.09 under mulched conditions. Martinez et al. (2008) reported higher RMD under mulch as compared to un-mulched conditions because of improved soil structure, greater availability of water and increased soil organic carbon content due to continuous crop resid1ues addition. The *Figure 2* presents data on effect of N levels on RMD in maize. Irrespective of much, irrigation and depth, higher value of RMD (μg cm^{-3}) was found under N3 (0.71), followed by N2 (0.55) and least under N1 (0.46). Increase in maize RMD with increase in N levels might be the result of favourable effect of N on plant biomass that also encouraged root growth (Singh, 2010).

Crop biomass

The data pertaining to the effect of mulching, N levels and irrigation regimes on maize biomass is presented in *Table 5*. Mulching showed significant impact on maize biomass yield. Irrespective of N and irrigation regimes, the increase in maize biomass yield was 7.5% and 11.4% during 2020 and 2021, respectively over un-mulched plots. The reason for higher value of plant biomass under mulching could be improved soil physical environment and reduced soil mechanical resistance to root penetration, because above ground biomass of plants is enhanced by a well-developed root system. More biomass under mulching might also be ascribed to taller plants and greater dry

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matter production. The greater values of plant biomass were also reported by Imran et al. (2015) in maize because of efficient utilization of the water and nutrients by plants under mulching. Similarly, the N level showed significant impact on biomass yield with increase in yield up to 29.5% and 28.6% in N3 over N1 during 2020 and 2021, respectively. Irrespective of mulch treatment, the maximum maize biomass yield (t ha^{-1}) was recorded under N3I2 (13.5) while the minimum was recorded under N1I1 i.e. 9.1 for pooled data of two years. Irrespective of irrigation treatments, the maize biomass (t ha^{-1}) was significantly higher under N3 (13.3) than N1 (9.4) but at par with N2 (11.8) for pooled data of two years. The increment in N levels lead to greater biomass accumulation, owing to greater photosynthesis, contributed by higher leaf area and greater N uptake resulting in the accumulation of significantly higher dry matter. However, irrigation regimes did not show significant influence on biomass yield of maize. Over pooled data of two years, there was only 4.2% increase in maize biomass yield under I2 as compared to I1 irrigation regime. In general, increase in irrigation level increased the biomass yield (Saren et al., 2004).

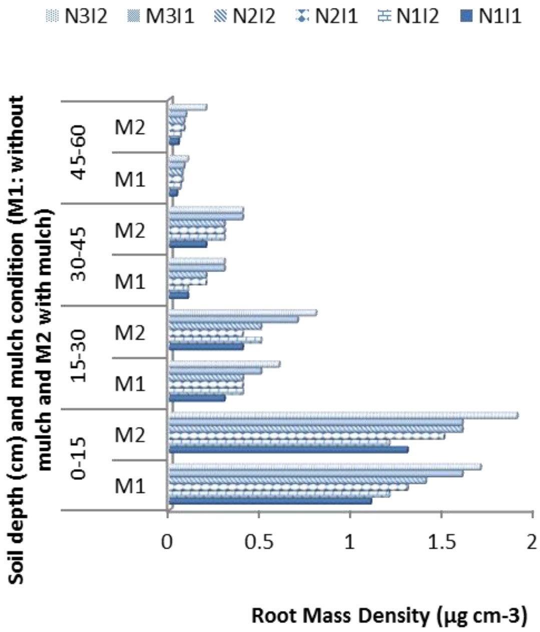

Figure 2. *Root mass density (µg cm^{-3}) as affected by nitrogen and irrigation regimes under mulched (M1) and un-mulched (M2) conditions*

Grain yield and water productivity

The *Table 5* illustrates the effect of N levels, mulch practice and irrigation regimes on maize grain yield. Significantly higher maize grain yield (t ha^{-1}) was observed under mulching in N3I2 (6.4 and 6.6) as compared to un-mulched N1I1 (3.4 and 3.5) treatment during 2020 and 2021, respectively. The reason behind higher yield under mulch was improved root proliferation in deeper layers and greater water and nutrient uptake. Irrigation regimes did not show significant effect on maize grain yield. However, higher grain yield (t ha^{-1}) was observed in I2 (5.4 and 5.6) and lower value under I1 (5.0 and 5.1) during 2020 and 2021, respectively.

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Table 5. *Effect of mulch, N levels and irrigation regimes on biomass yield and maize grain yield*

Mulch rate	N and Irrigation levels																	
	N1			**N2**			**N3**			**N1**			**N2**			**N3**		
	I1	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**	**I1**	**I2**	**Mean**
	2020 (Biomass yield, t/ha)									**2020 (Grain yield, t/ha)**								
M1	8.5	8.8	8.7	11.6	12.2	11.9	12.5	12.9	12.7	3.4	3.9	3.7	5.0	5.1	5.1	5.5	5.8	5.7
M2	9.4	10.0	9.7	12.0	12.9	12.5	13.2	14.1	13.7	4.0	4.6	4.4	5.6	5.8	5.7	6.1	6.4	6.3
Mean	9.0	9.5		11.8	12.4		12.9	13.5		3.7	4.3		5.3	5.4		5.8	6.1	
Treatment means	M1= 11.1; M2= 12.0; N1 = 9.3; N2 = 12.1; N3 = 13.2; I1 = 11.2; I2 = 11.8									M1= 4.8; M2= 5.5; N1 = 4.0; N2 = 5.3; N3 = 6.0; I1 = 5.0; I2 = 5.4								
LSD (0.05)	M = 0.7; I = NS; N = 2.3; M×I×N = NS									M = 0.3; I = NS; N = 0.8; M×I×N = 0.07								
	2021 (Biomass yield, t/ha)									**2021 (Grain yield, t/ha)**								
M1	8.4	8.9	9.7	10.4	10.6	10.5	12.2	12.5	12.4	3.5	4.2	3.7	5.2	5.6	5.3	5.7	6.1	5.9
M2	9.9	10.7	10.3	11.7	13.2	12.5	13.8	14.6	14.2	4.3	5.0	4.5	5.6	6.0	5.7	6.2	6.6	6.4
Mean	9.2	9.8		11.1	11.9		13.0	13.6		3.9	4.6		5.4	5.8		6.1	6.4	
Treatment means	M1= 10.9; M2= 12.3; N1 = 9.5; N2 = 11.5; N3 = 13.3; I1 = 11.4; I2 = 11.8									M1= 5.0; M2= 5.5; N1 = 4.2; N2 = 5.6; N3 = 6.2; I1 = 5.1; I2 = 5..6								
LSD (0.05)	M = 0.6; I = NS; N = 2.1; M×I×N = NS									M = 0.3; I = NS; N = 0.6; M×I×N = NS								

M1 = Un-mulched; M2= Mulched; I1= IW/PAN-E =0.6; I2= IW/PAN-E =0.9; N_1 = 100 kg N ha^{-1}; N_2 =125 kg N ha^{-1}; N_3 (150 kg N ha^{-1})

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The grain yield significantly increased with increase in N levels. Maize grain yield (t ha^{-1}) at N3 (6.0 and 6.2) was significantly higher in comparison to N1 (4.0 and 4.2) during 2020 and 2021, respectively. Higher yield with increase in N doses was due to higher dry matter accumulation in N3. There was a strong synergistic effect of irrigation and N on grain yields. Better root growth and better moisture extraction under mulch helped the crop to first develop adequate source (as reflected by high above-ground biomass accumulation) and then development of better sink size and capacity (higher grain mass as compared to un-mulched conditions). The effect of N and irrigation levels under mulch conditions on maize water use efficiency (WUE) is depicted in *Figure 3*. The N levels had a significant effect on maize WUE and it increased with increase in N levels, due to increased grain yield at higher N level. In case of mulching practice N3I2 had the maximum WUE and least under N1I1 un-mulched conditions. The WUE (t/ha-mm) was 10.5 under I2 irrigation regime, while it was 9.8 under I1 regime. Irrespective of N and irrigation levels the WUE (t/ ha-mm) varied significantly with mulching and was 9.8 under un-mulched condition and 10.6 under mulch application. Similarly, N showed significant effect as the pooled data for two years indicate WUE (t/ha-mm) of 11.4, 9.9 and 9.2 under N3, N2 and N1 levels, respectively. Halvorson et al. (2006) also reported that the WUE can be increased by N application.

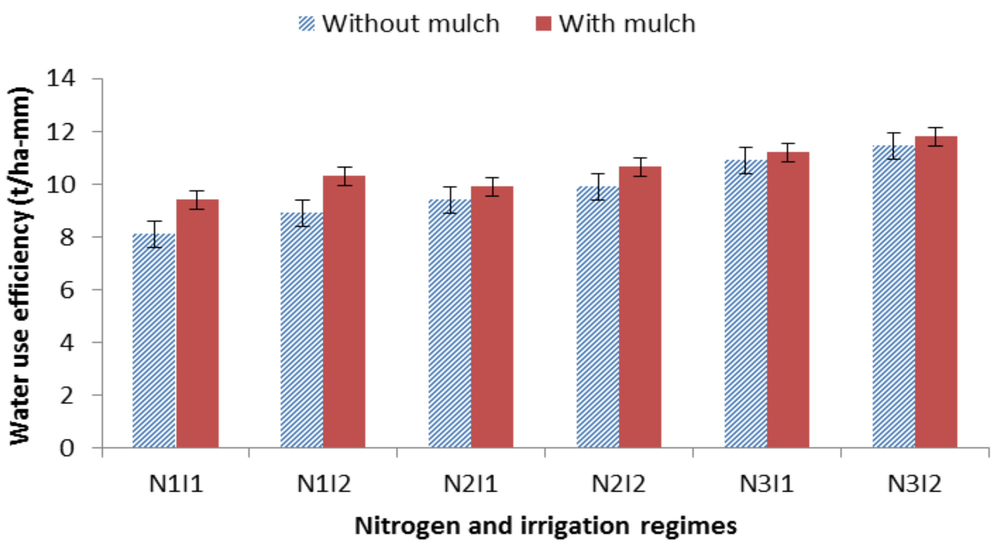

Figure 3. *Water use efficiency of maize (pooled data of 2 year) as affected by nitrogen and irrigation regimes under mulch and un-mulched conditions. (Bars showed standard error values)*

Conclusion

It is thus, concluded from the study that under mulch conditions even with lesser application of N i.e. @ 125 kg N ha^{-1} equal yield could be achieved to that with higher application of N @ 150 kg N ha^{-1} under un-mulched condition. Mulching thus, helped in saving nearly 20% of the nitrogen. All other plant parameters including height, root mass density, hundred grain weight and crop biomass also responded significantly more under mulching. For attaining maximum maize productivity of maize, the mulching practice along with nitrogen level of 125 kg N ha^{-1} and irrigation regime of IW/CPE

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ratio 0.9 needs to be practised in northwest India. However, there is need to conduct future studies on interactive effects of mulch, irrigation and nitrogen application under different soil textures and surface and sub-surface fertigation systems.

REFERENCES

[1] Anonymous (2021): Packages of practices for kharif crops. – Punjab Agricultural University, Ludhiana, pp. 28-42.

[2] Arora, V. K., Singh, C. B., Sidhu, A. S., Thind, S. S. (2011): Irrigation, tillage and mulching effects on soyabean yield and water productivity in relation to soil texture. – Agricultural Water Management 98: 563-568.

[3] Barrs, H. D., Weatherley, P. E. (1962): A re-examination of the relative turgidity technique for estimating water deficits in leaves. – Australian Journal of Biological Science 15: 413-428.

[4] Cheema, H. S., Singh, B. (1991): Software statistical package CPCS-1. – Department of Statistics, Punjab Agricultural University, Ludhiana.

[5] Cochran, W. G., Cox, G. M. (1957): Experimental designs. – John Wiley & Sons, New York, pp. 35-40.

[6] Esparza-Rivera, J. R., Stone, M. B., Stuchnoff, C., Pilon-Smits, E., Kendall, P. A. (2006): Effects of ascorbic acid applied by two hydrocooling methods on physical and chemical properties of green leaf stored at 5°C. – Journal of Food Science 71: 270-76.

[7] Gholami, L., Sadeghi, S. H., Homaee, M. (2013): Straw mulching effect on splash erosion, runoff and sediment yield from eroded plots. – Soil Science Society of America Journal 77: 268-278.

[8] Halvorson, A. D., Mosier, A. R., Reule, C. A., Bausch, W. C. (2006): Nitrogen and tillage effects on irrigated continuous corn yields. – Agronomy Journal 98: 63-71.

[9] Imran, S., Arif, M., Khan, M. A., Shah, W. (2015): Effect of nitrogen levels and plant population on yield and yield components of maize. – Advanced Crop Science and Technology 3: 170-78.

[10] Jayasankar, R., Ramakrishnayya, G. (1993): Effect of partial submergence on the leaf characteristics of rice cultivars. – Oryza 30: 265-66.

[11] Kaur, J., Sandhu, S. S., Sharma, S. (2021): Yield response of wheat grown under periodic heat stress imposed by using mini heat tents. – Journal of Agronomy and Crop Science 207: 285-303.

[12] Kumar, D. (2005): Breeding for drought resistance. – In: Ashraf, M., Harris, P. J. C. (eds.) Abiotic stresses: Plant Resistance through Breeding and Molecular Approaches. The Haworth Press, New York, pp. 145-175.

[13] Martinez, E., Fuentes, J. P., Silva, P., Valle, S., Acevedo, E. (2008): Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. – Soil and Tillage Research 99(2): 232-244.

[14] Martorano, L. G., Bergamaschi, H., Dalmago, G. A., Faria, R. T., Mielniczuk, D. J., Comiram, F. (2009): Indicadores da condicao hidrica do solo com soja em platino diretone prepare convencional. – Revista Brasile Engen Ambien 13: 397-405.

[15] Mbagatuzinde, K. (2020): Weed management in maize (*Zea mays* L.) through integration of micro irrigation, mulch and herbicide. – M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India.

[16] Meena, R., Tripathi, S. C., Sharma, R. K., Chhokar, R. S., Chander, S., Jha, A. (2018): Role of precision irrigation scheduling and residue-retention practices on water-use efficiency and wheat (*Triticum aestivum* L.) yield in north-western plains of India. – Indian Journal of Agronomy 63: 186-196.

[17] Motazedian, A., Kazemeini, S. A., Bahrani, M. J. (2019): Sweet corn growth and grain yield as influenced by irrigation and wheat residue management. – Agricultural Water Management 224: 105748.
[18] Munne-Bosch, S., Alegre, L. (2000): Changes in carotenoids, tocopherols and diterpenes during drought and recovery, and the biological significance of chlorophyll loss in Rosmarinus officinalis plants. – Planta 210: 925-931.
[19] Parija, B. (2011): Performance of kharif maize under different levels of farmyard manure and nitrogen. – M.Sc. Thesis, Department of Agronomy, Punjab Agricultural University, Ludhiana, India.
[20] Qamar, R., Ehsanullah, Saqib, M., Javeed, H. M. R., Rehman, A., Atiqueur-Rehman (2015): Influence of tillage and mulch on soil physical properties and wheat yield in rice-wheat system. – West African Journal of Applied Ecology 23: 21-38.
[21] Rani, A., Bandyopadhyay, K. K., Krishnan, P., Sarangi, A., Datta, S. P. (2019): Effect of tillage, residue and nitrogen management on soil water dynamics and water productivity of wheat in an Inceptisol. – Journal of Indian Society of Soil Science 67: 44-54.
[22] Ranjan, P., Patle, G. T., Prem, M., Solanke, K. R. (2017): Organic mulching-A water saving technique to increase the production of fruits and vegetables. – Current Agricultural Research Journal 5: 371-380.
[23] Saren, B. K., Day, S., Mandel, D. (2004): Effect of irrigation and sulphur on yield attributes, productivity and consumptive use efficiency of wheat (*Triticum aestivum* L.). – Indian Journal of Agricultural Sciences 74: 257-261.
[24] Schlemmer, M. R., Francis, D. D., Shanahan, J. F., Schepers, J. S. (2005): Remotely measuring chlorophyll content in corn leaves with differing nitrogen levels and relative water content. – Agronomy Journal 97: 106-112.
[25] Singh, G. (2010): Irrigation and nitrogen needs of august sown hybrid maize. – M.Sc. Thesis, Department of Agronomy, Punjab Agricultural University, Ludhiana, India.
[26] Singh, G., Singh, C. B. (2018): Residue mulch and irrigation effects on onion productivity in a subtropical environment. – International Journal of Agricultural Research and Review 6: 701-711.
[27] Sun, H., Shao, L., Liu, X., Miao, W., Chen, S., Zhang, X. (2012): Determination of water consumption and the water saving potential of three mulching methods in a jujube orchard. – European Journal of Agronomy 43: 87-95.

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