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Research Paper

Soil water balance and response of spring maize (*Zea mays*) to mulching and differential irrigation in Punjab

K.B. SINGH[1], S.K JALOTA[2] AND R.K. GUPTA[3]

Punjab Agricultural University, Ludhiana, Punjab 141 004

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ABSTRACT

A field experiment was conducted during 2007 and 2008 at Ludhiana, to study the effect of paddy straw mulching (0 and 6 t/ha) and irrigation regimes (irrigation water/open pan evaporation ratio 1.2 ($I_{1.2}$), 0.9 ($I_{0.9}$) and 0.6 ($I_{0.6}$)) on performance of spring maize (*Zea mays* L.) Mulching significantly increased mean seasonal soil-moisture storage and transpiration during both years with overall pooled values of 122.2 and 38.7 mm for soil-moisture storage and 566.5 and 549.2 mm for seasonal transpiration under mulching and no mulching treatments respectively. Mean seasonal soil-moisture storage and transpiration were significantly more under $I_{1.2}$ and $I_{0.9}$ treatments than $I_{0.6}$ during both years. However, during both years mulching significantly reduced mean seasonal soil evaporation compared with no-mulching. Mulching and irrigation significantly increased leaf-area index (LAI) of spring maize. During both seasons, mulching significantly increased grain yield, yield attributes and water-use efficiency (WUE) of spring maize over no-mulching with overall mean grain yield values of 4.96 and 4.22 t/ha and WUE values of 8.76 and 7.64 kg/ha/mm under mulching and no-mulching treatments respectively. Significantly higher grain yield and WUE were also observed under $I_{1.2}$ over $I_{0.6}$ irrigation treatment.

Key words : Evapo-transpiration, Grain yield, Soil-moisture storage, Spring maize, Water-use efficiency

In semi-arid sub-tropical regions of Punjab, spring maize is gaining popularity among the farmers after potato crop. Spring maize having high irrigation requirement is sensitive to water stress. The most critical period of maize growth during which water stress affects yield, is between 2 weeks before and 2–3 weeks after silking. Application of irrigation during the moisture-sensitive period of flowering and yield-formation stages, yet allowing moderate stress at vegetative and maturity stages results in the optimum yield with maximum water-use efficiency and water economy (Shaozhong *et al*., 2000). Trooijen *et al*. (1999) found water use efficiency of maize to be greater with limited irrigation, but full irrigation of maize was more profitable than limited one. Therefore, spring maize producers need to adopt management practices which enhance water productivity. In Punjab, during spring season, soil water evaporation is more due to high temperature and less rainfall. Mulching is a viable option for reducing high soil evaporative losses and increased crop yield through improvement in root growth due to conservation of soil moisture and decrease in soil temperature (Chaudhary and Prihar, 1974). The response of mulching on crop yields varies with irrigation and season (Gill *et al*., 1996; Tolk *et al*., 1999). Hence, there is an urgent need to quantify field water-balance components of spring maize in highly evaporative demand periods under changing climatic conditions. Since a meager information is available with respect to interactive effects of mulching and irrigation on field water balance, an experiment was conducted to study the effects of mulching and irrigation regimes on water-balance components, yield and water use of spring maize.

MATERIALS AND METHODS

The field experiment was conducted at research farm, Department of Soil Science, Punjab Agricultural University, Ludhiana (30°56' N, 75˚52' E, 247 m above seas-level) during 2007 and 2008. The soil was deep alluvial loamy sand (mixed hyperthermic, Typic Ustipsamment). In 1.8 m profile, soil retained 440 and 149 mm water at field capacity and wilting point respectively. Profile bulk density varied from 1.54 to 1.74 g/cm^3. The crop received 123 and 218 mm rainfall during 2007 and 2008 with corresponding open pan evaporation of 820 and 722 mm respectively. Treatments comprises 2 rates, viz. 0 (M_0) and 6 (M_6) t/ha of paddy residue mulch and 3 irrigation re-

[1]**Corresponding author Email:** kbsingh@pau.edu
[1]Soil Physicist, Department of Soil and Water Engineering; [2]Emritus Scientist, [3]Senior Soil Chemist, Department of Soil Science

gimes (irrigation water/open pan-evaporation ratio of 1.2 ($I_{1.2}$), 0.9 ($I_{0.9}$) and 0.6 ($I_{0.6}$). The paddy residue @ 6 t/ha was spread between the rows after sowing of maize as mulch. The schedule of irrigations, sowing, harvesting and rainfall are given in Table 1. The treatments were replicated thrice in a split-plot design with mulching in main and irrigation in sub-plots of size 5 m × 9 m. Buffers were kept on the sides of each sub-plot to avoid seepage. Irrigation water was measured using Parshall flume. After a pre-sowing irrigation, the field was prepared by conventional tillage. Spring maize (cv. 'Punjab Maize Hybrid 1') was dibbled at 22 cm in 60-cm-spaced rows. Nitrogen was applied @ 125 kg N/ha as urea in 3 equal splits-at seeding, knee height and tasselling. During both the seasons, crop was fertilized by drilling 25 kg P/ha as single superphosphate, 25 kg K/ha as muriate of potash and 5 kg Zn/ha as zinc sulphate at the time of sowing. Soil water content was determined gravimetrically in 0–15, 15–30, 30–60, 60–90, 90–120, 120–150 and 150–180 cm depths and was multiplied with corresponding soil layer bulk density to calculate volumetric moisture content which was further multiplied with depth of layer to calculate soil-water storage. Actual crop evapotranspiration (ET_a) was estimated using the soil water balance equation as:

$$ET_a = I + P - R - D \pm \Delta SW$$

where I represents the irrigation water, P the precipitation, R the surface runoff, D the deep drainage and ΔSW the change in soil-water storage. Runoff (R) was absent as sufficient dikes were maintained. Deep drainage was zero when soil profile moisture storage was less than field-capacity storage. When the soil-moisture storage exceeded the field-capacity storage after irrigation or rainfall then deep drainage was calculated as the difference between the field capacity storage and soil moisture storage plus irrigation/rainfall. The actual evapotranspiration (ET_a) under mulching was partitioned into soil evaporation (E_s) and plant transpiration (T_p) as:

$$\text{Soil evaporation } (E_s) = ET_a \times e^{-\alpha\ LAI}$$

$$\text{Plant transpiration } (T_p) = ETa - E_s$$

where α is extinction coefficient of radiation, the value of which was set to 0.7 as referenced by Scopel *et al.* (2004) and LAI is the leaf area index at different days after sowing.

The following equation of Maraux and Lafolie (1998) was used to estimate LAI during crop growth and senescence:

$$LAI(t) = LAI_{max}\left(\frac{1}{1 + e^{a_1(t - t_{inf})}} - e^{a_2(t - t_{end})}\right)$$

where LAI_{max} is the maximum LAI value observed, a_1 and a_2 are shape factors controlling the growing and drying rates, t_{inf} is time at which the maximum growing rate is reached (inflexion point) and t_{end} is the time of complete senescence. The terms LAI_{max}, t_{inf} and t_{end} were measured and a_1 and a_2 were fitted. To get the soil evaporation from the unmulched treatment, difference in ET_a of mulched and unmulched was added to soil evaporation calculated from LAI of the unmulched and ET_a of the mulched treatment at same irrigation level. Leaf area of 5 random plants was calculated by multiplying leaf length with maximum leaf width and 0.75 (a locally calibrated factor). Leaf-area index was calculated by dividing sum total of leaf area of 5 plants with 0.66 m^2 area. Plants from a net 30 m^2 were harvested to determine yields at 15% moisture content. Water-use efficiency (WUE) for grains was calculated by dividing grain yield with total seasonal actual transpiration. The statistical significance of the treatment effects on different parameters was inferred from least significant difference (LSD) at 5% level of significance using analysis of variance for split-plot design.

RESULTS AND DISCUSSION

Field water balance components

Rainfall and irrigation: During 2008, 95 mm more rainfall was received compared to 2007. During both years, 675, 600 and 450 mm irrigation water was applied in $I_{1.2}$, $I_{0.9}$ and $I_{0.6}$ irrigation regimes, respectively, in both mulching treatments. During 2007 and 2008, up to 70 days after sowing rainfall received was 62.2 and 23.1% and then from 70 to 110 days after sowing it was 5 and 31.9% respectively. During senescence stage of spring maize (110 days after sowing) 32.8 and 45% rainfall was received during the experimental years 2007 and 2008 respectively.

Seasonal transpiration: Seasonal transpiration was significantly higher under mulched treatments than unmulched during both years (Table 2). Pooled analysis of 2 years data revealed that mean seasonal transpiration (MST) of 566.5 and 549.2 mm was recorded under mulched and no-mulched soil respectively. Mean seasonal transpiration was significantly more under $I_{1.2}$ and $I_{0.9}$ compared to $I_{0.6}$ during both years under study. However, the differences in MST between $I_{1.2}$ and $I_{0.9}$ treatments were significant only during 2008 and also when pooled for both years. Significant differences in MST were also observed in 2007 and 2008 with respective mean values 544.3 and 571.3 mm. Significant interaction was also observed between mulching and irrigation, which indicates that more frequent irrigation and mulching increased transpiration because of increased soil-moisture storage (Tolk *et al.*, 1999; Li *et al*., 2013).

Seasonal soil evaporation: Mulching significantly reduced mean seasonal soil evaporation (MSE) compared with no mulching (Table 2) for both years. The reduction in mean seasonal soil evaporation (MSE) with mulching was 64.0 and 75.9 % during 2007 and 2008 respectively. Pooled data showed 68.2% reduction in MSE with mulching compared with no mulching. Non-significant differences in MSE were observed in all irrigation treatments during both years. However, significantly less (49.2%) MSE was obtained in 2008 compared to 2007. Reduction in soil evaporation with mulching was also observed by Li *et al.* (2013).

Seasonal soil water storage: The difference in initial (at sowing) and final (at harvesting) soil moisture storage was compared for different treatments (Table 2). During 2007, it was observed that under mulching there was net gain in the soil-moisture storage while under no mulching there was net loss in soil-moisture storage (SMS), indicating significant increase in SMS under mulching because of reduction in soil evaporation. Similarly under $I_{1.2}$ and $I_{0.9}$ treatment there was net gain in SMS and under $I_{0.6}$ there was net loss in SMS from the initial SMS because of extraction of SMS in less irrigation treatment. However, during 2008 there was net gain in SMS compared with initial values due to relatively high rainfall. Mulching significantly increased mean SMS during both years with overall pooled values of 122.2 and 38.7 mm under mulching and no mulching respectively. Significantly higher mean seasonal SMS was observed in $I_{1.2}$ compared to $I_{0.9}$ and $I_{0.6}$ irrigation regimes during both years. Seasonal soil-moisture storage was also significantly high in $I_{0.9}$ compared to $I_{0.6}$ irrigation regime during both years. The increase in soil-moisture storage with mulching was due to reduction in soil evaporation (Todd *et al.,* 1991). The differences in soil-moisture storage in different irrigations were due to application of variable amount of irrigations.

Seasonal drainage: During 2007, no seasonal drainage was observed under any treatment (Table 2). During 2008, drainage was observed only under frequently irrigated ($I_{1.2}$) mulched treatment due to increase in soil-moisture storage. Scopel *et al.* (2004) also reported that advantage of water conservation by surface mulch is partly offset by increased drainage losses. No drainage was observed in other treatments during 2008. Therefore differences in

Table 1. Details of seeding, harvesting, irrigation and rainfall during 2 cropping seasons

Year, sowing and harvesting	Irrigation regimes	Irrigation sequence (days after seeding)									Irrigation (mm)	Rainfall (mm)
		I	II	III	IV	V	VI	VII	VIII	IX		
2007 21 February 29 June	$I_{1.2}$	34	43	51	63	70	76	83	89	100	675	123
	$I_{0.9}$	34	43	58	68	76	86	94	102		600	
	$I_{0.6}$	34	43	63	76	89	100				450	
2008 13 February 10 June	$I_{1.2}$	22	35	45	64	72	80	88	96	108	675	218
	$I_{0.9}$	22	39	62	75	84	92	100	110		600	
	$I_{0.6}$	22	45	72	88	96	108				450	

Table 2. Mean seasonal transpiration, soil evaporation, soil storage and drainage of spring maize under different mulching and irrigation treatments

Treatment	Mean seasonal transpiration (mm)			Mean seasonal soil evaporation (mm)			Mean seasonal change in soilwater storage (mm)			Mean seasonal drainage (mm)		
	2007	2008	Pooled	2007	2008	Pooled	2007	2008	Pooled	2007	2008	Pooled
M_6	550.7	582.2	566.5	72.8	27.3	50.0	74.7	169.6	122.2	0	13.6	6.8
M_0	538.1	560.4	549.2	202.4	112.6	157.5	-42.1	119.7	38.7	0	0	0
SEm±	3.8	3.1	3.2	3.5	4.7	3.9	4.5	4.9	4.7	0	1.1	0.9
CD (P=0.05)	15.9	17.1	15.3	75.6	62.8	79.8	22.5	34.1	47.4	NS	7.9	NS
$I_{1.2}$	568.0	597.1	582.5	146.9	69.1	108.0	83.3	205.8	144.5	0	20.7	10.4
$I_{0.9}$	546.7	572.4	559.5	152.7	68.5	110.6	23.7	177.0	100.4	0	0	0
$I_{0.6}$	518.4	544.4	531.4	113.0	72.3	92.6	-58.3	51.3	-3.5	0	0	0
SEm±	4.3	5.2	4.7	3.5	2.7	3.1	5.1	4.4	4.8	0	0	0
CD (P=0.05)	19.8	21.5	17.4	NS	NS	NS	44.3	29.8	38.3	NS	NS	NS
Mean (years)	544.4	571.3		137.6	69.9		16.2	144.7		0	6.9	
CD (years)	16.8			51.9			69.6			NS		
CD (Mulching × Irrigation)			15.5			NS			25.8			NS

M_6, Paddy straw mulch @ 6 tonnes/ha; M_0, no paddy straw mulch; $I_{1.2}$, Irrigation water (IW): cumulative pan evaporation (CPE) ratio of 1.2; $I_{0.9}$, IW: CPE 0.9; $I_{0.6}$, IW: CPE 0.6

drainage were non-significant under mulching and irrigation treatments during both the years.

Leaf area index

Parameters fitted for leaf-area index (LAI) model are given in Table 3. A good agreement between the fitted and observed values was observed. Periodic LAI of spring maize is presented in Table 4. Significant increase in LAI was observed with mulching from 90 to 110 days after sowing (DAS) over bare soil during 2007. During 2008 significant increase in LAI with mulching was recorded from 70 to 110 days. These results are in accordance with the findings of significant increase in LAI of maize with mulching (Tolk *et al.*, 1999; Li *et al*., 2013). Leaf-area index of spring maize was also significantly increased under $I_{1.2}$ irrigation compared to $I_{0.6}$ from 70 to 110 days during 2007 and from 60 to 110 days during 2008. Significantly higher LAI was observed under $I_{1.2}$ compared to $I_{0.9}$ irrigation during 100 and 110 days in 2007 only because of irrigation response during high evaporativity year. Similar results were reported by Gill *et al.* (1996) where the crop response to mulching was linked to the interplay between water supply and seasonal evaporativity.

Yield attributes and grain yield

Pooled analysis showed significantly more grains/cob and 1,000-seed weight with mulching than no mulching because of the adequate soil moisture throughout growing season (Table 5). Similarly, as the number of irrigations increased from $I_{0.6}$ to $I_{1.2}$, significant increase in grains/cob and 1,000-seed weight was observed. During both years, grain yield of spring maize was significantly more under the mulching than without mulch with respective overall mean values of 4.96 and 4.22 t/ha (Table 5). During both the years significant difference in grain yield was observed under $I_{1.2}$ and $I_{0.6}$ treatments with respective overall mean values 5.09 and 4.01 t/ha. However, no significant difference in grain yield was observed between $I_{1.2}$ and $I_{0.9}$ irrigation treatments in both the years. Difference in grain yield of $I_{0.9}$ and $I_{0.6}$ was significant in 2007 and non-significant in 2008, whereas when overall pooled analyses was done it became significant with corresponding overall mean values 4.67 and 4.01 t/ha. Overall grain yield during 2007 was significantly less than during 2008. When pooled analyses were done significant interaction between mulching and irrigation treatments was observed. Earlier workers (Tolk *et al.,* 1999, Shen *et al.*, 2012) also observed increase in maize grain yield under mulching.

Table 3. Leaf-area index estimation coefficients

Treatment	2007					2008				
	LAI_{max}	t_{inf}	t_{end}	a_1	a_2	LAI_{max}	t_{inf}	t_{end}	a_1	a_2
M_6	5.63	45	135.3	–0.12	0.076	6.66	46.7	136.3	–0.11	0.08
M_0	5.43	45	132.7	–0.12	0.063	6.30	46.6	135.6	–0.11	0.08
$I_{1.2}$	5.9	45	138	–0.12	0.080	6.80	46.0	138.0	–0.11	0.08
$I_{0.9}$	5.7	45	135.5	–0.12	0.065	6.70	47.5	135.0	–0.11	0.08
$I_{0.6}$	5.0	45	128.5	–0.12	0.065	5.95	46.5	135.0	–0.11	0.08

M_6, Paddy straw mulch @ 6 tonnes/ha; M_0, no paddy straw mulch; $I_{1.2}$, Irrigation water (IW): cumulative pan evaporation (CPE) ratio of 1.2; $I_{0.9}$, IW: CPE 0.9; I 0.6, IW: CPE 0.6; LAI_{max}, maximum LAI; T_{inf}, time at which maximum growing rate reached; T_{end}, time of complete senescence; a_1, shape factors for growing; a_2, controlling shape factors for drying rate

Table 4. Periodic mean leaf-area index of spring maize

Treatment	Days after sowing (2007)						Days after sowing (2008)					
	60	70	80	90	100	110	60	70	80	90	100	110
M_6	4.7	5.3	5.6	5.5	5.3	4.7	5.1	6.1	6.6	6.6	6.3	5.9
M_0	4.5	5.1	5.4	5.2	4.7	4.0	4.9	5.8	6.2	6.3	6.0	5.5
SEm±	0.04	0.07	0.02	0.05	0.07	0.08	0.03	0.04	0.04	0.03	0.05	0.06
CD (P=0.05)	NS	NS	NS	0.18	0.25	0.34	NS	0.18	0.21	0.14	0.19	0.23
$I_{1.2}$	4.8	5.4	5.8	5.7	5.4	5.0	5.2	6.3	6.7	6.7	6.4	6.1
$I_{0.9}$	4.5	5.2	5.6	5.4	4.9	4.3	5.1	6.1	6.7	6.7	6.3	5.8
$I_{0.6}$	4.3	4.7	4.8	4.4	3.7	2.8	4.7	5.4	5.8	5.9	5.6	5.2
SEm±	0.03	0.08	0.05	0.07	0.06	0.05	0.07	0.08	0.06	0.09	0.06	0.09
CD (P=0.05)	NS	0.31	0.26	0.39	0.35	0.41	0.27	0.32	0.25	0.39	0.21	0.33

M_6, Paddy straw mulch @ 6 tonnes/ha; M_0, no paddy straw mulch; $I_{1.2}$, Irrigation water (IW): cumulative pan evaporation (CPE) ratio of 1.2; $I_{0.9}$, IW: CPE 0.9; $I_{0.6}$, IW: CPE 0.6

Table 5. Mean grain yield, yield attributes, economics and water-use efficiency (grain yield/total seasonal transpiration) of spring maize under different mulching and irrigation treatments

Treatment	Mean grain yield (t/ha)			Grains/ cob	1,000-grain weight (g)	Net returns (×10³ ₹/ha)	Benefit: cost ratio	Water-use efficiency (kg/ha/mm)		
	2007	2008	Pooled					2007	2008	Pooled
M_6	4.70	5.23	4.96	316	230	49.1	2.10	8.52	8.98	8.75
M_0	3.87	4.57	4.22	253	190	38.3	1.63	7.15	8.13	7.64
SEm±	0.11	0.07	0.10	13	8	0.95	0.04	0.13	0.17	0.16
CD (P=0.05)	0.34	0.28	0.41	42	25	3.90	0.17	0.45	0.58	0.65
$I_{1.2}$	4.94	5.25	5.09	325	235	50.8	2.16	8.70	8.79	8.74
$I_{0.9}$	4.34	4.99	4.67	270	202	44.8	1.92	7.94	8.72	8.34
$I_{0.6}$	3.57	4.46	4.01	210	160	35.4	1.52	6.88	8.19	7.53
SEm±	0.20	0.15	0.18	12	10	0.91	0.04	0.14	0.12	0.13
CD (P=0.05)	0.65	0.59	0.46	45	29	2.34	0.10	0.52	0.43	0.48
Mean (years)	4.28	4.89						7.83	8.56	
CD (P=0.05) (years)			0.29							0.57
CD (P=0.05) (Mulching × Irrigation)			0.63							0.39

M_6, Paddy straw mulch @ 6 tonnes/ha; M_0, no paddy straw mulch; $I_{1.2}$, irrigation water (IW): cumulative pan evaporation (CPE) ratio of 1.2; $I_{0.9}$, IW: CPE 0.9; $I_{0.6}$, IW: CPE 0.6

Economics

The maximum net returns were obtained under mulching over no mulching with benefit: cost ratio of 2.1 and 1.63 respectively (Table 5). Amongst different irrigations, higher net returns and the maximum benefit: cost ratio were recorded under $I_{1.2.}$ This might be owing to the highest grain yield compared with the other irrigation treatments where the moisture stress reduced the grain yield significantly.

Crop water use

Water-use efficiency (WUE) of spring maize significantly increased with mulching over no mulching with overall pooled values of WUE 8.76 and 7.64 kg/ha/mm (Table 5). The increase in WUE with mulching was 18.6 and 10.2% during 2007 and 2008 respectively. During both the years significant difference in WUE was observed in $I_{1.2}$ and $I_{0.6}$ treatments with respective overall mean values of WUE 8.74 and 7.53 kg/ha/mm. However, significant difference in WUE was noticed in $I_{1.2}$ and $I_{0.9}$ irrigation treatment in 2007 only. Difference in WUE of $I_{0.9}$ and $I_{0.6}$ was significant in both the years with corresponding overall mean values of WUE 8.34 and 7.53 kg/ha/mm. A WUE of 7.83 kg/ha/mm recorded during 2007 was significantly less than WUE obtained during 2008 (8.56 kg/ha/mm). Overall both mulching and irrigation increased WUE of spring maize owing to significant increase in grain yield and reduction in water loss through soil evaporation. Significant increase in WUE with mulching and irrigation was because of soil water being used for crop growth and yield rather than in soil evaporation (Tolk *et al.*, 1999). These results are in accordance with the findings (Shen *et al.,* 2012).

It was concluded that application of mulch in spring maize maintained adequate soil moisture through reducing soil evaporation which in turn helped in increasing leaf area, yield-attributing parameters and grain yield. Frequent irrigations in spring maize are helpful in maintaining economically viable grain yield. In dry season, high stress to spring maize was observed when irrigation scheduling was based on irrigation water: pan evaporation ratio of 0.6 which significantly reduced the grain yield.

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