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5 authors, including:

Sumanta Chatterjee
University of Wisconsin–Madison

Kk Bandyopadhyay

Rachit Singh
University of Texas at Dallas

Sanatan Pradhan
Indian Institute of Water Management

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Yield and Input Use Efficiency of Maize (*Zea mays* L.) as Influenced by Crop Residue Mulch, Irrigation and Nitrogen Management

Sumanta Chatterjee[1], K.K. Bandyopadhyay*, R. Singh, S. Pradhan[2] and S.P. Datta[3]
Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi 110 012

Field experiments were conducted in a sandy loam soil at the research farm of the Indian Agricultural Research Institute (IARI), New Delhi during the *kharif* season of 2012 and 2013 with the objective to study the effect of crop residue mulch, irrigation and nitrogen (N) on soil water dynamics, growth, yield, water and N use efficiency of maize. Maize (cv. HQPM 1) was grown in a split-split plot design with two levels of irrigation, two levels of mulch and three levels of N. The grain yield of maize increased significantly by 31 per cent under irrigated condition than that of rainfed condition in the year 2012. Application of crop residue mulch increased the grain yield of maize significantly by 11.5 and 28.4 per cent compared to no-mulch treatment in 2012 and 2013, respectively. Application of N significantly increased the grain yield of maize over the control. However, there was no significant difference between 75 kg and 150 kg N ha^{-1} with respect to grain and biomass yield of maize. The water use efficiency of maize increased significantly by 12.6 and 36 per cent in 2012 and 2013, respectively due to crop residue mulch. The apparent N recovery and agronomic N use efficiency increased significantly but physiological N use efficiency decreased under mulching. So, maize may be grown with 75 kg N ha^{-1} and wheat residue mulch @ 10 t ha^{-1} to achieve higher yield, water use efficiency and N use efficiency in Upper-Indo-Gangetic Plain region.

Key words: Maize, water use efficiency, agronomic water productivity, economic water productivity, N use efficiency

Maize (*Zea mays* L.) is the third most important cereal crop in the world after wheat and rice with respect to area and productivity. The productivity of maize largely depends on optimal management of inputs such as nitrogen (N) and water (Arun Kumar *et al*. 2007). Mulching can serve as a useful technology for storing water *in-situ* by reducing evaporation and facilitating infiltration into the soil profile for its utilization to crops, modifying soil hydrothermal regimes and improving crop yield (Acharya *et al*. 2005). Rathore *et al*. (1998) reported that straw mulched soil conserved more water than the soils without it. Mulching (organic and inorganic) is an appropriate management practice to enhance efficiency level of irrigation besides improving crop yield (Sarkar and Singh 2007). Under limited irrigation condition, rice husk mulching was beneficial for wheat as it maintained better soil and plant water status, leading to higher grain yield and enhanced water use efficiency (Chakraborty *et al*. 2008). Mulching resulted in alteration of mineral N distribution in the upper part of soil profile (Franzlubbers and Francis 1995) and improvement of availability of N in a few years (Angás *et al*. 2006). Ahmed and Srivastava (1980) reported that adequate soil water conserved by mulch in conjunction with N increased the crop yield significantly over the control at the same level of N. Organic mulches provided better soil water status and improved plant canopy in terms of biomass, root growth, leaf area index and grain yield, which subsequently resulted in higher water and N uptake and improved their use efficiencies (Chakraborty *et al*. 2010). Most of the studies on input use efficiency in agriculture have concentrated on developing technologies for efficient use of water and N in an isolated manner under conventional method of cultivation. The present

*Corresponding author (Email: kk.bandyopadhyay@gmail.com)
[1]ICAR-National Rice Research Institute, Cuttack, 753 006, Odisha
[2]ICAR-Indian Institute of Water Management, Bhubaneswar, 751 023, Odisha
[3]Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi, 110 012

investigation was, therefore, undertaken to study the combined effect of crop residue mulch, irrigation and N on soil water dynamics, yield and water and N use efficiency in maize.

Materials and Methods

Soil and weather condition

The field experiment on *kharif* maize, was conducted in 2012 and 2013 on a Typic Haplustept in the Research Farm of Indian Agricultural Research Institute (IARI), New Delhi (Fig. 1). The experimental site (28 °N, 77 °E, and 250 m above mean sea level), located in the Upper-Indo-Gangetic Plain of India, represents an irrigated, mechanized and input-intensive cropping area. The climate of New Delhi is sub-tropical semi-arid, with dry hot summers (March to June) and brief severe winters (December to February). The average monthly minimum and maximum temperature in January (the coldest month) ranges between 5.9 °C and 19.9 °C, respectively. The corresponding temperature in May (the hottest month) ranges between 24.4 and 38.6 °C, respectively. The average annual rainfall is 651 mm, and nearly three-fourth of this is received through south-west monsoon during July to September.

The soil of the experimental site was sandy loam (Typic Haplustept) of Gangetic alluvial origin, very deep (>2 m), flat and well drained. It was observed that the soil at 0-15 cm layer was moderately alkaline (pH 7.1), non-saline (EC 0.36 dS m^{-1}), low in organic C (OC 4.2 g kg^{-1}, Walkley and Black C) and total N (0.032%) and medium in available P (7.1 kg ha^{-1}) and K (281.0 kg ha^{-1}) content. The soil (0–15 cm) has

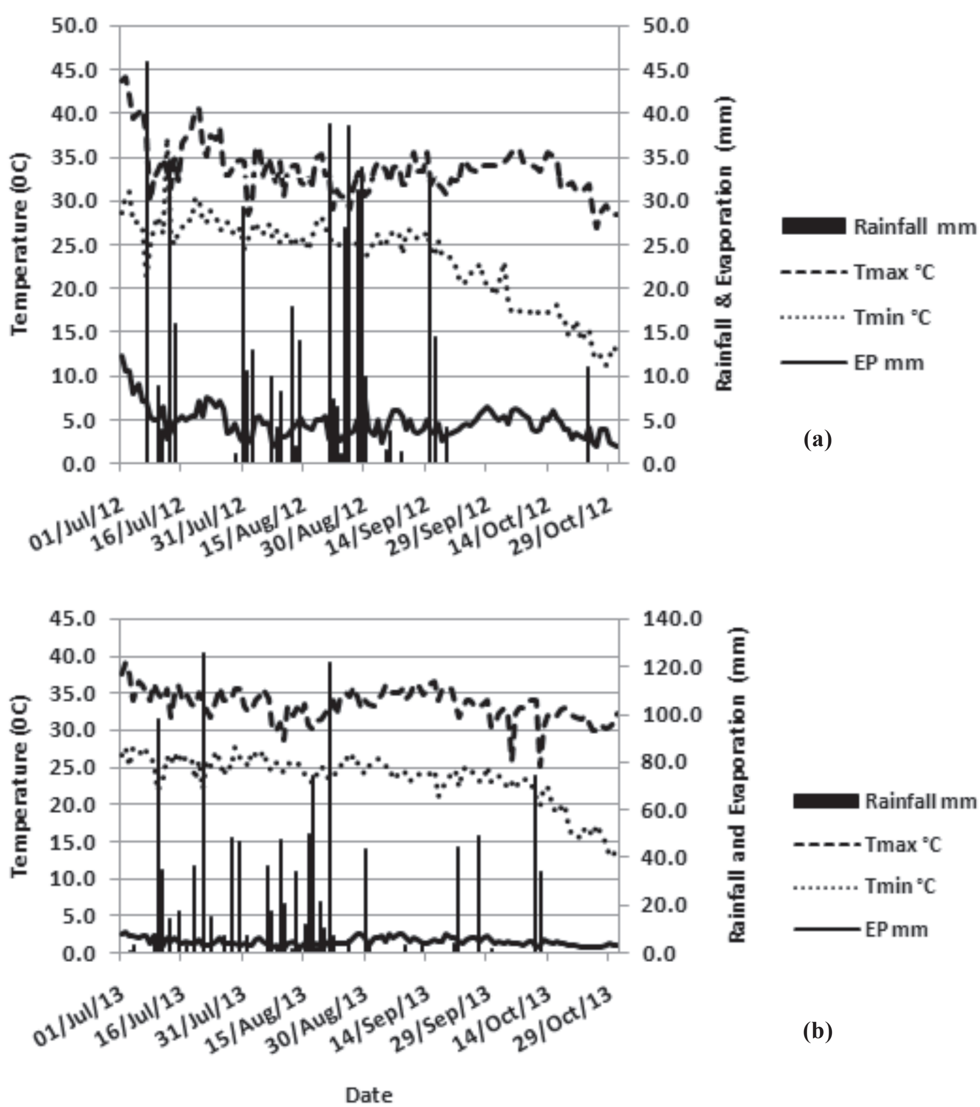

Fig. 1. Daily weather condition during maize growth period of the years (a) 2012 and (b) 2013

bulk density of 1.58 Mg m^{-3}, hydraulic conductivity (saturated) of 1.01 cm h^{-1}, saturated water content of 0.41 m^3 m^{-3}, sand, silt and clay of 64.0, 16.8 and 19.2%, respectively. The bulk density varied from 1.58 Mg m^{-3} in the 0-15 cm layer to 1.72 Mg m^{-3} in the 90-120 cm layer.

Treatment details

The treatments comprising of two levels of irrigation (rainfed and 4 irrigations at critical growth stages *i.e.* seedling, eight leaf stage, tasseling and silking stages in the absence of rainfall in these stages), two levels of mulching (without and with wheat residue mulching @ 10 t ha^{-1}) and three levels of N (0, 75 and 150 kg N ha^{-1}) were evaluated in a split-split plot design with three replications. The main plot factor was irrigation, sub-plot factor was mulch and sub-sub-plot factor was N. The sub-sub plot-size was 4.5 m×5 m. Maize (cv. HQPM-1) was sown every year during third week of July at 45 cm×15 cm spacing and harvested manually during last week of October. Nitrogen was supplied as urea in four splits *i.e.* 20% at sowing, 20% at four leaf stage, 30% at eight leaf stage and rest 30% at tasseling stage. All the plots received a uniform dose of 75 kg P_2O_5 ha^{-1} as single superphosphate (SSP) and 75 kg K_2O ha^{-1} as muriate of potash (MOP) applied at sowing. Four irrigations were supposed to be applied in the irrigated treatment at critical growth stages of maize as per the treatment envisaged in the absence of rainfall during these stages. However, rainfall occurred at two critical growth stages *i.e.* eight leaf stage and tasseling stage in both the years of study. So only 2 irrigations instead of 4 irrigations were applied in both the years of study.

Computation of ET and Water Use Efficiency

Seasonal evapo-transpiration (ET) was computed using water balance approach:

$$ET = P + I + Cp - Dp - Rf - \Delta S \quad \ldots(i)$$

where, P is precipitation, I is depth of irrigation, Cp is contribution through capillary rise from the water table, Dp is deep percolation loss, Rf is runoff, ΔS is change in soil water storage in the profile. Since the depth of groundwater was very low (6-8 m), Cp was assumed negligible. The value of Dp was considered negligible beyond 120 cm because of negligible changes in the soil water storage below 120 cm soil depth. There was no runoff (Rf) from the field as all the plots were provided with bunds. So the Eq (i) boils down to:

$$ET = P_{eff} + I - (Sf - Si) \quad \ldots(ii)$$

where, Sf is final water storage in the profile at harvest, Si is initial water storage in the profile at sowing, P_{eff} is effective precipitation. Effective precipitation was computed from daily rainfall data by FAO method (Brouwer and Heibloem 1986).

Water use efficiency was computed as follows:

Water use efficiency (WUE) =Y/ET …(iii)

where, Y=Yield (kg ha^{-1}) and ET = seasonal evapo-transpiration (mm)

Water productivity was computed as follows:

Agronomic water productivity (kg m^{-3}) = (G_y+S_y)/ Water use …(iv)

where, G_y= Grain yield (kg ha^{-1}); S_y= Straw yield (kg ha^{-1})

Water use = Consumptive use of water (m^3 ha^{-1})

Economic water productivity (Rs m^{-3}) = Price of grain and straw (Rs ha^{-1})/Water use …(v)

The MSP of maize grain was Rs. 1175 and Rs. 1310 q^{-1} during 2012 and 2013, respectively; whereas the price of maize straw was Rs. 3100 t^{-1} during both the years.

Determination of N Uptake and N Use Efficiency

Nitrogen concentration in grain and straw samples was determined using Kjeldhal digestion and distillation method (AOAC 1970). Nitrogen uptake in grain and straw was determined by multiplying the N concentration with the corresponding grain and straw biomass, respectively. The total N uptake in plant was determined by summation of N uptake in grain and straw.

Nitrogen use efficiency was computed as follows:

(i) Agronomic NUE = $(Y_T - Y_C)/N_{applied}$ …(vi)

where, Y_T = Yield in N treated plot; Y_C=Yield in control; $N_{applied}$ = N dose applied

(ii) Apparent N recovery = $(U_T - U_C)/N_{applied}$ …(vii)

where, U_T = N uptake in N treated plot; U_C = N uptake in control

(iii) Physiological NUE = $(Y_T - Y_C)/(U_T - U_C)$ …(viii)

Root studies

Root samples were collected at flowering stage using core sampler of 15 cm height and 7 cm diameter at 15 cm depth increments up to the depth of 30 cm. The shoot of the plant was cut close to the soil and the soil surface was cleaned by removing unwanted materials, if any. The core of the auger was inserted into the soil in such a manner that shoot was at the centre of the inserted core. The collected soil cores were sealed in polythene bags, brought to the laboratory, washed and processed for scanning. The lengths were recorded through the scanning and image analysis of the root skeleton (WINRHIZO system, Regent Instruments Inc., Canada). The root length was divided by the core volume to estimate root length density (RLD) (Chakraborty *et al.* 2008; Bandyopadhyay *et al.* 2010). Then these root samples were dried at 60 °C using a hot air oven till constant weight is achieved. The root weight was divided by the volume of the soil core to get the root mass density (RMD).

Statistical analysis

The analysis of variance (ANOVA) test was performed using the GLM procedure of SAS (SAS Institute Inc., 2003) to determine the effect of irrigation, mulch and N on crop yield, N uptake, NUE and WUE as applicable to split-split plot design. The means were compared using least significant difference (LSD) and Duncan's Multiple Range Test (DMRT). The coefficient of determination (R^2) of regression equations and correlation coefficient (r) were computed by following the least square method (Smith and Norman 2005) with a computer MS Excel programme.

Results and Discussion

Soil Water Dynamics

It was observed that in 2012, the profile water storage (Fig. 2) remained between field capacity (FC) and permanent wilting point (PWP) for the entire crop growth period, whereas, in 2013, it was above FC at 37 days after sowing (DAS) (Fig. 3). Application of

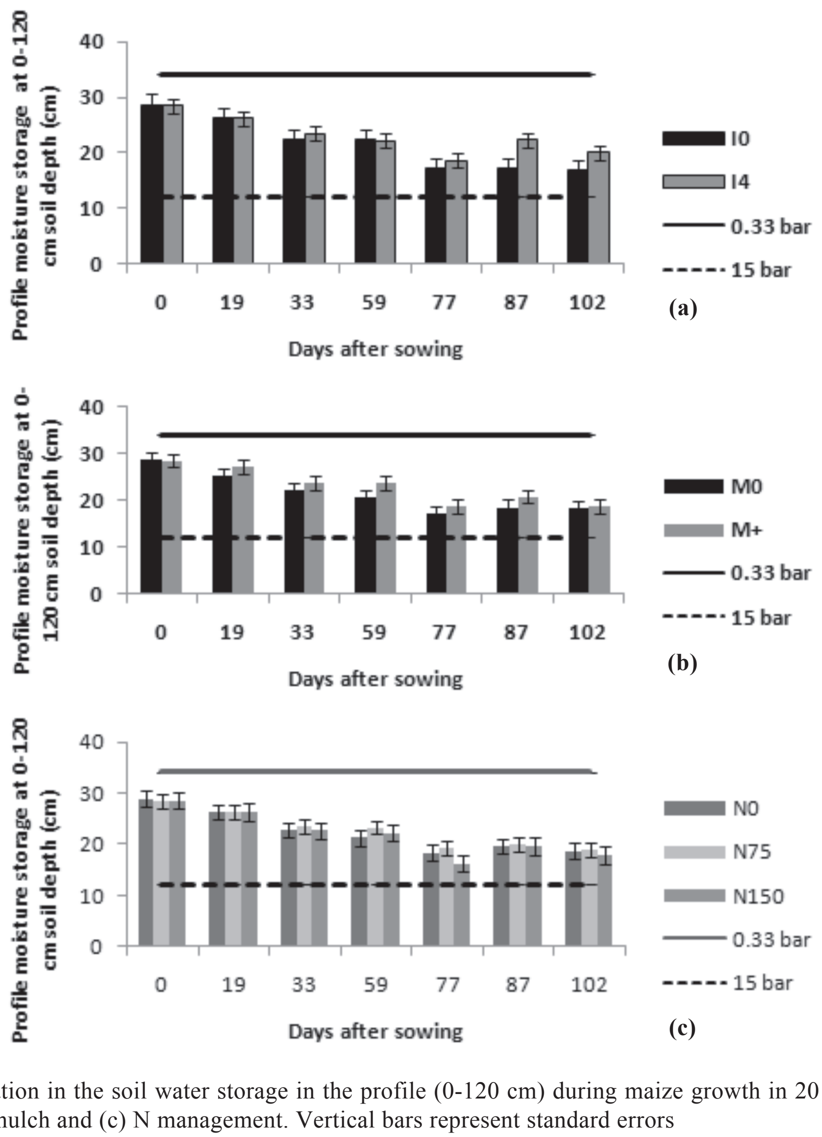

Fig. 2. Temporal variation in the soil water storage in the profile (0-120 cm) during maize growth in 2012 as influenced by (a) irrigation, (b) mulch and (c) N management. Vertical bars represent standard errors

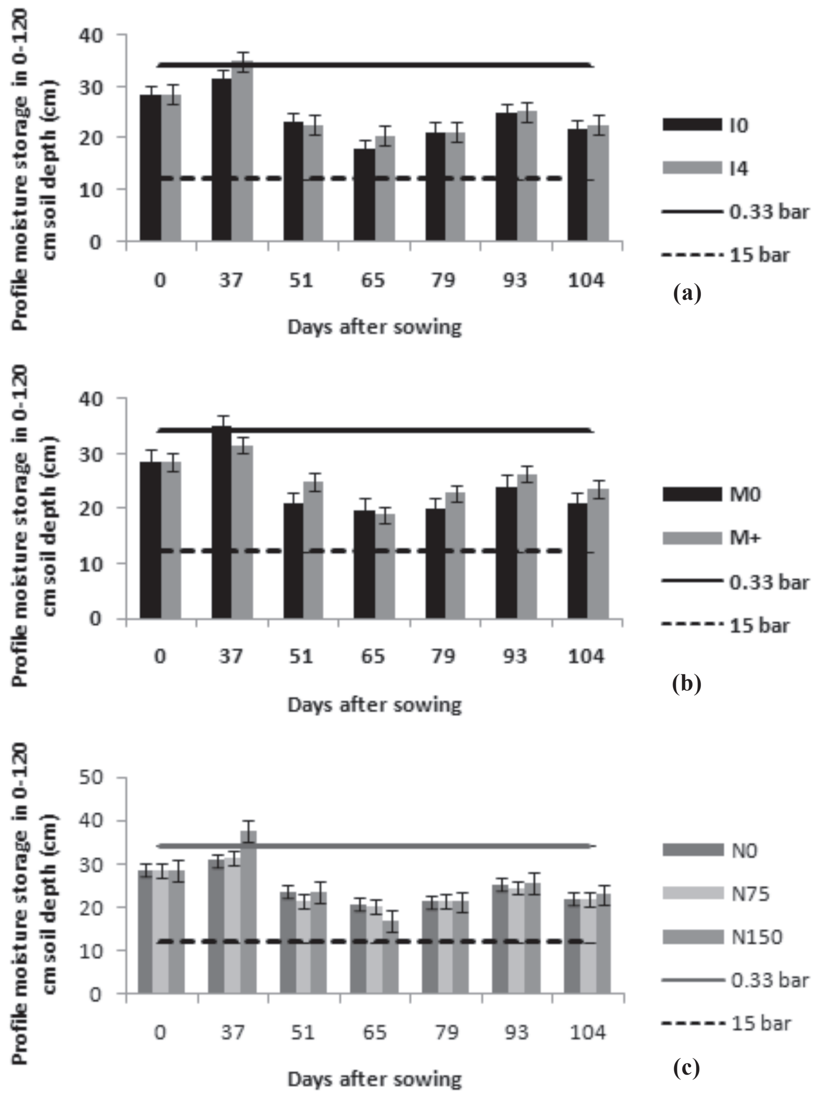

Fig. 3. Temporal variation in the soil water storage in the profile (0-120 cm) during maize growth in 2013 as influenced by (a) irrigation, (b) mulch and (c) N management. Vertical bars represent standard errors

crop residue mulch resulted in significantly higher profile water storage in both the years of study, which is mainly attributed to reduced evaporation from soil surface, improved infiltration and soil water retention and facilitating condensation of water during night due to temperature reversal (Acharya *et al*. 2005). These results are in agreement with the findings of Uwah and Iwo (2011). During the rain free period (77 and 102 DAS in 2012 and 65 DAS in 2013) soil water storage was lower with 150 kg N ha^{-1} compared to that of 75 kg N ha^{-1} and control, which may be attributed to increased growth and ET demand at higher N levels compared to control. This finding is in agreement with the findings of Bandyopadhyay *et al*. (2010) for soybean and Pradhan *et al*. (2013) for maize.

Leaf Area Index (LAI)

At the early vegetative stage (33 DAS), the effect of irrigation and crop residue mulch was not significant on leaf area index (LAI) of maize, whereas, N application significantly improved the LAI over control during this stage (Fig. 4). At flowering stage (67 DAS) and grain filling stage (79 DAS), crop residue mulch and N application significantly increased the LAI over the respective controls. The increase in LAI with crop residue mulch at the flowering and grain filling stages were 22.2 and 16.3%, respectively over the no-mulch treatment. Similarly, the increase in LAI due to irrigation at the flowering and grain filling stages were 37.3 and 26.4 per cent, respectively over the rainfed treatment.

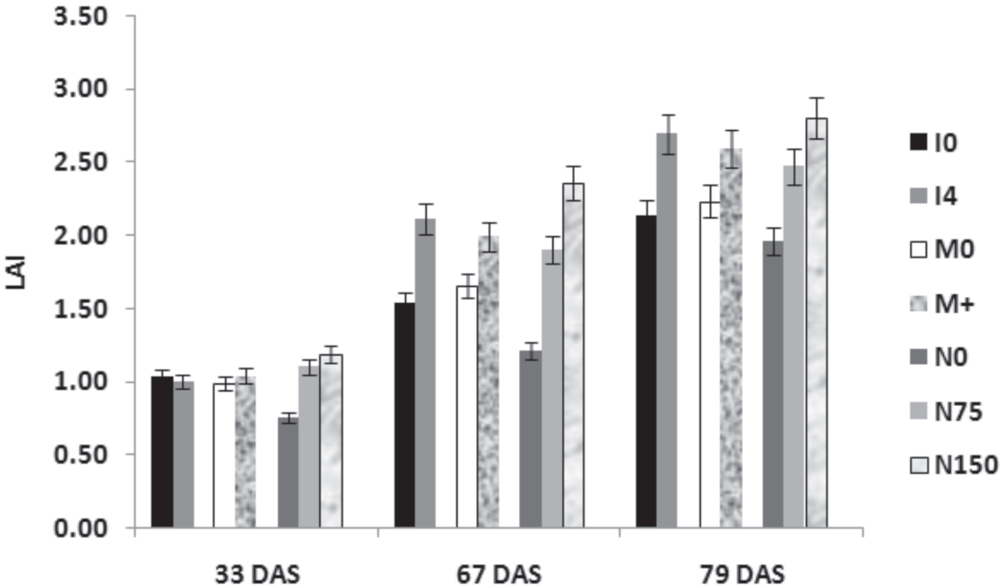

Fig. 4. Temporal variation in the Leaf area index of maize as influenced by irrigation, mulch and N management. Vertical bars represent standard errors

Application of 75 kg N ha^{-1} increased the LAI significantly over control by 46.3, 56.7 and 26.1 per cent at early vegetative stage, flowering and grain filling stages, respectively. Similarly, application of 150 kg N ha^{-1} increased the LAI over control by 57.5, 95.0 and 43.4 per cent, respectively at these stages. Decreased LAI under reduced N supply is in agreement with Pradhan *et al*. (2013). Application of irrigation, crop residue mulch and N significantly increased the LAI at flowering and grain filling stage by 22.2 and 16.3 per cent, 37.3 and 26.4 per cent and 75.9 and 34.8 per cent over the respective controls (rainfed condition, no-mulch treatment and no N). The possible cause of reduction of LAI under control treatments (rainfed condition, no-mulch treatment and no N) may be attributed to reduction in water and N availability to the crops which led to reduction in cell enlargement (McCree and Davis 1974), stunted growth (Jones *et al*. 1980) and reduced photosynthetic activity of leaves (Oppenheimer 1960).

Root Growth

The root length density (RLD) due to crop residue mulch increased significantly by 14.3 and 37.6 per cent over no-mulch treatment at 0-15 and 15-30 cm soil depth, respectively (Fig. 5). Better availability of soil water under mulch facilitated better crop growth as evidenced by higher LAI and RLD. Chakraborty *et al*. (2010) reported significantly higher root weight and root length densities compared to no

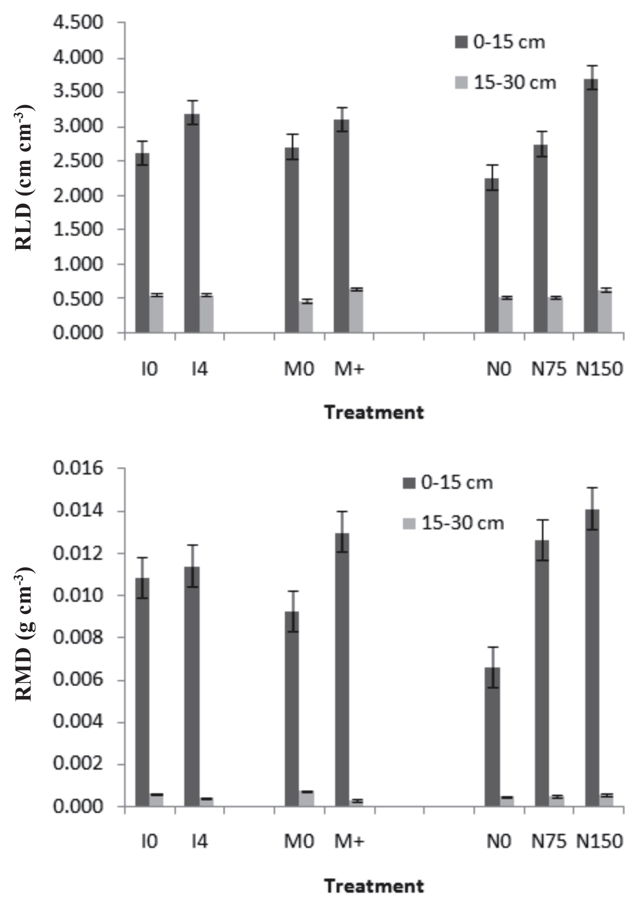

Fig. 5. Root length density and root mass density of maize during flowering stage in the year 2013 as influenced by irrigation, mulch and N management. Vertical bars represent standard errors

mulch treatments in wheat. Gao *et al*. (2014) also observed that in full film mulching there was significant increase in RLD, RMD and root diameter compared to half film mulch and no-mulch check of maize. Under irrigated condition, RLD increased significantly by 22.4 per cent at 0-15 cm soil depth over the rainfed treatment. Application of 150 and 75 kg N ha^{-1} significantly increased the RLD by 63.8 and 21.6 per cent, respectively and RMD by 114 and 92 per cent, respectively over the control. Anderson *et al*. (1987) and Durieux *et al*. (1994) also reported that application of N fertilizer stimulated root growth at surface but not at lower depths. The RMD of maize increased significantly due to irrigation, crop residue mulch and N application over the respective control treatments at 0-15 cm soil depth.

Grain Yield

Grain yield of maize as influenced by irrigation, crop residue mulch and N management has been presented in table 1 for the year 2012 and 2013. The maize crop growth period of the year 2013 was unusual and received more rainfall (919.7 mm) compared to maize crop growth period of the year 2012 (482 mm). So the crop of 2013 experienced aeration stress especially during the initial and crop development stage period. In 2013, the bright sunshine hour was significantly lower ($P \leq 0.05$) and RH was significantly higher than the year 2012. This may be the reason for reduced grain and biomass yield of maize in 2013 than that of the year 2012. Application of crop residue mulch increased the grain yield of maize significantly by 11.5 and 28.4 per cent compared to no-mulch treatment in 2012 and 2013, respectively. Increased crop productivity due to crop residue mulch has also been reported by several workers (Chakraborty *et al*. 2010; Uwah and Iwo 2011). The grain yield in 2012 increased significantly by 31 per cent under irrigated condition than that of rainfed condition, whereas, in 2013 there was no significant difference in grain yield of maize due to irrigation. This may be attributed to excess rainfall received in 2013 leading to aeration stress. Pradhan *et al*. (2013) also did not find any significant variation in grain and biomass yield due to irrigation in *kharif* maize. Application of N @ 75 and 150 kg N ha^{-1} increased the grain yield of maize by 68.4 and 72.8 per cent over the control in 2012 and 52.5 and 44.6 per cent in 2013, respectively. However, there was no significant difference in grain yield of maize due to 75 and 150 kg N ha^{-1} in both the years. Pradhan *et al*. (2013) also reported significantly higher grain and biomass yield of maize due to N application. The interaction of irrigation × mulch × N was not significant on grain yield of maize.

Table 1. Grain yield and biomass yield of maize as influenced by irrigation, mulching and N management

Treatment	Grain yield (t ha^{-1})		Biomass yield (t ha^{-1})	
	2012	2013	2012	2013
Irrigation				
Rainfed	4.65b*	4.35a	24.63b	16.20a
Irrigated	6.09a	4.42a	28.86a	16.64a
Mulch				
Without mulch	5.08b	3.84b	24.78b	13.69b
With wheat residue mulch @ 10 t ha^{-1}	5.66a	4.93a	28.70a	19.16a
Nitrogen				
Control	3.65b	3.31b	21.11b	12.39b
75 kg N ha^{-1}	6.15a	4.79a	28.38a	18.31a
150 kg N ha^{-1}	6.31a	5.05a	30.74a	18.57a

**Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT*

Biomass yield

There was reduction in biomass yield of maize by 63 per cent in 2013 compared to that of 2012 (Table 1). The biomass yield increased significantly by 17.2 per cent due to irrigation in 2012. However, in the year 2013, there was no significant difference in the biomass yield due to irrigation. Averaged over irrigation and N levels, the biomass yield of maize increased significantly by 15.8 and 40 per cent due to crop residue mulch in 2012 and 2013, respectively. Application of N @ 75 and 150 kg N ha^{-1} increased the biomass yield by 34.4 and 45.6 per cent in 2012 and 47.8 and 50 per cent in 2013 compared to control, respectively. However, there was no significant difference in the biomass yield due to 75 and 150 kg N ha^{-1} in both the years of study. The biomass yield of maize followed the trend similar to the grain yield of maize.

Seasonal Evapo-transpiration (ET) and Water Use Efficiency (WUE)

The seasonal ET increased significantly due to irrigation over rainfed treatment but ET was not influenced by mulching and N levels (Table 2). Averaged over mulching and N levels, the WUE increased significantly by 25.6 per cent under irrigated condition than that of rainfed condition in 2012 (Table 2). However, the effect of irrigation was not significant on WUE of maize in 2013. The WUE of

Table 2. Seasonal ET and WUE of maize as influenced by irrigation mulching and N management

Treatment	Seasonal Evapotranspiration (mm)		Water use efficiency (kg/ha-mm)	
	2012	2013	2012	2013
Irrigation				
Rainfed	562.2b*	779.2b	8.2b	5.6a
Irrigated	591.7a	892.1a	10.3a	4.9a
Mulch				
Without mulch	579.7a	849.1a	8.7a	4.5b
With wheat residue mulch @ 10 t ha^{-1}	574.2a	822.3a	9.8a	6.1a
Nitrogen				
Control	575.5a	838.7a	6.3b	4.0b
75 kg N ha^{-1}	571.9a	839.8a	10.7a	5.8a
150 kg N ha^{-1}	583.4a	828.6a	10.8a	6.1a

**Values in a column followed by same letters are not significantly different at p<0.05 as per DMRT*

maize increased significantly by 12.6 and 36 per cent due to crop residue mulch in 2012 and 2013, respectively. Increased WUE due to mulching has also been reported by Sarkar and Singh (2007) and Chakraborty *et al*. (2010). Application of 75 and 150 kg N ha^{-1} increased the WUE by 70 and 71 per cent over the control in 2012 and by 45 and 53 per cent in 2013, respectively. However, there was no significant difference in WUE of maize due to 75 and 150 kg N ha^{-1} in both the years. The WUE of maize increased significantly due to irrigation, mulch and N application. Zaongo *et al.* (1997) reported that greatest WUE was obtained in the treatment where irrigation, mulch and N fertilizer were combined. The interaction of irrigation, mulching and N levels was not significant on ET and WUE of maize for both the years of study.

Agronomic Water Productivity (AWP) and Economic Water productivity (EWP)

Averaged over mulch and N levels, application of irrigation significantly increased the AWP by 25.6 per cent than the rainfed treatment in 2012, whereas, the effect of irrigation was not significant on AWP of maize in 2013 (Table 3). Application of crop residue mulch significantly increased AWP by 12.6 and 36 per cent in 2012 and 2013, respectively. Application of 75 and 150 kg N ha^{-1} significantly increased AWP by 70 and 71 per cent in 2012 and by 42.5 and 52.5 per cent in 2013 over control, respectively. However, there was no significant difference in AWP of maize due to 75 and 150 kg N ha^{-1} in both the years.

Averaged over mulch and N levels, application of irrigation significantly increased the EWP by 20 per cent over the rainfed treatment in 2012, however, there was significant reduction in EWP by 11.4 per cent under irrigated treatment than that of rainfed treatment in 2013 (Table 3). Excess rainfall received in 2013 may be responsible for decrease in EWP during this year. Application of crop residue mulch resulted in EWP of 18.45 and 10.74 Rs m^{-3} as against 15.96 and 9.54 Rs m^{-3} for no-mulch treatment in 2012 and 2013, respectively. Application of 75 and 150 kg N ha^{-1} significantly increased the EWP of maize crop by 55 and 59 per cent over control in 2012 and by 46 and 52 per cent over control in 2013, respectively. However, there was no significant difference in EWP of maize due to 75 and 150 kg N ha^{-1}. The interaction of irrigation, mulch and N levels was not significant on AWP and EWP of maize.

N uptake

Averaged over mulch and N levels, N uptake by grain (NUG) increased significantly by 31.8 per cent in 2012 under irrigated condition, whereas, in 2013, the effect of irrigation was not significant on NUG in maize (Table 4). Averaged over irrigation and N levels, application of crop residue mulch increased NUG significantly by 26.4 per cent and 41.1 per cent in 2012 and 2013, respectively. Application of 75 and 150 kg N ha^{-1} significantly increased the NUG over control by 112 and 155 per cent in 2012 and 115 and 164 per cent in 2013, respectively. There was no

Table 3. Agronomic water productivity (AWP) and economic water productivity (EWP) of maize as influenced by irrigation, mulching and N management

Treatments	Agronomic water productivity (kg m^{-3})		Economic water productivity (Rs m^{-3})	
	2012	2013	2012	2013
Irrigation				
Rainfed	0.82b*	0.56a	15.66b	12.12a
Irrigated	1.03a	0.50a	18.75a	10.74b
Mulch				
Without mulch	0.87b	0.45b	15.96b	9.54b
With wheat residue mulch @ 10 t ha^{-1}	0.98a	0.61a	18.45a	13.32a
Nitrogen				
Control	0.63b	0.40b	12.47b	8.63b
75 kg N ha^{-1}	1.07a	0.57a	19.33a	12.59a
150 kg N ha^{-1}	1.08a	0.61a	19.81a	13.08a

**Values in a column followed by same letters are not significantly different at p<0.05 as per DMRT*

Table 4. Nitrogen uptake by grain and straw of maize as influenced by irrigation, mulching and N management

Treatments	N uptake by grain ($kg\ ha^{-1}$)		N uptake by straw ($kg\ ha^{-1}$)		Total N uptake by grain and straw ($kg\ ha^{-1}$)	
	2012	2013	2012	2013	2012	2013
Irrigation						
Rainfed	58.1b*	51.8a	72.1a	76.0a	130.2b	127.8a
Irrigated	76.6a	54.3a	80.6a	75.3a	157.2a	129.6a
Mulch						
Without mulch	59.5b	44.0b	67.9b	61.3b	127.4b	105.3b
With wheat residue mulch @ 5 t ha^{-1}	75.2a	62.1a	84.8a	90.0a	160.0a	152.1a
Nitrogen						
Control	35.6b	27.5c	54.6c	44.7c	90.2c	72.2c
75 kg N ha^{-1}	75.5a	59.1b	78.1b	85.0b	153.7b	144.1b
150 kg N ha^{-1}	90.9a	72.6a	96.4a	97.3a	187.2a	169.9a

**Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT*

Table 5. Apparent N recovery, agronomic N use efficiency and physiological N use efficiency of maize as influenced by irrigation, mulching and N management

Treatments	Apparent N recovery (kg N uptake/kg N applied)		Agronomic N use efficiency (kg grain/ kg N applied)		Physiological N use efficiency (kg grain/ kg N uptake)	
	2012	2013	2012	2013	2012	2013
Irrigation						
Rainfed	0.83a	0.87a	27.0a*	11.6a	30.0a	15.7a
Irrigated	0.69a	0.77a	24.0a	19.8a	33.6a	26.4a
Mulch effect						
Without mulch	0.59b	0.74b	19.1b	16.3a	37.4a	23.7a
With wheat residue mulch @ 5 t ha^{-1}	0.92a	0.87a	31.9a	15.1a	28.2a	18.4b
Nitrogen						
Control	—	—	—	—	—	—
75 kg N ha^{-1}	0.87a	0.96a	33.3a	19.7a	42.5a	23.6a
150 kg N ha^{-1}	0.65b	0.65b	17.6b	11.6b	23.1b	18.6b

**Values in a column followed by same letters are not significantly different at $p<0.05$ as per DMRT*

significant difference in the NUG due to 75 and 150 kg N ha^{-1} in 2012. However, application of 150 kg N ha^{-1} significantly increased NUG by 23 per cent compared to that with 75 kg N ha^{-1} in 2013.

Application of crop residue mulch significantly increased N uptake by straw (NUS) by 24.9 and 46.8 per cent in 2012 and 2013, respectively over no-mulch treatment. Application of 75 and 150 kg N ha^{-1} significantly increased the NUS over control by 43.1 and 76.5 per cent in 2012 and 90.2 and 117.7 per cent in 2013, respectively. Application of 150 kg N ha^{-1} significantly increased the NUS by 23.3 and 14.5 per cent compared to that with 75 kg N ha^{-1} in 2012 and 2013, respectively.

Averaged over mulch and N levels, total N uptake by grain and straw (NUGS) under irrigated treatment increased significantly by 20.7 per cent over the rainfed treatment in 2012. However, the effect of irrigation was not significant on NUGS in maize in 2013. The N uptake by grain and straw followed similar trend as that of biomass yield of wheat. Crop residue mulching significantly increased the NUGS by 25.6 and 44.4 per cent in 2012 and 2013, respectively. Application of 75 and 150 kg N ha^{-1} significantly increased the NUGS of maize over control by 70.3 and 107.5 per cent in 2012 and 99.6 and 135.3 per cent in 2013, respectively. Application of 150 kg N ha^{-1} increased significantly the NUGS compared to 75 kg N ha^{-1} by 21.9 and 17.9 per cent in 2012 and 2013, respectively. Similar findings have been reported by several workers (Acharya *et al*. 2005; Chakraborty *et al*. 2010). Crop residue mulch increased soil water in the surface soil and hence there was greater N availability to plant roots, in turn, leading to higher grain yield (Tolk *et al*. 1999). Acharya and Sharma (1994) also reported that mulching showed significantly greater total uptake of N, phosphorus and potassium than un-mulched ones.

Nitrogen Use Efficiency (NUE)

Averaged over irrigation and N levels, application of crop residue mulching significantly increased apparent N recovery (ANR) by 56 and 17.6 per cent over no-mulch treatment in 2012 and 2013, respectively (Table 5). Application of 150 kg N ha^{-1} significantly reduced the ANR by maize by 25.4 and 32.5 per cent compared to that of 75 kg N ha^{-1} in 2012 and 2013, respectively.

Application of crop residue mulch significantly increased agronomic N use efficiency (ANUE) by 67 per cent over no-mulch treatment in 2012, whereas, the effect of irrigation on ANUE was not significant in 2013. Application of 150 kg N ha^{-1} registered significantly lower ANUE compared to that with 75 kg N ha^{-1} by 89.2 and 49.1 per cent in 2012 and 2013, respectively.

The effect of irrigation and crop residue mulch was not significant on physiological N use efficiency (PNUE) of maize in both the years of study. Application of 150 kg N ha^{-1} significantly reduced the PNUE by 45.6 and 26.9 per cent compared to 75 kg N ha^{-1} in 2012 and 2013, respectively.

Conclusions

From this study it may be concluded that the grain and biomass yield of maize increased significantly due to irrigation, crop residue mulch and N application under normal rainfall years. However, there was no significant difference between 75 and 150 kg N ha^{-1} with respect to maize grain and biomass yield. Water use efficiency, agronomic water productivity and economic water productivity also increased due to irrigation, crop residue mulch and N application. The apparent N recovery and agronomic N use efficiency increased significantly but physiological N use efficiency decreased under mulching. The apparent N recovery, agronomic N use efficiency and physiological N use efficiency decreased significantly due to application of 150 kg N ha^{-1} compared to 75 kg N ha^{-1}. So maize may be grown with 75 kg N ha^{-1} and wheat residue mulch @ 10 t ha^{-1} to achieve higher yield, water use efficiency and N use efficiency in upper-Indo-Gangetic Plain regions.

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