Indian Journal of Agricultural Sciences **83** (5): 542–8, May 2013/Article

Soil water dynamics, root growth and water and nitrogen use efficiency of rainfed maize (*Zea mays*) in a semi-arid environment

S PRADHAN[1], U K CHOPRA[2], K K BANDYOPADHYAY[3], P KRISHNAN[4], R SINGH[5] and A K JAIN[6]

Indian Agricultural Research Institute, New Delhi 110 012

Received: 7 August 2012; Revised accepted: 19 February 2013

ABSTRACT

A field experiment was conducted during *kharif* season of 2010 and 2011 in a sandy loam soil at New Delhi to study the effect of irrigation (depending on the rainfall) and nitrogen levels (0 kg N/ha, 60 kg N/ha, 120 kg N/ha and 180 kg N/ha) on soil water dynamics, root growth, productivity, water and nitrogen use efficiency of maize (*Zea mays* L.) (cv HQPM 1). Sufficient and well distributed rainfall during the *kharif* season of 2010 did not require application of irrigation and hence only nitrogen effects were observed. However in the year 2011, lower rainfall in the early period crop growth required application of a life saving irrigation to all treatments. After that no irrigation was supplied because of adequate and well distributed rainfall. Hence in both the years, only nitrogen effects were seen but not the irrigation effects. At early growth period, poor canopy coverage in no fertilizer treatment exposed the soil for evaporation resulting in lower soil moisture storage. However at peak growth and later stages, lowest soil moisture storage was observed in the treatments receiving 180 kg N/ha followed by 120 kg N/ha, 60 kg N/ha and the 0 kg N/ha treatments, probably because of better crop and root growth and correspondingly higher uptake of water by the crop. The RLD showed significant ($P<0.05$) variation among the nitrogen treatments in 0-15 and 15-30 cm soil depth for both the years of study. The plant water stress measured in terms of relative water content (RWC) and leaf water potential (LWP) decreased with the increase in nitrogen levels. The water expense efficiency increased significantly both for grain yield and total dry matter production where as partial factor productivity of nitrogen decreased significantly with the increase in nitrogen levels. There was significant increase in the grain yield and total dry matter production of maize with the increase in nitrogen doses. Hence it can be concluded that in years of well distributed and sufficient rainfall 180 kg N/ha will result higher grain and total dry matter yield and water expense efficiency of maize in sandy loam soils of Delhi region.

Key words: Maize, Nitrogen use efficiency, Root growth, Soil water, Water use efficiency

Maize (*Zea mays* L.) is the third most important cereal crop after wheat and rice, grown in virtually every suitable agricultural region of the globe. In India, it is cultivated as a food as well as feed crop under varying soil, topography, seasons and management practices throughout the country (Singh *et al*. 2007). Among the various inputs, water and fertilizer (nutrients) are considered as the two key inputs making maximum contribution to maize productivity (Lenka *et al*. 2009). Out of the three macro elements (NPK), application of nitrogen fertilizer brings out highest yield increase in maize (Szeles *et al*. 2012). Increased nitrogen doses increases photosynthetic activity, leaf area index, leaf area density and root length density of maize (Szeles *et al*. 2012, Uribelarrea *et al*. 2009, Durieux *et al*. 1994). Efficient nutrient utilization and higher yields require optimal water supply. Seedling, knee height, flowering and grain filling stages are higly sensitive to water stress and respond well to irrigation at these stages (Jat *et al*. 2009). Limited water supply during vegetative development reduces stem and leaf cell expansion, resulting in reduced plant height and less leaf area. Water stress during tasseling could potentially cause even a 40–50% yield reduction. Water deficiency during tasseling and flowering reduces the grain number of cobs per row, whereas post-pollination water stress decreases kernel weight, resulting in significant yield reduction (Lauer 2003). Hence assured water supply during critical growth stages, will result in better utilization of applied nitrogen fertilizer and higher yield in maize. However, maize is basically grown as *kharif* (wet) season crop in the semi-arid tracts of the country where monsoon rainfall amount and distribution is highly erratic and uneven. So, farmers of this region go for

[1]Scientist, (e mail: sanatan28@gmail.com), [2]Principal Scientist and Professor (e mail: uchopra@rediffmail.com), [3]Principal Scientist (e mail: kk.bandyopadhyay@gmail.com), [4]Principal Scientist (e mail: prameelakrishnan@yahoo.com), [5]Principal Scientist and Head (e mail: rsingh.iari@gmail.com), [6]Principal Scientist (e mail: akjain.iari@gmail.com), Division of Agricultural Physics

irrigation at the critical stages of maize if rainfall is not sufficient. In the years of sufficient and well distributed rainfall, no irrigation is applied. Keeping these in view an experiment was planned to study the effect of irrigation (depending on the rainfall) and nitrogen doses on grain yield, total dry matter accumulation, water expense efficiency, and nitrogen use efficiency in maize.

MATERIALS AND METHODS

A field experiment was laid out in the research farm of Indian Agricultural Research Institute, New Delhi during the *kharif* season (July to October) of 2010 and 2011 with maize (HQPM 1) as test crop. The experimental site is located between 28°37' and 28°39' N latitude and 77°90' and 77°11' E longitude and at an altitude of 228.7 m above mean sea level in a semi-arid subtropical climatic belt. It is characterized by extreme temperatures, the annual maximum temperature goes up to as high as 45°C in summer, whereas the minimum temperature dips to as low as 1°C in winter. Summers are long (early April-August) with the monsoon setting in between (July-September). The soil is sandy loam in texture (Typic Haplustept) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction. The soil was low in organic carbon (5.0 g/kg) and total nitrogen (0.032%) and medium in available P (12.1 kg/ha) and K (281.0 kg/ha) content. The bulk density varied from 1.51 Mg/m^3 in the 0-15 cm layer to 1.62 Mg/m^3 in the 60-90 cm layer. Soil moisture content ranged from 24-26% V/V at field capacity (0.033 MPa) to 8-10% V/V at permanent wilting point (1.5 MPa) in different layers of 0-90 cm soil depth.

The experiment was planned in a split plot design with irrigation levels as the main plot and nitrogen doses as subplot factors, replicated three times. The subplot size was 4 m × 5 m. The irrigation levels were I_0 (Rainfed), I_1 (2 irrigations; seedling stage and flowering stage), I_2 (3 irrigations; seedling stage, knee height stage and flowering stage) and I_3 (4 irrigations; seedling stage, knee height stage, flowering stage and grain filling stage). The nitrogen treatments consisted of N_0: 0 kg of N/ha; N_1: 60 kg N/ha; N_2: 120 kg of N/ha and N_3: 180 kg N/ha. Nitrogen was applied in four splits, i e 20% N at sowing, 20% N at 4 leaf stage; 30% N at 8 leaf stage and the rest 30% N at flowering stage. The whole amount of P (80 kg P_2O_5/ha) and K (80 kg K_2O/ha) fertilizers were applied as basal application. The general recommended dose of fertilizers for maize (cv HQPM 1) is 150-180 kg N, 70-80 kg P_2O_5 and 70-80 kg K_2O/ha of land (Jat *et al*. 2009). Two preparatory tillage operations were carried out by duck foot tine cultivator for preparation of seed bed and mixing of fertilizers. The crop was sown at a seed rate of 20 kg/ha manually with a row spacing of 60 cm and plant spacing of 20 cm in 23rd July of 2010 and 11th July of 2011.

Soil moisture content in the profile (0-90 cm) was determined gravimetrically at regular intervals during the crop growth period of 2010 and 2011 to study the distribution and redistribution of the soil water in the profile. Water expense was computed by water balance method using the following equation (Bandyopadhyay *et al*. 2003, Sharma 2005 and Kumar *et al*. 2006).

$$\text{Water expense (WE)} = P + I - \Delta S$$

where P is precipitation, I is irrigation, ΔS is change in soil moisture storage in the profile.

$$\Delta S = S_f - S_i,$$

where S_f is final soil moisture storage in the profile at harvest and S_i is initial soil moisture storage in the profile at sowing.

Water expense efficiency (WEE) was estimated by dividing the grain yield of maize with the water expense.

Root samples were collected at flowering stage using core sampler (15 cm height and 7 cm diameter). The collected soil cores were sealed in polythene bags, brought to the laboratory, washed and processed for analysis. The length of the cleaned, air-dried roots from each depth was placed under WINRHIZO system (Regent Instruments Inc., Canada) and lengths were recorded through the scanning and image analysis of the root skeleton. The root length was divided by the volume of the core to compute root length density (RLD) for each soil depth.

The leaf area index (LAI) was measured by plant canopy analyzer (LAI-2000) at regular intervals. The leaf area duration was computed using the following relationship:

$$\text{Leaf area duration (LAD)} = \sum [(LAI_{(n-1)} + LAI_n)/2]\ (t_n - t_{n-1})$$

where LAI_n is sampling at time t_n and $LAI_{(n-1)}$ is sampling at time $t_{(t-1)}$.

Second fully expanded leaf from top was randomly collected from each experimental plot between 11.00 and 12.00 hr and transferred quickly to the laboratory in a moistened polythene bag for determining the chlorophyll content, relative water content (RWC) and leaf water potential (LWP) of the crop.

For determining RWC (Barr and Weatherley 1962), the mid-leaf section of about 5 cm^2 was cut with sharp blade in the laboratory, placed in a pre weighed air-tight vial and weighed to obtain leaf fresh weight (FW). Then the leaf sections were floated in distilled water in a petri-dish under low light conditions in the laboratory. After about 4 hr, the leaf sections were removed, blotted dry and re-weighed in the same vial to obtain leaf turgid weight (TW). Then they were dried at 65±5°C in an oven till constant weight and weighed with vial to get the dry weight (DW). The RWC was determined using the following formula:

$$\text{RWC (\%)} = [(FW-DW)/(TW-DW)] \times 100$$

where FW is the fresh weight, TW is the turgid weight, and DW is the dry weight.

LWP was measured using a pressure chamber instrument (Model 1000) following the method of Scholander *et al*. (1964).

For determining leaf chlorophyll content (LCC), 50 mg

Table 1 Weather conditions during the period of study

Particulars	July	August	September	October
	2010			
Mean air temperature (°C)	30.7	29.0	27.2	25.4
Relative humidity (%)	74.9	83.8	85.8	67.6
Wind speed (km/hr)	6.2	2.5	2.1	1.6
Rainfall (mm)	237.2	342.6	314.2	22.0
Pan evaporation (mm/day)	5.7	3.9	3.8	4.3
Sunshine hours (hr)	4.1	3.1	3.8	6.2
	2011			
Mean air temperature (°C)	30.2	29.4	28.9	21.1
Relative humidity (%)	77.6	81.5	80.3	59.6
Wind speed (km/hr)	4.7	1.2	4.7	4.0
Rainfall (mm)	43.8	226.8	163.6	0.0
Pan evaporation (mm/day)	3.7	3.6	3.6	4.4
Sunshine hours (hr)	2.6	4.2	6.5	7.0

of fresh leaf was extracted by a nonmacerated method equilibrating it with 10 ml of dimethyl sulfoxide (DMSO) in a capped vial and kept in an oven at 65°C for about 3 hours (Hiscox and Israelstam 1979). The decanted solution was used to estimate the absorbance at 645 and 663 nm wavelengths using UV-visible spectrophotometer. The total leaf chlorophyll content was calculated using the formula given below (Arnon 1949).

$$LCC = \{[(20.2 \times A_{645}) + (8.02 \times A_{663})] \times V\} / (100 \times W)$$

where LCC is total leaf chlorophyll content in mg/g of fresh weight, A_{645} is absorbance at 645 nm, A_{663} is absorbance at 663 nm, V is final volume of chlorophyll extract in DMSO and W is weight of plant sample.

The net sub-plot areas were harvested for grain yield. Partial factor productivity of N (PFPN) for maize was calculated by dividing grain yield (kg/ha) with total nitrogen applied (kg/ha) and expressed as kg of grain per kg of nitrogen supplied. The data were analyzed by analysis of variance as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weather

Mean monthly air temperature, relative humidity, wind speed, total rainfall, pan evaporation and sunshine hours during the period of study are presented in Table 1. The mean monthly air temperature, relative humidity, wind speed and sunshine hours of the crop growth period of both the years did not show significant ($P<0.05$) variation. However, the average pan evaporation during the crop growth period was significantly ($P<0.01$) higher in 2010 (4.43 mm/day) than 2011 (3.80 mm/day). The *kharif* season of the year 2010 (920.6 mm) showed significantly higher and well distributed rainfall than the *kharif* season of the year 2011 (538.4 mm). Well distributed and sufficient rainfall in the *kharif* season of the year 2010 led to no application of irrigation water to the maize crop. Hence only nitrogen application effects were observed. However due to lower rainfall in the month of July 2011 (82% lower rainfall compared to the month of July, 2010), one life saving irrigation of 60 mm was applied uniformly to all treatments at initial stages of crop growth. However, sufficient and well distributed rainfall occurred in the rest crop growth period of 2011 and did not require application of irrigation water there onwards. Hence in both the years, only nitrogen effects were observed but not the irrigation effects, which is clear from the maize grain yield, total dry matter, water expense efficiency and partial factor productivity analysis data (Table 2).

Table 2 Grain yield, total dry matter (TDM) yield, water expense efficiency (WEE) and partial factor productivity of nitrogen (PFPN) of maize (Pooled over the year 2010 and 2011)

Treatments	Grain yield (kg/ha)	TDM yield (kg/ha)	WEE of grain (kg/ha/cm)	WEE of TDM (kg/ha/cm)	PFPN (kg of grain/kg of N applied)
Irrigation effects					
I0	5081a*	17910a	8.06a	29.12a	55.45a
I1	5295a	16837a	8.45a	27.74a	53.95a
I2	5376a	17466a	8.58a	28.22a	53.01a
I3	5378a	17333a	8.61a	28.12a	56.32a
Nitrogen effects					
0 kg N/ha	3180d	12774d	5.31d	21.51d	
60 kg N/ha	4251c	15554c	6.89c	26.1c	70.86a
120 kg N/ha	6153b	19289b	9.72b	30.85b	51.28b
180 kg N/ha	7546a	21928a	11.79a	34.73a	41.92c

*Numbers followed by same letters are not significantly different at P=0.01 as per DMRT test

Soil water dynamics

Soil moisture storage of maize crop was measured to a soil depth of 90 cm at regular intervals by thermo-gravimetric method for both the years of study and is presented in Fig 1. The soil moisture storage at sowing was 46 % less in the year 2011 (126 mm) than the year 2010 (235 mm). Further, year 2011 experienced much less rainfall than the year 2011 during the initial period (up to 20 days after sowing). So, in the year 2011, an irrigation of 60 mm water was given to all plots for survival of plants. After that no irrigation was required because of sufficient and well distributed rainfall. The soil moisture storage in all the treatments for both the years remained well within the FC and PWP (the classical lower and upper limit suction for plant available water) throughout the crop growth period (Fig 1). The optimal availability of soil moisture through out the crop growth period is attributed to the sufficient and well distributed rainfall. At early growth period no fertilizer treatment (0 kg N/ha) also showed lower soil moisture storage in both the years. Poor canopy coverage as indicated by lower LAI (Fig 2) in no fertilizer treatment exposed the soil for evaporation resulting in lower soil moisture storage. Bandyopadhyay et al. (2003) also observed higher soil moisture loss through evaporation under low canopy coverage of soybean crop due to no fertilizer supply. However at peak growth and later stages, lowest soil moisture storage was observed in the treatments receiving 180 Kg N/ ha followed by 120 kg N/ha, 60 kg N/ha and the 0 kg N/ha treatments, probably because of better leaf area index and root length density (Fig 2 and 3) and correspondingly higher uptake of

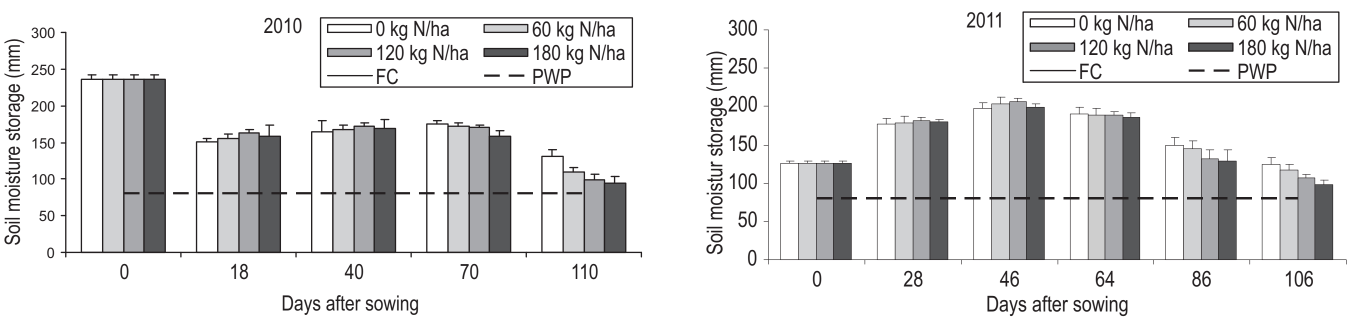

Fig 1 Temporal variation in the soil moisture storage in the profile (0-90 cm) during maize growth for the 2010 and 2011

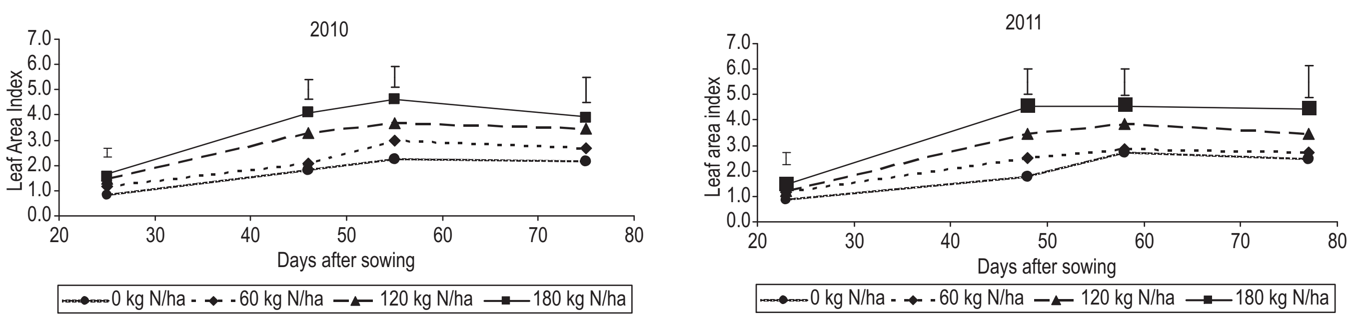

Fig 2 Leaf Area Index (LAI) as influenced by nitrogen levels for the year 2010 and 2011. The error bars indicate least significant difference at $P<0.05$; NS: indicate not significantly different at $P<0.05$

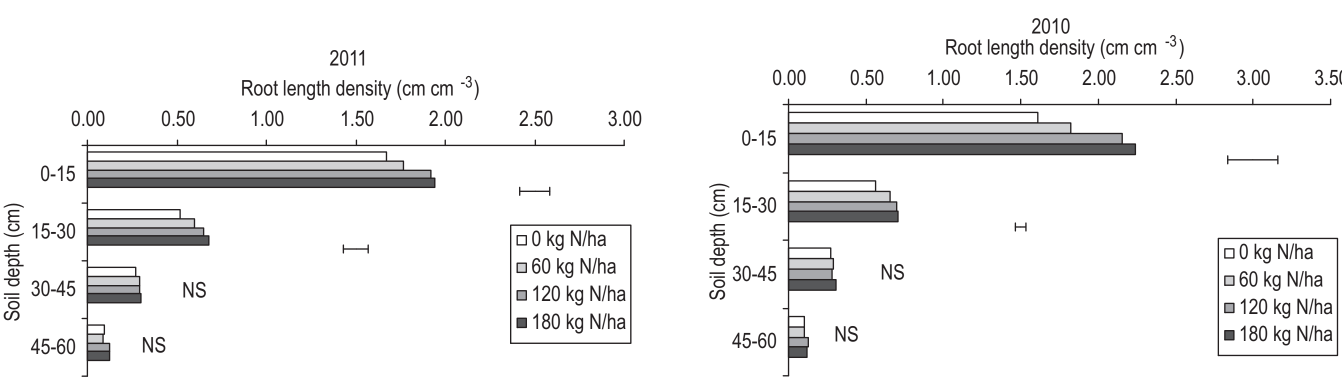

Fig 3 Root length density as influenced by nitrogen levels for the year 2010 and 2011. The error bars indicate least significant difference at $P<0.05$; NS: indicate not significantly different at $P<0.05$.

water by the crop. Similar type of result were observed by Hati *et al*. (2001) for wheat crop in a Vertisol for manured and fertilized plots than unfertilized plot because of better crop growth in the fertilized plots. The distribution of moisture content in the profile (data not given) depicts that difference in the moisture content due to different doses of nitrogen fertilizers was more prominent in the upper layer than in the lower layers which emphasizes higher moisture extraction from upper layers because of higher root density in those layers. Highest water extraction from the profile was from the treatment receiving 180 kg N/ha followed by 120 kg N/ha, 60 kg N/ha and 0 kg N/ha treatments.

Leaf Area Index and root growth

The leaf area index (LAI) of maize increased till 50–60 days after sowing and then it declined (Fig 2). The fall in LAI during the later part of crop growth was due to senescence of older leaves. The peak value of leaf area index coincided with silking stage. This is in agreement with Panda *et al.* (2004) who also observed highest LAI during silking and grain filling stage under optimum growing conditions. The LAI showed significant ($P<0.05$) variations among the nitrogen treatment for both the years of study. The highest LAI was observed in 180 kg N/ha treatment and the lowest in 0 kg N/ ha. Greater LAI in 180 kg N/ha treatment was attributed to production of new leaves and also increase in size of the existing leaves due to better availability and uptake of nitrogen. Cox *et al.* (1993) also observed increase in LAI of forage maize with increased application of nitrogen. Pooled over the years, the average leaf area index followed quadratic relationship with time (t in days) as given in Eq (1):

$$LAI = -0.0016t^2 + 0.2032t - 2.8537, R^2 = 0.99^{**} \quad (1)$$

The total leaf area duration (LAD) significantly ($P<0.05$) varied among the treatments (data not presented). There was no significant ($P<0.05$) variation in LAD between 0 and 60 kg N/ha and 120 and 180 kg N/ha in both the years of study. Averaged over the years , total LAD was 49, 37 and 18 % less in 0, 60 and 120 kg N/ha than the 180 kg N/ha. Higher LAD in higher nitrogen treatments resulted in more PAR interception for a longer duration which gave rise to increased biomass and grain yield production. The LAD could account for 99 % variation in the grain yield (Y) of the maize as evident from Eq. (2):

$$Y = 34.08\ LAD - 1379.3, R^2=0.99^{**} \quad (2)$$

Irrespective of the treatments, the maximum root length density (RLD) of maize was observed in the 0-15 cm soil layer and there was significant decrease ($P<0.01$) in the RLD with depth (Fig 3). Averaged over treatments and year, the percentage of RLD in 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm were 66, 22, 10 and 4 % respectively. The RLD showed significant ($P<0.05$) variation among the nitrogen treatments in 0-15 and 15-30 cm soil depth for both the years of study. The RLD of 0-15 and 15-30 cm soil depth increased with the increase in nitrogen application rates being highest at 180 kg N/ha and lowest in 0 kg N/ha. Durieux *et al*. (1994) and Anderson (1987) also reported that application of N fertilizer stimulated root growth at the surface but not at lower depths. Averaged over the years, the RLD at 0-30 cm soil depth could account for 95% variations in grain yield of maize (Y), as evident from Eq (3):

$$Y = 6812.9\ RLD - 11907, R^2 = 0.95^{**} \quad (3)$$

Chlorophyll content, relative water content and leaf water potential

The leaf chlorophyll content in grain filling stage was significantly higher than that at silking stage for both the years of study (Table 3). With increase in N dose, the cholorophyll contetnt increased significantly but there was not significant difference in chlorophyll content among 60, 120 and 180 kg N/ha at the silking stage and between 120 and 180 kg N/ha at grain filling stage during the year 2010. Whereas during the year 2011, the chlorophyll content at 180 kg N/ha was significantly higher than that at 120 kg N/ha. This may be attributed to significantly higher rainfall received during the year 2010 (especially during the early growth period) than the year 2011, which might have facilitated higher leaching loss of N (Table 1) during the year 2010. Szeles *et al*. (2012) also observed no significant changes in chlorophyll content of maize leaves as a result of N doses under natural precipitation. Averaged over the years, chlorophyll content at grain filling stage (CH_g) of maize leaves showed better correlation with grain yield of maize than at silking stage and accounted for 97% variations in the grain yield (Y) of maize as evident from Eq 4:

$$Y = 3221.8\ CH_g - 3666, R^2 = 0.97^{**} \quad (4)$$

The relative water content (RWC) increased with the increase in N levels (Table 4). The difference is more prominent during grain filling stage than the silking stage. During the year 2011, the RWC at 180 kg N/ha was significantly higher than that of 120 kg N/ha. However during the year 2010, there was no significant difference in the RWC at 120 and 180 kg N/ha, which may be attributed to relatively higher rainfall received during the year 2010.

Table 3 Chlorophyll content of maize leaf for the years 2010 and 2011.

	2010		2011	
	Silking	Grain filling	Silking	Grain filling
0 kg N/ha	1.29b*	2.24c	1.29c	2.15d
60 kg N/ha	1.65ab	2.39bc	1.79b	2.52c
120 kg N/ha	1.81ab	2.97ab	1.79b	2.84b
180 kg N/ha	2.03a	3.52a	2.11a	3.59a

* Numbers followed by same letters are not significantly different at P= 0.05 as per Duncan's Multiple Range Test

Table 4 RWC of maize for the years 2010 and 2011

	2010		2011	
	Silking	Grain filling	Silking	Grain filling
0 kg N/ha	93.24b*	86.35c	92.29	85.76
60 kg N/ha	95.48a	87.34bc	93.42	87.42
120 kg N/ha	96.11a	89.49abc	95.68	90.35
180 kg N/ha	96.26a	93.51a	97.13	94.34

* Numbers followed by same letters are not significantly different at P=0.05 as per Duncan's Multiple Range Test

The LWP followed almost similar trend as that of RWC, i e the LWP decreased significantly (less negative) at higher doses of N supply (Table 5). Just like RWC, the difference in LWP due to variation in N dose was more prominent at grain filling stage than at silking stage. The water stress as indicated by RWC and LWP was maximum in 0 kg N/ha for all the stages in both the years (i e lower RWC and higher LWP). This may be attributed to the fact that N stress in control treatment behaved similar to water stress. N stress might have reduced transpiration, increased the canopy temperature resulting in low plant water status (Aggarwal *et al*. 2004). They have also reported that the effect of N stress is similar to water stress accelerating the phenological development. Among N and water stress, the one that was more prominent affects the rate of development. N stress affected the carbohydrate partitioning and senescence similar to water stress. Averaged over years, the LWP and RWC could account for 98% variation in the grain yield of maize.

Crop yield, water and nitrogen use efficiency

The grain yield, total dry mass, water expense efficiency with respect to grain yield (WEE_{gy}), water expense efficiency with respect to total dry mass (WEE_{tdm}) and partial factor productivity of nitrogen were pooled over the years and are presented in Table 2. The grain yield of maize showed significant ($P<0.01$) differences among the nitrogen treatments. The highest grain yield was observed in 180 kg N/ha treatment and lowest in 0 kg N/ha. Averaged over the years, 58, 44 and 18% lower grain yield was observed in 0, 60, 120 kg N/ha than 180 kg N/ha, respectively. The total dry matter followed similar trend as that of grain yield of maize. Averaged over the years, 42, 29 and 12% lower total dry mass was observed in 0, 60, 120 kg N/ha than 180 kg N/ha, respectively. The higher yield at higher level of N application could be attributed to higher rate of photosynthesis (indicated by high dry matter accumulation), better water use (indicated by lower soil moisture storage and better water expense efficiency), higher nitrogen uptake (indicated by higher chlorophyll content), lower plant water stress (indicated by higher RWC and lower LWP) and better root growth (indicated by better RLD). Bennett *et al*. (1989) and Ogola *et al*. (2002) also observed reduced biomass and grain yield of maize crops under lower nitrogen dose in the optimal irrigation or available water condition.

Table 5 Leaf water potential (MPa) of maize for the year 2010 and 2011.

	2010		2011	
	Silking	Grain filling	Silking	Grain filling
0 kg N/ha	– 1.22a*	– 1.38a	– 1.27a	– 1.35a
60 kg N/ha	– 1.21a	– 1.33a	– 1.23ab	– 1.30ab
120 kg N/ha	– 1.18a	– 1.30a	– 1.19b	– 1.27b
180 kg N/ha	– 1.11a	– 1.18b	– 1.09c	– 1.17c

* Numbers followed by same letters are not significantly different at P=0.05 as per Duncan's Multiple Range Test

The water use efficiency of maize in terms of water expense efficiency with respect to grain yield and total dry matter also showed significant ($P<0.01$) differences among the nitrogen treatments being highest in 180 kg N/ha and lowest in 0 kg N/ha. Water expense efficiency with respect to grain yield (WEE_{gy}) was 55, 42 and 18% lower in 0, 60, 120 kg N/ha as compared to the 180 kg N/ha, whereas water expense efficiency with respect to total dry matter (WEE_{tdm}) was 38, 25 and 11% lower in 0, 60, 120 kg N/ha as compared to the 180 kg N/ha. The better water expense efficiency in higher doses of N can be attributed to better crop and root growth. Bandyopadhyay *et al.* (2003) also observed better water expense efficiency in integrated use of fertilizer and farmyard manure treatment in soybean compared to control treatment because of better crop and root growth in the former treatment.

The nitrogen use efficiency of maize as measured through partial factor productivity of nitrogen decreased with the increase in nitrogen doses. This may be attributed to the fact that with the increase in the nitrogen level, there was not proportionate increase in the grain yield and there was increase in the losses of nitrogen through leaching, volatilization and deep percolation. Bandyopadhyay *et al*. (2009) also observed decreased partial factor productivity of nitrogen in cotton at higher doses of nitrogen.

CONCLUSIONS

From this study it may be concluded that there was significant increase in the grain yield and total dry matter production of maize with the increase in nitrogen doses. The WEE of maize in terms of grain yield and total dry matter production increased significantly whereas partial factor productivity of nitrogen decreased significantly with the increase in nitrogen levels. The plant water stress measured in terms of RWC and LWP decreased with the increase in nitrogen levels. The leaf area duration and root length density of maize at 0-15 and 15-30 cm soil layer increased with the increase in nitrogen levels. The RLD in 0-30 cm soil layer could account for 95% variation in the grain yield of maize. So maize (cv HQPM 1) may be grown with 180 kg N/ha under rainfed condition during the years of sufficient and well distributed rainfall to obtain higher yield and water expense efficiency in the semiarid tropical environment of Delhi region.

REFERENCES

Aggarwal P K, Kalra N, Chander S and Pathak H. 2004. Infocrop: A generic simulation model for annual crops in tropical environments. Division of Enviromental Science, IARI, New Delhi.

Anderson E L. 1987. Corn root growth and distribution as influenced by tillage and nitrogen fertilization. *Agronomy Journal* **79**: 544–9.

Arnon D I. 1949. Copper enzymes in isolated chloroplasts, polyphenoloxidase in *Beta vulgaris*. *Plant Physiology* **24**: 1–15.

Bandyopadhyay K K, Misra A K, Ghosh P K, Hati K M and Mandal K G. 2003. Effect of integrated use of farmyard manure and inorganic fertilizers on soil water dynamics, root growth, crop yield and water expense efficiency of rainfed soybean in a Vertisol. *Journal of Agricultural Physics* **3**: 95–103.

Bandyopadhyay K K, Prakash A H, Sankaranarayanan K, Dharajothi B and Gopalakrishnan N. 2009. Effect of irrigation and nitrogen on soil water dynamics, productivity and inpu-use efficiency of *Bt* cotton (*Gossypium hirsutum*) in a Vertic Ustropept. *Indian Journal of Agricultural Sciences* **79**: 448–53.

Barr H D and Weatherley P E. 1962. A re-examination of the relative turgidity technique for estimating water deficit in leaves. *Australian Journal of Biological Sciences* **15:** 413–28.

Bennett J M, Mutti L S M, Rao P S C and Jones J W. 1989. Interactive effects of nitrogen and water stress on biomass accumulation, nitrogen uptake, and seed yield of maize. *Field Crop Research* **19**: 297–311.

Cox W J, Kalonge S, Cherney D J R and Reid W S. 1993. Growth, yield, and quality of forage maize under different nitrogen management practices. *Agronomy Journal* **85**: 341–7.

Durieux R P, Kamprath E J, Jackson W A and Moll R H. 1994. Root distribution of corn: The effect of nitrogen fertilization. *Agronomy Journal* **86**: 958–62.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*. John Willey & Sons, NY.

Hati K M, Mandal K G, Mishra A K, Ghosh P K and Acharaya C L. 2001. Effect of irrigation regimes and nutrient management on soil water dynamics, evapotranspiration and yield of wheat in vertisols. *Indian Journal of Agricultural Sciences* **71**: 581–6.

Hiscox J D and Israelstam G F. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57**: 1 332–4.

Jat M L, Dass S, Yadav V K, Sekhar J C and Singh D K. 2009. Quality protein maize for food and nutritional security in India. DMR Technical Bulletin 2009/4, pp 23.

Lauer J. 2003. What happens within the corn plant drought occurs. University of Wisconsin Extension (http://www.uwex.edu/ces/ag/issues/drought2003/corneffect.html).

Lenka S, Singh A K and Lenka N. 2009. Water and nitrogen interaction on soil profile water extraction and ET in maize-wheat cropping system. *Agricultural Water Management* **96**: 195–207.

Ogola J B O, Wheeler T R and Harris P M. 2002. Effects of nitrogen and irrigation on water use of maize crops. *Field Crop Research* **78**: 105–17.

Panda R K, Behera S K and Kashyap P S. 2004. Effective management of irrigation water for maize under stressed conditions. *Agricultural Water Management* **66**: 181–203.

Scholander P L, Hammel H T, Bradstree E D, Hemmingsen E Q. 1964. Hydrostatic pressure and osmotic potential in leaves of mangroves and some other plants. *Proceedings of the National Academy of Sciences of USA* **52:** 119–25.

Sharma B M. 2005. Effect of density of acacia and phosphorus fertilization on yield and water expense efficiency of rainfed cowpea in arid environment. *Journal of the Indian Society of Soil Science* **53**: 46–9.

Singh R. Sharma A R and Behera U K. 2007. Tillage and crop establishment practices for improving productivity of maize (*Zea mays* L.) under different weed control methods. *Indian Journal of Agricultural Sciences* **77**: 731– 37.

Szeles A V, Megyes A and Nagy J. 2012. Irrigation and nitrogen effects on the leaf chlorophyll content and grain yield of maize in different crop years. *Agricultural Water Management* **107**: 133–44.

Uribelarrea M, Crafts-Brandner S J, Below F E. 2009. Physiological N response of field-grown maize hybrids (*Zea mays* L.) with divergent yield potential and grain protein concentration. *Plant and Soil* **316:** 151–60.