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Archana KumariDepartment of Agronomy, Bihar
Agricultural University, Sabour,
Bihar, India**Sanjay Kumar**Department of Agronomy, Bihar
Agricultural University, Sabour,
Bihar, India**Mainak Ghosh**Department of Agronomy, Bihar
Agricultural University, Sabour,
Bihar, India**Swaraj Kumar Dutta**Department of Agronomy, Bihar
Agricultural University, Sabour,
Bihar, India**Amit Kumar Pradhan**Department of Soil Science and
Agricultural Chemistry, BAU,
Sabour, Bihar, India**Vinod Kumar**Department of Agronomy, Bihar
Agricultural University, Sabour,
Bihar, India**Corresponding Author:****Vinod Kumar**Department of Agronomy, Bihar
Agricultural University, Sabour,
Bihar, India

Effect of tillage, sowing time and irrigation levels on soil available moisture and water use efficiency of maize (*Zea mays* L.)

Archana Kumari, Sanjay Kumar, Mainak Ghosh, Swaraj Kumar Dutta, Amit Kumar Pradhan and Vinod Kumar

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Abstract

A field experiment was conducted during the *rabi* season of 2016-17 at Research farm of Bihar Agricultural College, Sabour, to evaluate the effect of tillage, sowing time and irrigation levels on soil available moisture and water use efficiency of maize (*Zea mays* L.). The experiment comprised of two tillage methods *viz.* conventional tillage (CT) and zero tillage (ZT) in main plot, two sowing dates- 30th October and 10th November as sub-plot and three irrigation levels (I₂ - 2 irrigations at six-leaf stage and tasseling, I₄ - 4 irrigations at four-leaf stage, ten leaf stage, tasseling and milking and I₆ - 6 irrigations at four-leaf stage, eight leaf stage, ten leaf stage, tasseling, milking and dough stage) as sub-sub plot treatment. The results indicated that the seasonal evapotranspiration (SET) increased significantly with increase in number of irrigation application. With the increase in two irrigations from I₂ to I₄ the grain yield water use efficiency (WUE_y) increased by 30 percent while with further increase in two irrigations (I₆) resulted in 10 percent reduction in WUE_y over I₄ irrigation level. However, the I₆ irrigation level recorded 17 percent higher WUE_y over I₂ irrigation level. Although grain yield were higher with six irrigations but significantly higher water use efficiency was obtained due to ZT, early planting and I₄ irrigation level.

Keywords: Zero tillage, date of sowing, water use efficiency of maize and irrigation

Introduction

In India, maize has been widely cultivated as a rainfed crop during *kharif* season but it can also be successfully grown during the *rabi* season as yield of *rabi* maize is considerably higher than that of *kharif* maize (Patel *et al.*, 2006) [16]. The *rabi* maize has been widely accepted by farmers of Bihar with a cultivated area of 0.28 million ha with total production of 2.1 million tonnes (Directorate of Economics & Statistics, 2018-19) [4]. To augment the higher maize yield per unit area and sufficient water use efficiency, proper crop agronomic management is necessary. Sowing of the crop at right time ensures better plant growth, boosting the maize yield by increasing the resource use efficiency and also by inhibiting weed growth. Tillage system is an integral part of crop production and it has been confirmed by different scientists that conventional intensive tillage increases soil compaction, reduces soil aggregates stability, disrupts soil productivity, decreases retention and transportation of water and solutes and exacerbates losses due to run-off erosion (Goddard *et al.*, 2008) [6]. In contrast many beneficial effects of zero-till and minimum tillage have also been reported like increased porosity, organic carbon, water holding capacity and decreased bulk density. It is well documented that zero tillage and crop residues management improves soil health and quality by improving various soil properties like reduced penetration resistance as well as the apparent density of soil that checks the soil evaporation rate (Rivas *et al.*, 1998) [20]. Water infiltration and soil aeration that depend on bulk density are also modified (Rice *et al.*, 1987) [19]. Zero tillage affects water availability to plants, essentially through soil water capture and root uptake capacity (Gajri *et al.*, 1994; Ojeniyi, 1986) [5, 14]. Zero tillage has also been reported to increase total nitrogen and microbial biomass in various soils (McCarty *et al.*, 1995) [10]. The crop residues in zero tillage become a mulch over the soil surface that protects the soil productive layer against run-off reducing the nutrient loss and erosion through runoff

(Perret *et al.*, 1999, Smart and Bradford, 1999) [17, 22] and increases the percentage of organic matter in the superficial soil layer (Rivas *et al.*, 1998) [20]. Irrigation is another important management practice for higher crop production with better nutrient uptake which is mainly dependent on both irrigation frequency and total water application affecting root distribution and total root length (Robertson *et al.*, 1980) [21]. This determines the vital plant physiological processes like cell elongation, cell division, cell wall synthesis, nitrate reductase activity and photosynthesis that are very sensitive to plant water status. Therefore, performance of a plant in terms of its growth, yield and nutrient content is mainly dependent on plant water status. Availability of optimum moisture in the soil enhances the efficiency of applied nutrients, and any reduction of soil moisture at these stages will considerably reduce the yield. The present investigation was carried out to evaluate the effect of tillage, sowing time and irrigation levels on soil available moisture and water use efficiency of maize (*Zea mays* L.).

Management associated with soil health and quality by improving soil properties, minimizing soil erosion, soil water evaporation and conserving soil moisture is well documented. Zero tillage increases the mechanical resistance and the * E-mail: pmonneveux@yahoo.fr

Plant and Soil (2006) 279:95–105 □ Springer 2006 DOI 10.1007/s11104-005-0436-3 apparent density of soil and curbs the soil evaporation rate (Rivas *et al.*, 1998) [20]. Water infiltration and soil aeration that depend on bulk density are also modified (Rice *et al.*, 1987) [19].

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Materials and Methods

A field experiment was conducted during the *rabi* season of 2016-17 at Bihar Agricultural University farm, Sabour (25°15'40" N, 87°2'42" E; 37 m above mean sea level), Bhagalpur, Bihar, India. The soil of the experimental field was sandy loam with neutral in reaction, medium in organic carbon (0.6%) and available phosphorus (35.2 kg P₂O₅ ha⁻¹), while low in available soil nitrogen (220.1 kg ha⁻¹), and rich

in soil potassium (327 kg K₂O ha⁻¹). The experiment comprised of twelve treatment combinations laid out in split-split design with three replications. The two tillage methods *viz.* zero tillage (T₁ - ZT) and conventional tillage (T₂ - CT) were kept as main plots, while in sub-plot it was two sowing dates (D₁ - 30 October and D₂ - 10 November), and in sub-sub plot there were three irrigation levels *i.e.* I₂ (2 irrigations at six-leaf stage and tasseling), I₄ (4 irrigations at four-leaf stage, ten leaf stage, tasseling and milking) and I₆ (6 irrigations at four-leaf stage, eight leaf stage, ten leaf stage, tasseling, milking and dough stage). The maize crop was sown on 30 October and 10 November in the year 2016 with a spacing of 60×20 cm and harvested on 7 April and 20 April 2017, respectively. The experimental data recorded were analyzed statistically in split-split plot design to test the significance of the overall differences among treatments by using the F test and conclusions were drawn at 5% probability level. For recording the soil moisture, soil samples were collected at regular intervals from different depths of each treatment and the moisture content was determined gravimetrically. The soil moisture samples were collected from each soil depth of 0-15 cm, 15-30 cm, 30-45 cm and 45-60cm and oven dried at 105 °C until a constant weight was attained. The soil moisture was measured before and after irrigation and the summation of the values provided the measurement for seasonal evapotranspiration for the entire period. The seasonal evapotranspiration was calculated based on the following formula –

$$\text{Seasonal Evapotranspiration} = \left[\sum_{i=1}^n \frac{Mb_i - Me_i}{100} \right] \times BD_i \times D_i$$

Where,

Mb_i = Soil moisture % before irrigation.

Me_i = Soil moisture % after irrigation.

n = No. of soil layers considered in root zone depth (D).

BD_i = Bulk Density of ith soil layer.

Water Use Efficiency

Water use efficiency of the grain produced was calculated as the ratio of grain yield at 0% humidity (in kg ha⁻¹) after passing it in the oven for 72 h at 105 °C to seasonal evapotranspiration (in mm).

$$WUE_y = \frac{\text{Yield}}{\text{Seasonal Evapotranspiration}}$$

Where,

WUE_y refers to water use efficiency of grain produced

$$WUE_{bm} = \frac{\text{Biomass}}{\text{Seasonal Evapotranspiration}}$$

Where,

WUE_{bm} refers to water use efficiency of the biomass produced.

Results and Discussion

Effect of tillage, dates of sowing and irrigation levels on the soil moisture variability of maize crop

Water plays a vital role in the metabolism of plants by providing hydrogen for the reduction of carbon dioxide in the photosynthetic process which makes it a key input in the agricultural production system. The availability of fresh water

is also pertinent towards achieving sustainability in agricultural production. However, the lack of available water for agricultural production has also emerged as a major issue both at national and international scale. Thus irrigation plays a vital role for achieving the yield targets. Next to water, tillage plays an essential role in altering physicochemical and biological properties of soil and providing congenial conditions for better root growth of maize crop. However repetitive tillage can negatively influence the soil physicochemical properties as well as adversely impact the availability of soil moisture to the crops. Zero tillage along with residue retention has been observed to maintain a constant balance inside available moisture thereby improving yield of crops. Understanding the effect of sowing time and tillage on yield formation becomes an essential step for planning a suitable management strategy for improving the yields of maize crop for the region.

Variation in profile soil moisture availability under I₂ level of irrigation

Under I₂ level of irrigation, two irrigations were applied during six leaf stage and just before silking in maize crop. The data pertaining to the variation in profile soil moisture availability is presented in the figure 1. The available soil moisture in 0 to 90 cm soil depth gradually declined from sowing to harvesting of maize crop irrespective of tillage systems and sowing dates. During the initial period of crop growth the soil moisture depletion was steep under D₂ sowing as compared to D₁ irrespective of tillage; however zero tillage (ZT) plots maintained higher soil moisture content compared to conventional tillage (CT) plots.

After the application of first irrigation during six leaf stage of maize crop, the available soil moisture content varied within 306 to 307 mm under D₁ sowing while it varied within 255 to 260 mm under D₂ sowing. After the application of first irrigation the D₁ sown crop recorded higher soil moisture extraction as compared to D₂ sown crop which might be due to the profuse growth of the crop during the period. During the vegetative period, ZT under D₁ sowing maintained higher soil profile moisture as compared to CT plots and also ZT and CT plots under D₂ sowing. After the application of second irrigation during just before silking, the data showed a steep decline in the soil profile moisture under both tillage systems and date sowings. However the depletion in soil moisture was higher for D₂ sown crop as compared to D₁ sowing.

Interestingly it was also observed that under D₁ sowing at the time of harvest ZT plots maintained 21 mm higher soil moisture content over CT plots while under D₂ sowing the ZT and CT had a very low moisture difference of 6 mm. At the initial stage of crop growth the early growth and development of D₁ sown crop resulted in higher depletion of soil moisture and also due to CT the profile soil moisture was easily lost through evaporation while in ZT plots due to presence of retained residues of previous crop the soil evaporation was relatively less resulting in higher profile moisture content. However, due to the late harvest of D₂ sown crop coinciding with high-temperature period and low irrigation levels, resulted in higher soil moisture extraction under both ZT and CT tillage and therefore there was minimal difference in profile moisture content under both the tillage of D₂ sown crop.

Variation in profile soil moisture availability under I₄ level of irrigation

Under I₄ level of irrigation, four irrigations were applied

during four leaf stage, ten leaf stages, just before silking and milking stages respectively in maize crop. The data pertaining to the variation in profile soil moisture availability is presented in the figure 1. In contrast to I₂ level of irrigation the first irrigation was applied at four leaf stage of the maize crop. The initial depletion in available soil moisture for D₂ sowing was higher as compared to D₁ sown crop. The data recorded no pertinent difference in soil moisture availability due to tillage. After the application of first irrigation at four leaf stage, the D₂ sown crop recorded comparatively higher depletion in profile soil moisture over D₁ sown crop.

The D₁ sown crop did not project any visible difference in soil moisture availability due to tillage up to 6 leaf stage, however with the further development of the crop, at eight leaf stage ZT plots maintained higher soil moisture availability as compared to CT plots irrespective of dates of sowing. Within 10 leaf stage up to just before silking of the maize crop the conventionally tilled D₁ sown crop recorded higher soil moisture depletion over other treatments. This might be due to higher biomass production under D₁ sowing coupled with higher rate of moisture lost from CT plots. Due to the presence of surface residue in ZT plots resulted in minimising the loss of soil moisture through evaporation due to which the D₁ sown ZT plots maintained higher level of soil moisture availability up to dough stage in maize crop. The post anthesis period under I₄ level of irrigation recorded visible difference in soil moisture availability due to tillage and date of sowing. The ZT plots under D₁ sowing maintained the highest soil moisture availability followed by CT plots under D₁ sowing followed by ZT plots under D₂ sowing while the lowest soil moisture availability was recorded for CT plots under D₂ sowing.

After the application of last irrigation at milking stage of the crop, the ZT plots utilised about 122 mm and 119 mm to of profile soil moisture while under CT system the crop could utilise only 110 mm and 107 mm of available soil moisture under D₁ and D₂ sowing respectively. Due to maintenance of residues over the soil surface under ZT resulted in reduced loss of soil moisture through evaporation and therefore it maintained higher soil moisture levels which could be utilised by the crop.

Variation in profile soil moisture availability under I₆ level of irrigation

Under I₆ level of irrigation, six irrigations were applied during four leaf stage, eight leaf stage, booting, just before silking, milking and dough stages respectively in maize crop. The data pertaining to the variation in profile soil moisture availability is presented in the figure 1 as compared to I₂ and I₄ irrigation levels, the profile soil moisture variability was much higher under I₆ irrigation level.

The difference in the profile available soil moisture between ZT and CT plots under I₆ irrigation level was initially lower up to 6 leaf stage but the difference gradually increased up to booting stage of the crop thereafter which the profile soil moisture recorded a decreasing trend up to harvest irrespective of tillage systems. The ZT plots maintained an average of about 13 mm of higher soil moisture over CT plots. The difference in soil moisture availability between ZT and CT plots was maximum during the booting stage of the crop irrespective of dates of sowing. During the reproductive phase of the crop that is within tasseling two milking stage of maize the difference in soil moisture with in CT and ZT plots was higher under D₂ sowing conditions as compared to D₁ sown crop. Noticeably it was also observed that of the total

water consumed by the crop for evapotranspiration purpose, under D₁ sowing condition almost 50 percent of the total water was utilised by the crop during the vegetative growth period and the rest was utilised from flowering to harvest of the crop irrespective of tillage systems.

However for D₂ sowing under CT, 55 percent (275 mm) of the total SET was used for vegetative growth of the crop and the rest 45 percent during the reproductive phase of the crop. In contrast ZT plots under D₂ sowing condition recorded consumption of 52 percent (250 mm) of the total

water use for vegetative growth and rest for the reproductive growth and grain filling purpose. This indicated that when the sowing of the maize crop was very late higher proportion of the water use for evapotranspiration was diverted towards the vegetative growth of the crop. It also indicates that this partitioning of water between vegetative and reproductive phase could be offset through tillage intervention wherein ZT could balance the water use of the crop by conserving moisture within the soil profile and distributing it equally between the two growth phases of the crop.

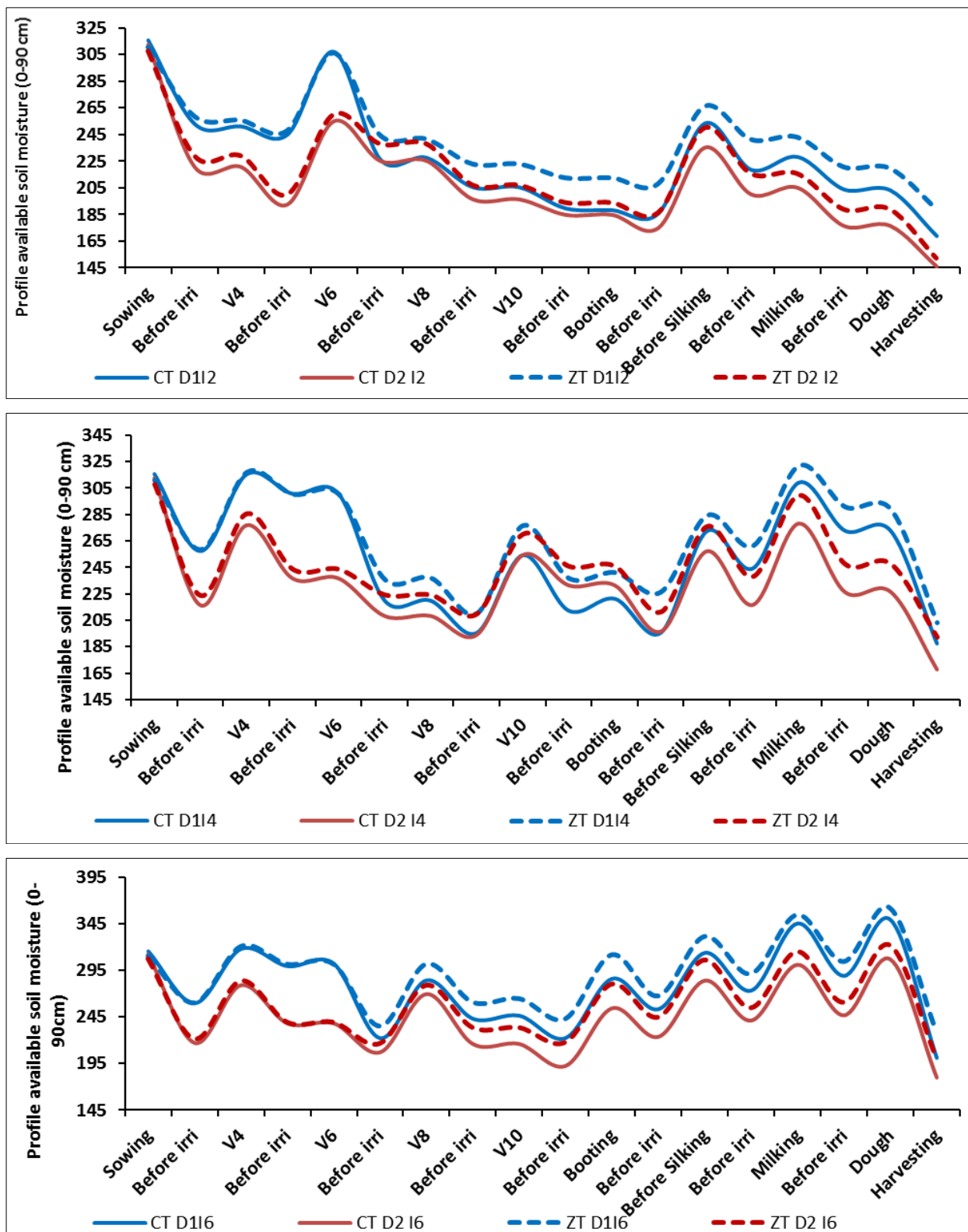


Fig 1: Variation in profile soil moisture availability to maize crop as influenced by tillage, sowing time and irrigation levels

Effect of dates of sowing, tillage and irrigation levels on the soil moisture extraction pattern by maize crop

The data on soil moisture extraction pattern (mm) of maize crop from different soil depths as influenced by tillage, date of sowing and irrigation levels is presented in the figure 2. The moisture extraction pattern from different soil layers was found to be highest from the upper soil layer of 0 to 15 cm irrespective of dates of sowing, tillage and irrigation levels. With the gradual increase in soil depth the soil moisture extraction continuously decreased up to 60 to 90 cm of the total water utilised for evapotranspiration purpose on an average 34 percent of the soil water was absorbed by the crop from 0 to 15 cm soil layer, 30 percent from 15 to 30 cm soil depth, 23 percent from 30 to 60 cm soil depth and rest 12 to 15 percent from 60 to 90 cm soil depth. The trend was same under CT plots for both the date of sowing. However under ZT system it was observed that the percent contribution of soil water for evapotranspiration purpose from the uppermost soil layer (0 to 15 cm) gradually decreased with increasing irrigation levels from I₂ to I₆ while the percent contribution from the lower soil layers 15 to 30 cm and 30 to 60 cm

gradually increased. The percent contribution from the lowest soil layer 60 to 90 cm however remained at par irrespective of tillage, date of sowing and irrigation levels.

The depletion in soil moisture was higher for D₂ sown crop as compared to D₁ sowing irrespective of irrigation levels. Interestingly it was also observed that under D₁ sowing at the time of harvest ZT plots maintained higher soil moisture content over CT plots while under D₂ sowing the ZT and CT plots had a very low moisture content difference. The difference in soil moisture availability between ZT and CT plots was maximum during the booting stage of the crop irrespective of dates of sowing. When the maize crop was sown late, higher proportion of the water use for evapotranspiration was diverted towards the vegetative growth of the crop. It was also observed that the partitioning of water between vegetative and reproductive phase could be offset through tillage intervention wherein ZT could balance the water use of the crop by conserving moisture within the soil profile and distributing it equally between the two growth phases of the crop.

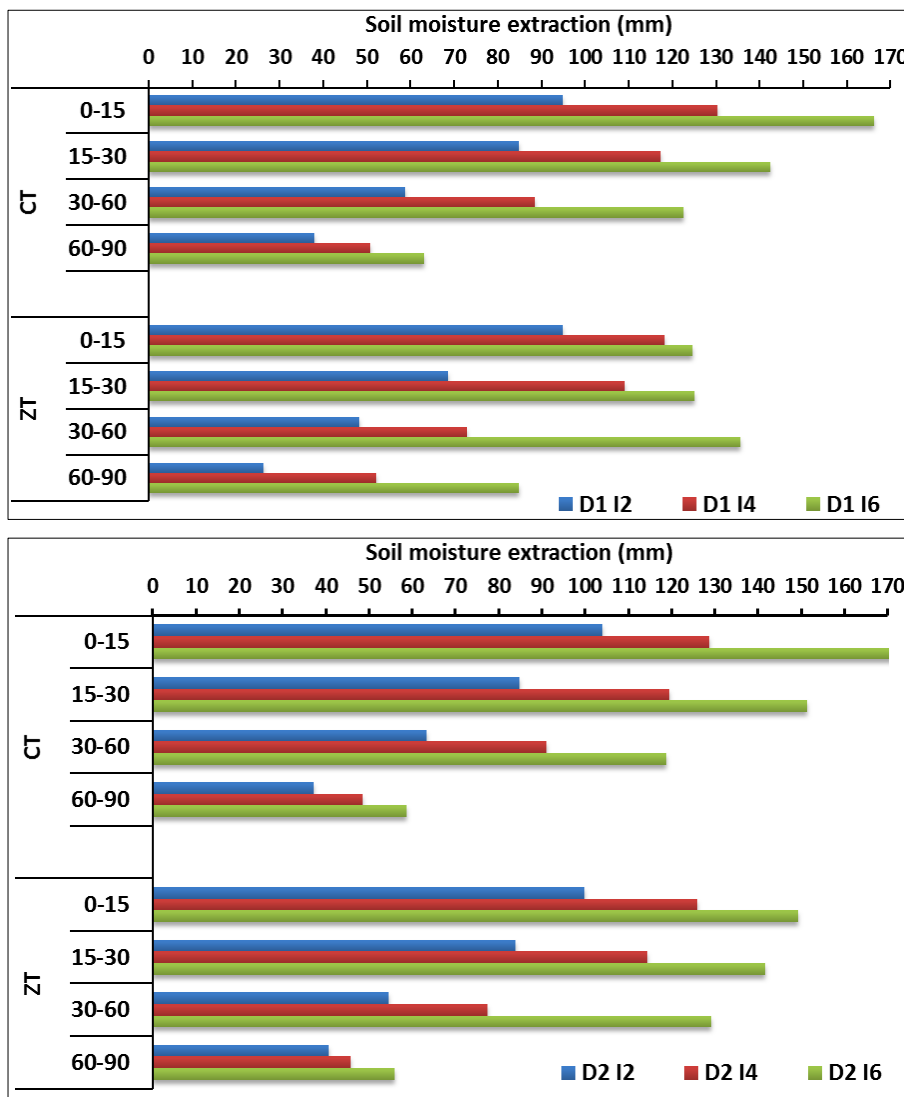


Fig 2: Soil moisture extraction pattern by maize crop as influenced by tillage, sowing time and irrigation level

Seasonal evapotranspiration and water use efficiency of maize

Seasonal evapotranspiration

The data on seasonal evapotranspiration (SET) of maize crop and the water use efficiency determined by the ratio of total

biomass produced to SET expressed as WUE_b and the ratio of economic yield to SET expressed as WUE_y is presented in Table 1. The SET included the total soil moisture utilised within consecutive irrigations throughout the growing period of maize crop from sowing to harvest. The SET was

significantly affected due to tillage systems dates of sowing and irrigation levels. From the data it was evident that due to ZT the consumption of soil moisture could be significantly reduced over CT. In the present experiment ZT resulted in 8.7 percent reduction in SET (358 mm) over conventional tillage (392 mm). Due to presence of surface residues the portion of soil evaporation was greatly reduced under ZT as a result of which it significantly reduced the SET under ZT. Due to early planting of maize crop under D₁ sowing (30th October) significantly recorded about 1.7 percent lower SET (372 mm) over the comparatively late sown crop on (10th November) that is D₂ sown crop (378 mm).

The evapotranspiration of the crop depends on the seasonal rainfall under rain fed condition while under irrigated condition it is directly correlated to the combined amount of irrigation water applied. Seasonal evapotranspiration increased significantly with the increased number of irrigations. The I₆ irrigation level recorded significantly highest SET value (482 mm) followed by I₄ (375.6 mm) and I₂ (268 mm) irrigation levels. With the increase of two irrigations over I₂, seasonal evapotranspiration increased by 40 percent under I₄ irrigation level while with the application of six irrigations (I₆) the SET increased by 28 percent over I₄ irrigation level. The interaction effect of the treatments showed a mixed response of tillage, date of sowing and irrigation levels.

Interaction between tillage and date of sowing was found to be significant with the highest SET value being recorded with CT under D₁ sowing (395 mm) which was statistically at par with CT under D₂ sowing (390 mm) while the lowest SET was recorded with ZT under D₁ sowing condition (349 mm). There was no significant effect within tillage and irrigation levels interaction however the interaction between date of sowing and irrigation levels was found to be significant. It was observed that D₁ sown crop recorded significantly higher SET values with increased irrigation under I₄ and I₆ irrigation levels ranging within 371 to 380 mm and 480 to 484 mm respectively. In contrast the SET under two irrigations was higher for D₂ sown crop (284 mm) as compared to D₁ sown crop (251 mm). Due to early sowing of the maize crop the initial growth of the crop was fast until the appearance of low temperatures during end of December up to mid-January period where the growth of the crop was restricted. However due to early planting the maize crop attained higher biomass production which under favourable irrigation environment utilised higher quantum of soil moisture as compared to late sown crop. The results also indicate that maize crop grown under restricted irrigation or low irrigation environment utilises less soil moisture which was evident from the SET pattern under I₂ irrigation level. However due to averaging of the SET over different dates of sowing the result was reversed while comparing the subplot treatment. This was mainly due to very low SET values for I₂ irrigation level under D₁ sowing.

The late harvesting of D₂ crop coincided with high-temperature period towards the end of the crop which might have significantly contributed towards the higher SET values for I₂ irrigation level under D₂ sowing.

The seasonal evapotranspiration was significantly affected due to tillage systems, dates of sowing and irrigation levels. Due to ZT the consumption of soil moisture was significantly reduced over CT. In the present experiment ZT resulted in 8.7 percent reduction in SET (358 mm) over conventional tillage (392 mm). Due to early planting of maize crop (D₁) lower SET of 1.7 percent (372 mm) was recorded over the late sown

crop (D₂) (378 mm). Interaction between tillage and date of sowing was found to be significant with the highest SET value being recorded with CT under D₁ sowing (395 mm) which was statistically at par with CT under D₂ sowing (390 mm) while the lowest SET was recorded with ZT under D₁ sowing condition (349 mm).

From previous studies hydraulic conductivity would be expected to be higher with zero tillage along with residue retention compared to conventional tillage due to large macropore for conductivity of water. Moreover soil management practices that increase the organic matter content in the soil also has a positive impact on the soil water holding capacity. It has been observed that zero tillage soil management systems along with residue retention has the potential to increase soil water holding capacity. Moreover due to presence of residue on the soil surface infiltration is generally higher with ZT as compared to CT. (McGarry *et al.*, 2000)^[11] found that the time to pond, final infiltration rate and also total infiltration rate was significantly higher with ZT along with residue retention over CT.

Another factor involving availability of soil water for plant absorption is soil evaporation. It is basically determined by two factors based on how wet the soil is and how much energy the soil surface receives to sustain evaporation process. Due to tillage the moist soil is brought above to the surface increasing losses to drying. Therefore, due to tillage the proportion of soil water evaporation is increased compared to ZT plots. Also the amount of energy received by the soil surface depends upon the residue cover in the soil. Residue and mulches reduce soil water evaporation by reducing soil temperature, impeding vapour diffusion, and reducing the wind speed gradient at soil atmosphere interface. Consequently, the soil moisture is conserved and more water is available for the crops. More soil water enables profuse growth of the crop and also reducing the chances for mid-season drought. Thus, tillage and residue management may significantly affect the crop yield besides other management aspects.

Water- use efficiency (WUE) of Biomass

Water use efficiency derived as the ratio of biomass or yield produced to the seasonal evapotranspiration was significantly affected due to tillage, date of sowing and irrigation levels is presented in Table 1. The water- use efficiency of biomass production (WUEb) was significantly higher under ZT (54.5 kg ha⁻¹mm) as compared to CT. Due to no tillage and residue retention resulted in 19 percent increase in water use efficiency as compared to tilled system. Due to early planting of maize crop under D₁ the WUEb was 10 percent higher (52.5 kg ha⁻¹mm) over the late sown crop. This could be attributed to the fact that although the SET values were lower under D₁ sowing condition however due to higher biomass production the water use efficiency significantly increased for D₁ sowing.

It is well-known that the water use efficiency decreases with increasing irrigation levels or amounts due to proportionately less increase in production with increasing evapotranspiration. On the contrary it was observed that the highest WUEb was recorded under I₄ irrigation level (53.6 kg ha⁻¹ mm) which was statistically at par to I₂ (52.5 kg ha⁻¹ mm) irrigation level but significantly higher over I₄ irrigation level (44.2 kg ha⁻¹ mm). Under I₄ irrigation levels the water-use efficiency of biomass production increased by 2 percent compared to I₂ irrigation level while it was 21 percent higher over I₆ irrigation level.

Among the different interaction effects the date of sowing and irrigation interaction was found to be significant wherein the highest WUE_b was obtained under D₁ I₂ treatment (57.2 kg ha⁻¹ mm) which was statistically at par with D₁ I₄ treatment (54.4 kg ha⁻¹ mm) while D₂ I₆ treatment recorded significantly lowest WUE_b of 42.7 kg ha⁻¹ mm. A closer look at the interaction effect also revealed that for the D₁ sown crop the highest WUE_b was obtained under I₂ irrigation level followed by I₄ and I₆ respectively while under D₂ sowing condition the highest WUE_b was recorded for I₄ irrigation level followed by I₂ and I₆ respectively. The soil moisture utilised by a crop for evapotranspiration is ultimately used for its growth and development towards biomass production which is finally manifested in the form of grain yield which is of economic importance to the farmers.

Unlike the biomass water use efficiency of the grain yield (WUE_y) was derived as the ratio of grain yield produced to the total SET. Among the tillage treatments, ZT recorded significantly higher WUE_y (25.5 kg ha⁻¹ mm) which was about 27 percent higher over CT system. Due to early planting of the maize crop (D₁ sowing) it recorded 21 percent higher WUE_y (25 kg ha⁻¹ mm) as compared to D₂ sown crop. In contrast to the water- use efficiency of biomass production (WUE_b) the grain yield water use efficiency recorded a different pattern of variation. The significantly highest grain yield water use efficiency was obtained under I₄ irrigation level (25.6 kg ha⁻¹ mm) followed by I₆ irrigation level (23.1 kg ha⁻¹ mm) while the lowest water use efficiency was recorded under I₂ irrigation level (19.7 kg ha⁻¹ mm).

Table 1: Seasonal evapotranspiration (mm), water use efficiency of biomass (WUE_b) and water use efficiency of grain (WUE_y) (kg ha⁻¹ mm) of maize as influenced by tillage, sowing time and irrigation levels

Treatment	Seasonal Evapotranspiration (mm)	WUE _b (kg/ ha mm) Biomass	WUE _y (kg/ ha mm) Grain
Tillage			
T ₁	392.4	45.7	20.1
T ₂	358.1	54.5	25.5
SEm (±)	3.91	1.0	0.2
LSD (0.05)	23.80	5.8	1.0
Date of sowing			
D ₁	372.1	52.5	24.9
D ₂	378.4	47.8	20.7
SEm (±)	1.33	0.8	0.4
LSD (0.05)	5.22	3.1	1.5
Irrigation			
I ₂	268.0	52.5	19.7
I ₄	375.6	53.6	25.6
I ₆	482.2	44.2	23.1
SEm (±)	2.9	0.8	0.3
LSD (0.05)	8.8	2.4	0.8
Interaction			
T × D	S	NS	S
T × I	NS	NS	S
D × I	S	S	S
T × D × I	NS	NS	NS

T₁=Conventional Tillage; T₂=Zero Tillage; D₁=30 October; D₂=10 November; I₂=Irrigation at V₆ and tasseling; I₄=Irrigation at V₄, V₁₀, tasseling, milking; I₆=Irrigation at V₄, V₈, V₁₀, tasseling, milking, dough stage of the crop

The data reveal that with the increase in two irrigations from I₂ to I₄ the grain yield water-use efficiency increased by 30 percent while with further increase in two irrigations (I₆) over I₄ irrigation level resulted in 10 percent reduction in WUE_y however the I₆ irrigation level recorded 17 percent higher WUE_y over I₂ irrigation level. From the results it was evident that although lower irrigation levels increased the water use efficiency for biomass production however maize crop responds efficiently towards increased irrigation levels due to which higher grain water use efficiency was obtained under I₆ irrigation levels as compared to I₂ irrigation level.

The interaction effect of tillage, date of sowing and irrigation levels was also found to be significant and various combination levels. The significantly highest WUE_y was recorded under zero tillage D₁ sowing condition (28.5 kg ha⁻¹ mm) while the lowest value was recorded under CT D₂ sowing condition (19 kg ha⁻¹ mm). When tillage and irrigation levels interaction, zero tillage under I₄ irrigation level recorded the maximum WUE_y (29 kg ha⁻¹ mm) which was significantly higher over other tillage and irrigation level interactions, while the lowest value was recorded under CT I₂ level of irrigation (17 kg ha⁻¹ mm).

The data of sowing and irrigation interaction noticeably

higher WUE_y was obtained under D₁ sowing condition for all the irrigation levels as compared to D₂ sown crop. Among the different treatment combinations, D₁ I₄ treatment recorded significantly higher WUE_y (27.6 kg ha⁻¹ mm) followed by D₁ I₆ (24.6 kg ha⁻¹ mm) while the lowest values were obtained under D₂ I₂ treatment combination. The combined interaction effect of tillage date of sowing and irrigation levels did not have any significant effect on SET, WUE_b or WUE_y as compared to the isolated interaction effect of various treatment combinations.

Among the tillage treatments, ZT recorded significantly higher grain water use efficiency (WUE_y) (25.5 kg ha⁻¹ mm) which was about 27 percent higher over CT system. Due to early planting of the maize crop (D₁ sowing) it recorded 21 percent higher WUE_y (25 kg ha⁻¹ mm) as compared to D₂ sown crop. With the increase in two irrigations from I₂ to I₄ the grain yield water use efficiency increased by 30 percent while with further increase in two irrigations (I₆) over I₄ irrigation level resulted in 10 percent reduction in WUE_y however the I₆ irrigation level recorded 17 percent higher WUE_y over I₂ irrigation level. Maize is a sensitive crop to moisture. Water stress at flowering and seed formation stages reduces the yield of crop. Water stress hastens tasseling,

pollen dehiscence and delays silking (emergence of female flowers). Result is barrenness due to failure of pollination. Water stress at flowering reduces yield of crop by 40 to 80 percent. Therefore in the initial stages upto vegetative growth, irrigations should be scheduled at longer intervals whereas during flowering at shorter intervals. Moisture stress during different development stages of corn may reduce final grain yield to different degrees, and the extent of yield reduction depends not only on the severity of the stress, but also on the stage of the plant development (Claasen and Shaw, 1970)^[1].

Maize crop exhibits yield reduction in response to soil water deficit during any growth phase (Howe and Rhoades, 1995; Denmead and Shaw, 1960)^[10, 2]. Many researchers have also reported that the grain yield is more sensitive to moisture stress from tasseling and continuing through grain filling (Denmead and Shaw, 1960; Norwood and Currie, 1997; Kipkorir *et al.*, 2002)^[2, 12, 9]. The critical stage of irrigation to maize is flowering and grain filling stages and any reduction in soil moisture at these stages will considerably reduce the grain yield (Dioudis *et al.*, 2009)^[3]. A single irrigation at tassel initiation stage increased maize yield by 29% over no irrigation and an additional irrigation during the vegetative and grain-filling stages increased maize yield an additional 11 and 13%, respectively (Norwood and Currie, 1997)^[13]. Results pertaining to the higher water use efficiency with ZT was also recorded by Kaur *et al.*, 2005^[8] and Ram *et al.*, 2010^[18] for wheat crop cultivated under no tillage situation. Parihar *et al.*, 2011^[15] reported that establishment of maize through ZT could provide maximum water productivity over CT in the Indo Gangetic plain (IGP).

Conclusion

The seasonal evapotranspiration (SET) increased significantly with increase in number of irrigation application. With the increase in two irrigations from I₂ to I₄ the grain yield water use efficiency (WUEy) increased by 30 percent while with further increase in two irrigations (I₆) resulted in 10 percent reduction in WUEy over I₄ irrigation level. However, the I₆ irrigation level recorded 17 percent higher WUEy over I₂ irrigation level. Although grain yield were higher with six irrigations but significantly higher water use efficiency was obtained due to ZT, early planting and I₄ irrigation level.

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