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

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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 (I1 - 2 irrigations at six-leaf stage and tasseling, I2 - 4 irrigations at four-leaf stage, ten leaf stage, tasseling and milking and I3 - 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 I1 to I2 the grain yield water use efficiency (WUEy) increased by 30 percent while with further increase in two irrigations (I3) resulted in 10 percent reduction in WUEy over I1 irrigation level. However, the I3 irrigation level recorded 17 percent higher WUEy over I1 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 rained 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) \(^{10}\). 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) \(^{10}\). 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) \(^{10}\). 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) \(^{10, 14}\). 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 managements 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) [23]. 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 evapot-oration rate (Rivas et al., 1998) [20]. Water iniflra-tion 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. I1 (2 irrigations at six-leaf stage and tasselling), I2 (4 irrigations at four-leaf stage, ten leaf stage, tasselling and milking) and I3 (6 irrigations at four-leaf stage, eight leaf stage, ten leaf stage, tasselling, 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. Theexperimental 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 45-60 cm 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 –

\[
\text{Seasonal Evapotranspiration} = \left[ \sum_{i=1}^{n} \frac{M_{bi} - M_{ei}}{100} \right] \times BD_i \times D_i
\]

Where,

- \(M_{bi}\) = Soil moisture % before irrigation.
- \(M_{ei}\) = Soil moisture % after irrigation.
- \(n\) = No. of soil layers considered in root zone depth (D).
- \(BD_i\) = Bulk Density of \(i^{th}\) 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).

\[
\text{WUEy} = \frac{\text{Yield}}{\text{Seasonal Evapotranspiration}}
\]

Where,

- WUEy refers to water use efficiency of grain produced

\[
\text{WUEbm} = \frac{\text{Biomass}}{\text{Seasonal Evapotranspiration}}
\]

Where,

- WUEbm 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 I₁ level of irrigation**

Under I₁ 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 D₁ 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 I₁ 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 comparatively 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 I₁ 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 when 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 tasselling 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 condition 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 1-2 to 1-6 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.

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 WUEb and the ratio of economic yield to SET expressed as WUEy 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 I1 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 I1, seasonal evapotranspiration increased by 40 percent under I1 irrigation level while with the application of six irrigations (I6) the SET increased by 28 percent over I1 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).

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\(^{-1}\)mm) 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\(^{-1}\)mm) 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 I1 irrigation level (44.2 kg ha\(^{-1}\) mm). Under I6 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 WUEb was obtained under D1 I2 treatment (57.2 kg ha\(^{-1}\) mm) which was statistically at par with D1 I3 treatment (54.4 kg ha\(^{-1}\) mm) while D2 I0 treatment recorded significantly lowest WUEb of 42.7 kg ha\(^{-1}\) mm. A closer look at the interaction effect also revealed that for the D1 sown crop the highest WUEb was obtained under I2 irrigation level followed by I1 and I4 respectively while under D2 sowing condition the highest WUEb was recorded for I1 irrigation level followed by I2 and I4 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 (WUEy) was derived as the ratio of grain yield produced to the total SET. Among the tillage treatments, ZT recorded significantly higher WUEy (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 WUEy (25 kg ha\(^{-1}\) mm) as compared to D2 sown crop. In contrast to the water-use efficiency of biomass production (WUEb) the grain yield water use efficiency recorded a different pattern of variation. The significantly highest grain yield water use efficiency was obtained under I1 irrigation level (25.6 kg ha\(^{-1}\) mm) followed by I4 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 (WUEb) and water use efficiency of grain (WUEy) (kg ha\(^{-1}\) mm) of maize as influenced by tillage, sowing time and irrigation levels

| Treatment | Seasonal Evapotranspiration (mm) | WUEb (kg/ha mm) Biomass | WUEy (kg/ha mm) Grain |
|-----------|----------------------------------|-------------------------|-----------------------|
| **Tillage** |                                 |                         |                       |
| T1        | 392.4                            | 45.7                    | 20.1                  |
| T2        | 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** |                             |                         |                       |
| D1        | 372.1                            | 52.5                    | 24.9                  |
| D2        | 378.4                            | 47.8                    | 20.7                  |
| SEM (±)   | 1.33                             | 0.8                     | 0.4                   |
| LSD (0.05)| 5.22                             | 3.1                     | 1.5                   |
| **Irrigation** |                           |                         |                       |
| I1        | 268.0                            | 52.5                    | 19.7                  |
| I2        | 375.6                            | 53.6                    | 25.6                  |
| I3        | 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     | NS                               | NS                      | S                     |
| T × I     | NS                               | NS                      | S                     |
| D × I     | S                                | NS                      | S                     |
| T × D × I | NS                               | NS                      | NS                    |

T=Conventional Tillage; T2=Zero Tillage; D=30 October; D2=10 November; I1=Irrigation at V6 and tasselling; I2=Irrigation at V4, V6, V10, tasselling, milking; I3=Irrigation at V4, tasselling, milking; I4=Irrigation at V4, milking, dough stage of the crop

The data reveal that with the increase in two irrigations from I1 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 WUEy however the I6 irrigation level recorded 17 percent higher WUEy over I3 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 WUEy 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 WUEy (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 WUEy 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 WUEy (27.6 kg ha\(^{-1}\) mm) followed by D1 I6 (24.6 kg ha\(^{-1}\) mm) while the lowest values were obtained under D2 I1 treatment combination. The combined interaction effect of tillage date of sowing and irrigation levels did not have any significant effect on SET, WUEb or WUEy as compared to the isolated interaction effect of various treatment combinations.

Among the tillage treatments, ZT recorded significantly higher grain water use efficiency (WUEy) (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 WUEy (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 WUEy however the I6 irrigation level recorded 17 percent higher WUEy 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 tasselling,
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) [12, 19]. 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 I3 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 I2 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.

**References**

1. Claasen MM, Shaw RH. Water deficit effects on grain. II. Grain components. Agronomy Journal. 1970; 62:652-655.
2. Denmead OT, Shaw RH. The Effects of Soil Moisture Stress at Different Stages of Growth on the Development and Yield of Corn. Agronomy Journal. 1960; 52(5):272-274.
3. Dioudis PS, Filintas AT, Papadopoulos AH. Corn yield response to irrigation interval and the resultant savings in water and other overheads. Irrigation and drainage, 2009; 58(1):96-104.
4. Directorate of Economics & Statistics, 2018-19.
5. Gajri PR, Arora VK, Chaudhary MR. Maize growth response to deep tillage, straw mulching and farmyard manure in coarse textured soils of NW India. Soil Use Manage. 1994; 10:15-20.
6. Goddard T, Zoebisch M, Gaa, Ellis, Watlon AS. No tillage farming system, world association on soil and water conservation. 2008; 39:1.
7. Howe OW, Rhoades HF. Irrigation practice for corn production in relation to stage of plant development. Soil Sci. Soc. Am. Proc. 1995; 19:94-98.
8. Kaur T, Mahey RK. Indian Journal of Environment and Ecoplaning. 2005; 10(4):373-376.
9. Kipkorir EC, Raes D, Massawe B. Seasonal water production functions and yield response factors for maize and onion in Perkerra, Kenya. Agricultural Water Management. 2002; 56(3):229-240.
10. McCarthy GW, Meisinger JJ, Jenniskens MM. Relationship between total-N, biomass-N and active-N in soil under different tillage and N fertilizer treatments. Soil Biol. Biochem. 1995; 27:1245-1250.
11. McGarry D, Bridge BJ, Radford BJ. Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics. Soil and Tillage Research. 2000; 53(2):105-115.
12. Norwood CA, Currie RS. Dryland corn vs. grain sorghum in western Kansas. Journal of production agriculture. 1997; 10(1):152-157.
13. Norwood CA, Currie RS. Dryland corn vs. grain sorghum in western Kansas. Journal of production agriculture. 1997; 10(1):152-157.
14. Ojeniyi SO. Effects of zero-tillage and disk plowing on soil water, soil temperature and growth and yield of maize (Zea mays L.). Soil Tillage Res. 1986; 7:173-182.
15. Parihar CM, Jat SL, Singh AK, Jat ML. Energy scenario and water and productivity of maize based cropping system under conservation agriculture practices in south Asia. In: Abstracts of 5th world congress on conservation agriculture, incorporating the 3rd farming system design conference held at Brisbane, Australia from 26th to 29th September, 2011, 144-5.
16. Patel JB, Patel VJ, Patel JR. Influence of different methods of irrigation and nitrogen levels on crop growth rate and yield of maize (Zea mays L.). Indian Journal of Crop Sciences. 2006; 1(1-2):175-177.
17. Perret S, Michellon R, Tassin J. Agroecological practices as tools for sustainable management of erosion of exposed tropical catchments: quantifying their effects on soil restoration and erosion control in Reunion island (Indian Ocean French Overseas Territories). In Sustainable Management of Tropical Catchment. Ed. D M T Herper Brown, Wiley, London, 1999, 400.
18. Ram H, Kler DS, Singh Y, Kumar K. Indian Journal of Agronomy. 2010; 55(3):185-190.
19. Rice CW, Grove HJ, Smith MS. Estimating soil net nitrogen mineralization as affected by tillage and soil drainage due to topographic position. Can. J Soil. Sci. 1987; 67:513-520.
20. Rivas E, Rodriguez M, Manrique U. Efecto de la labranza sobre las propiedades fisicas y quimicas del suelo y el rendimiento de maiz en los llanos altos del estado Monagas. Agron. Trop. 1998; 48:157-174.
21. Robertson WK, Hammond LC, Johnson JT, Boote KJ. Effects of plant-water stress on root distribution of corn, soybeans, and peanuts in sandy soil. Agron. J. 1980; 72:548-550.
22. Smart JR, Bradford JM. Conservation tillage corn production for a semi-arid, subtropical environment. Agron. J. 1999; 91:116-121.