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# Irrigation scheduling in drip fertigated maize (*Zea mays*) using FAO-CROPWAT model

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**Abstract**
Overexploitation of available water resources due to increasing population has made vital to plan efficient use of water and better irrigation practices like scheduling. The study was carried out for maize to develop an optimal irrigation scheduling to increase crop yield. The crop water requirement was found to be 365.2 mm and irrigation requirement 275.3 mm. Irrigation should be carried out at critical depletion to achieve 0% yield reduction of crop and maximum rainfall efficiency. The research showed that the irrigation management model could effectively and efficiently estimate the crop water requirements. It allowed to develop the recommendations for improved irrigation practices and the planning of irrigation schedules under varying water supply conditions.

**Keywords:** Surface drip, sub-surface drip, water use efficiency, evapotranspiration, productivity

## Introduction

Maize (*Zea mays*) also known as corn, is a cereal grain originated from southern Mexico about 10,000 years ago and has become a staple food in many parts of world. It is the third most important cereal crop in the world, known as queen of cereals. In addition to being consumed directly by humans, maize is also used for corn ethanol, animal feed and other maize products, such as corn starch and corn syrup.

Improper scheduling of irrigation often leads to reduction in crop yields. In areas having ample and cheap water resources with assured supplies throughout the crop season, it may be possible to schedule irrigation as and when required to meet the full water needs of crops and realize maximum yields. However, in recent years water resources have become scarce due to low rainfall, expansion in cultivated area and poor recharge of ground water, especially in the arid and semi-arid areas. In such areas, instead of intensive irrigation over a limited area, the right approach would be to serve maximum area with reduced irrigation intensity in order to increase the overall production and irrigation water use efficiency which can be ensured by irrigating the crop at such phenological stages of growth which are very critical in their demand for water. Since water is a precious commodity and the studies on scheduling of irrigation, water use efficiency, consumptive use of water and moisture distribution pattern in the soil are of direct interest for maximizing crop yields.

Reduction in agricultural productivity and water use efficiency are mainly due to conventional method of irrigation (flooding) and poor adoption of scientific water management practices. Agriculture can be enhanced by use of appropriate irrigation technologies and adequate water management (Adeoti, 2009) [1]. Drip method of irrigation helps to reduce the over exploitation of ground water that partly occurs because of inefficient use of water under surface method of irrigation. Environmental problems associated with the surface method of irrigation like water logging and salinity are also completely absent under drip method of irrigation. Drip method helps in achieving saving in irrigation water, increase water use efficiency, decrease tillage requirement, higher quality products, increased crop yields and higher fertilizer use efficiency. At field level, water use efficiency under conventional method of irrigation is very low (50 to 60 per cent) as against drip method (95 per cent). Drip irrigation system optimize the irrigation water and put it uniformly and directly to the root zone of the plants at frequent interval based on crop water requirement through a closed network of pressure plastic pipes. Superiority of drip system in terms of water saving and increased yield along with other benefits over surface method of irrigation is proved by many research evidences. Drip irrigation system improves the WUE because of improving the yield and quality of produce (Yang *et al.*, 2020) [18].

Pressurized irrigation system has been found to be quite effective under limited water availability not only in achieving higher productivity but also economizing other inputs such as fertilizers, pesticides, labour etc. Drip irrigation system is a conventional and effective means of supplying water directly to soil and nearer to the roots of plant without much loss of water resulting in higher water productivity (Ayars *et al.*, 1999; Wang *et al.*, 2022) [4, 17].

For efficient utilization of irrigation water under drip irrigation system, it is necessary to find out proper scheduling of irrigation. Evapotranspiration based scheduling of irrigation is proper and scientific to provide required irrigation water through drip system for harnessing potential yield of maize crop. There is need to work out optimum irrigation schedule based on crop water requirement for optimum utilization of limited water resources. Crop water requirement is defined as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit the plant growth and crop yield (Hess, 2005) [10]. Improving the water use efficiency in irrigated farming can also help to realize the full benefits of other production inputs, like fertilizers, high quality seeds, tillage, energy and machinery (Sharma et al., 2015) [14]. Crop water requirement (CWR) depend on climatic conditions, crop area and type, soil type, growing seasons and crop production frequencies (FAO, 2009; George et al., 2000) [7, 8]. Computer simulation models are an emerging trend in the field of water management. With the availability of CROPWAT software, estimation of irrigation scheduling for an individual crop is no longer a weary and time intensive exercise for irrigation engineers. It is one of the models being extensively used in the field of water management throughout the world which is designed by Smith (1991) [16] of the Food Agricultural Organization (FAO).

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (FAO 1993) [6]. Water use requirement for same crop varies under different weather conditions. To achieve effective planning on water resources, accurate information is needed for crop water requirements, irrigation withdrawal as a function of crop, soil type and weather conditions. The FAO Penman-Monteith method (Pereira et al., 2015) [13] was preferred for use in determination of reference evapotranspiration (ETo) as it is reported to provide very consistent values on actual crop water use data worldwide (Allen et al., 2006; Cai et al., 2007; Lopez-Urrea et al., 2012) [3, 5, 11, ].

Considering the above facts, a trial was conducted during *kharif* season 2020 with the objective to find out drip irrigation schedule for maize and the effect of drip irrigation on growth and yield of maize.

## Materials and Methods

### Study site characteristics

The study was carried in the WTC (Water Technology Centre) farm inside ICAR-Indian Agricultural Research Institute, New Delhi having latitude of 28°38'21.3" N and longitude of 77°08'56.5" E at an altitude of 228 m above mean sea level. The top soil layer of 30 cm at the site was sandy loam with $pH_{1:2}$ 7.3, electrical conductivity ($EC_{1:2}$) 0.25-0.3 $dSm^{-1}$, available N (202 kg $ha^{-1}$), P (0.5 M $NaHCO_3$ extractable, 29 kg P $ha^{-1}$) and K (1 N $NH_4OAc$ extractable, 144 kg K $ha^{-1}$).

### Experimental details

### Treatments

The experiment consisted of sixteen treatments of irrigation methods, irrigation levels and nutrient doses (surface drip (SD), sub-surface drip (SSD) with ETc 0.6 and 0.8 and 0, 60, 80 and 100% of Recommended Dose of Fertilizer (NPK)) and compared with an additional treatment of conventional surface irrigation with application of 100% NPK fertilizer. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The extra plot was treated as dummy. The treatments with their symbols are shown in Table.1

**Table 1:** Treatments with their symbol

| Treatment | Symbol |
|---|---|
| SSD X 0.6ETc X 0%RDF | T1 |
| SSD X 0.6ETc X 60%RDF | T2 |
| SSD X 0.6ETc X 80%RDF | T3 |
| SSD X 0.6ETc X 100%RDF | T4 |
| SSD X 0.8ETc X 0%RDF | T5 |
| SSD X 0.8ETc X 60%RDF | T6 |
| SSD X 0.8ETc X 80%RDF | T7 |
| SSD X 0.8ETc X 100%RDF | T8 |
| SD X 0.6ETc X 0%RDF | T9 |
| SD X 0.6ETc X 60%RDF | T10 |
| SD X 0.6ETc X 80%RDF | T11 |
| SD X 0.6ETc X 100%RDF | T12 |
| SD X 0.8ETc X 0%RDF | T13 |
| SD X 0.8ETc X 60%RDF | T14 |
| SD X 0.8ETc X 80%RDF | T15 |
| SD X 0.8ETc X 100%RDF | T16 |
| Conventional surface irrigation X 100%RDF | T17 |

SSD: Sub-surface drip; SD: Surface drip; ETc: Crop Evapotranspiration; RDF: Recommended Dose of Fertilizer

### Other details

i) Total number of treatments: 17
ii) Replications: 3
iii) Total number of plots: 52
iv) Experimental design: RCBD
v) Plot size: 21 $m^2$
vi) Variety: Pusa Jawahar
vii) Drip lateral to lateral spacing : 60cm
viii) Emitter spacing in in-lines: 30cm
ix) Depth of in-lines: 20cm

### Layout of the experiment

The allocation of treatments to different experimental units was done with the help of random number table as advocated by Fisher and Yales (1963). The layout of the experiment is shown in Fig. 1.

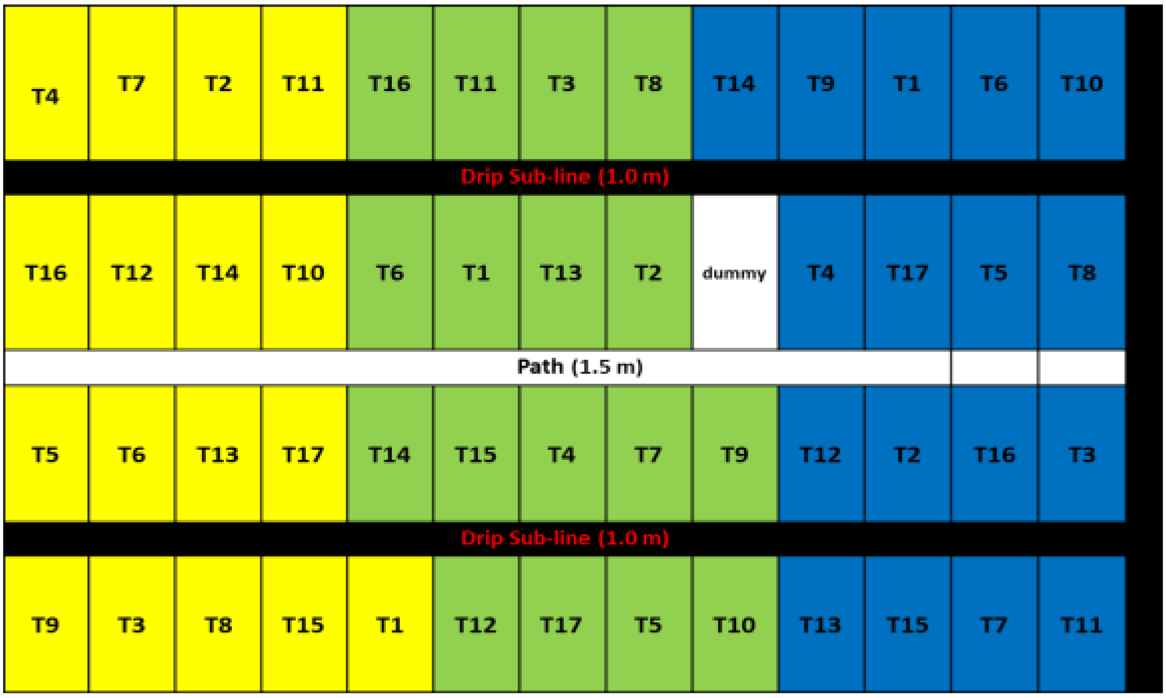


**Fig 1:** Layout of the experiment

### Varietal characteristics

**Pusa Jawahar hybrid maize-I (PJHM- 1):** It has been released in collaboration with Jawaharlal Nehru Krishi Vishwa Vidhyalaya, Jabalpur for cultivation in Madhya Pradesh. This hybrid has an average grain yield of 6.5 Mg ha$^{-1}$ with potential yield of 10.2 Mg ha$^{-1}$ and maturity of 95 days. It has dark green foliage, slightly upright leaves, semi-dent and orange color seed. It has enough field tolerance to flowering stalk rot and downy mildew. Because of its stay green nature, PJHM 1 can also be treated as dual propose hybrid. Green foliage of the plant can be utilized as fodder after harvesting cob.

### Details of crop raising

### Field preparation

The seed beds of 7 x 3 m$^2$ were prepared and zero tillage was followed. The crop was sown at a row spacing of 60 cm and plant to plant spacing of 20 cm by dibbling method. The recommended doses of N, $P_2O_5$ and $K_2O$ were 150, 75 and 60 kg ha$^{-1}$, respectively.

### Treatment application

**Irrigation:** The irrigation water was supplied by surface drip, sub-surface drip and conventional surface irrigation in different treatments according to the ETc determined by FAO-CROPWAT software. The field was divided with two sub-main (50 mm) placed at a depth of 50 cm connected with 63 mm of main line. Five laterals of 16 mm were punched out from the sub-main in each plot. The required pressure of 1 kg cm$^{-2}$ and discharge of 2lph was maintained with overflow valve with the supply source. Separate valves were provided for regulating the water supply in each plot.

### Model description and input data

CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of FAO, Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, UK and National Water Research Centre, Egypt. It is a computer program for the calculations for reference evapotranspiration and crop water requirements based on climate, soil and crop data. CROPWAT can use standard soil and crop property values if local soil and crop data is not available and climate data input can accommodate daily, decadal or monthly values. It also develops irrigation schedules for different management conditions and calculates the scheme water supply for different cropping patterns. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rainfed conditions or deficit irrigation (Adriana *et al.*, 1999) [2]. This model is location-based and has no GIS capabilities. CROPWAT for Windows uses the FAO (1992) Penman-Monteith method for calculation reference crop evapotranspiration.

**Climate data:** It was collected from the ICAR-Indian Agricultural Research Institute (IARI) Agromet Observatory. The data included maximum and minimum temperature (˚C), humidity (%), wind speed (km day$^{-1}$) and sun hours (hours). These data were required to calculate reference evapotranspiration ($ET_o$, mm day$^{-1}$) as per Penman-Monteith method. Radiation (MJ m$^{-2}$ day$^{-1}$) and $ET_o$ were calculated by CROPWAT depending on climate data.

**Rain data:** Rain data was also collected from the Agromet observatory of ICAR-Indian Agricultural Research Institute (IARI) and applied in CROPWAT software to obtain effective rainfall.

**Crop data:** The information of the crop was obtained from FAO manual 56 for maize crop which included crop name; planting date; harvest, crop coefficient, Kc; rooting depth; length of plant growth stages; critical depletion and yield response factor.

**Soil data:** The information of the soil was also obtained from the FAO manual 56 for medium soil which included soil data like total available soil moisture; maximum rain infiltration rate; maximum rooting depth; initial soil moisture depletion and initial available soil moisture.

**Thinning and weeding:** Thinning was done to maintain uniform plant stand and weeds were removed manually after 30 days after sowing in order to minimise competition.

**Harvesting:** The cobs were first harvested manually in the standing crop and put in separate bags treatment wise and tagged. Then the plants were removed, sun dried and tied in bundles along with tags. The plant bundles and cobs were weighed to determine the yield.

### Statistical analysis

The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) [9] for randomized complete block design. The treatment differences were compared at 5% level of significance.

### Results and Discussion

The CROPWAT 8.0 model was used to prepare the irrigation schedule for maize crop. The model predicted the daily, decadal as well as monthly crop water requirement at different growing stages of maize crop. The crop water requirement and irrigation requirement for the maize crop was found to be 365.2 mm and 275.3mm respectively as shown in Fig. 2. The graph of crop water requirement and irrigation requirement of maize crop is shown in Fig. 3. For the application of irrigation, the critical soil moisture depletion was considered at 100%. From the results, it was found that the yield reduction will not occur at any growing stage with maximum rainfall efficiency as predicted with irrigation at 100% critical depletion and by refilling the soil to the field capacity (Table 3). The detailed results of total gross irrigation, total net irrigation, actual water use by crop and potential water use by crop is given in the Table 2. The rain efficiency of 10% was found and by this efficiency, effective rainfall was found to be 79.3 mm. The total net irrigation varied from the irrigation requirement due to change in effective rainfall efficiency. The Fig. 4 shows the irrigation schedule pattern at 100% critical depletion.

Crop Water Requirements

ETo station: IARI    Crop: MAIZE (Grain)

Rain station: IARI, New Delhi    Planting date: 24/07

| Month | Decade | Stage | Kc | ETc | ETc | Eff rain | Irr. Req. |
|---|---|---|---|---|---|---|---|
| | | | coeff | mm/day | mm/dec | mm/dec | mm/dec |
| Jul | 3 | Init | 0.30 | 1.42 | 11.3 | 48.3 | 0.0 |
| Aug | 1 | Init | 0.30 | 1.37 | 13.7 | 16.9 | 0.0 |
| Aug | 2 | Deve | 0.39 | 1.32 | 13.2 | 83.9 | 0.0 |
| Aug | 3 | Deve | 0.65 | 2.55 | 28.0 | 51.6 | 0.0 |
| Sep | 1 | Deve | 0.91 | 3.75 | 37.5 | 9.5 | 28.0 |
| Sep | 2 | Mid | 1.14 | 5.43 | 54.3 | 9.2 | 45.1 |
| Sep | 3 | Mid | 1.18 | 5.03 | 50.3 | 0.0 | 50.3 |
| Oct | 1 | Mid | 1.18 | 4.93 | 49.3 | 0.0 | 49.3 |
| Oct | 2 | Mid | 1.18 | 3.65 | 36.5 | 0.0 | 36.5 |
| Oct | 3 | Late | 1.14 | 2.86 | 31.5 | 0.0 | 31.5 |
| Nov | 1 | Late | 0.89 | 1.81 | 18.1 | 2.6 | 15.6 |
| Nov | 2 | Late | 0.61 | 1.22 | 12.2 | 0.0 | 12.2 |
| Nov | 3 | Late | 0.41 | 1.86 | 9.3 | 2.3 | 7.0 |
| | | | | | 365.2 | 224.3 | 275.3 |

**Fig 2:** Daily and decadal ETc and irrigation requirement

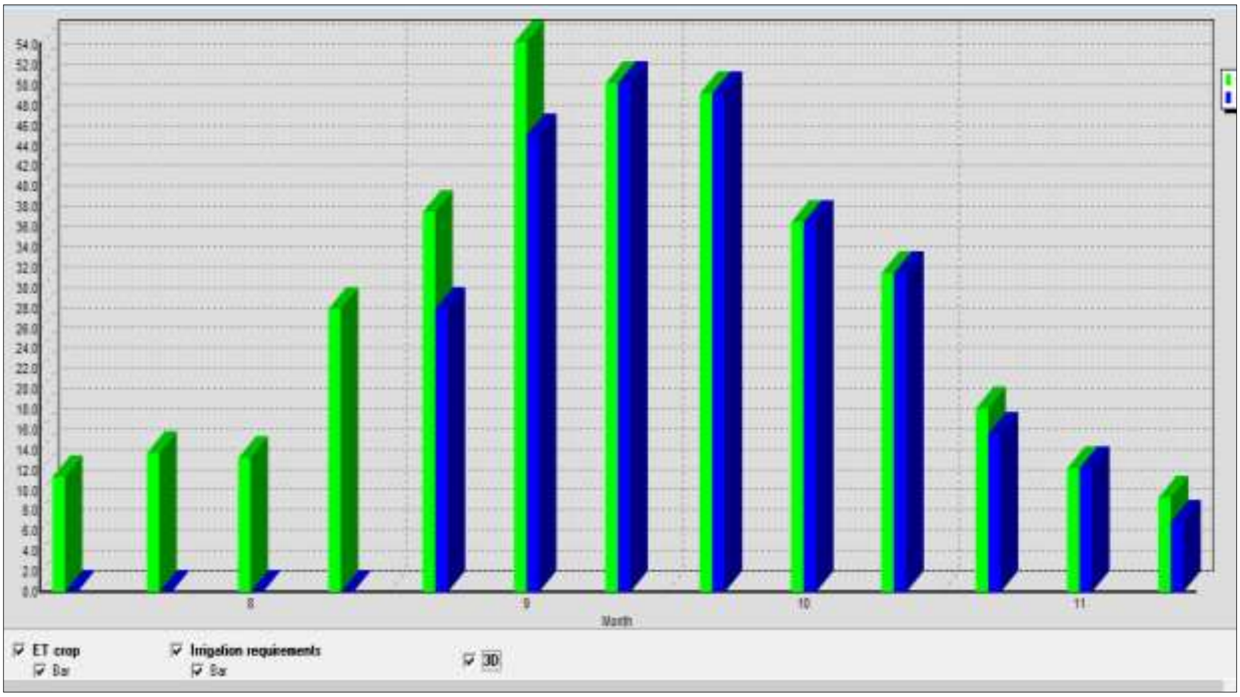


**Fig 3:** Crop water requirement and irrigation requirement

**Table 2:** Total gross irrigation, total net irrigation and efficiency of rain

| Totals | | | |
|---|---|---|---|
| Total gross irrigation | 232 mm | Total rainfall | 757.7 mm |
| Total net irrigation | 162.4 mm | Effective rainfall | 79.3 mm |
| Total irrigation losses | 0 mm | Total rain loss | 678.4 mm |
| Actual water use by crop | 364.5 mm | Moist deficit at harvest | 122.8 mm |
| Potential water use by crop | 364.5 mm | Actual irrigation requirement | 285.2 mm |
| Efficiency irrigation schedule | 100% | Efficiency rain | 10.5% |
| Deficiency irrigation schedule | 0% | | |

**Table 3** Yield reduction at 100% of critical depletion

| Yield reductions | | | | | |
|---|---|---|---|---|---|
| Stage label | A | B | C | D | Season |
| Reduction in ETc | 0 | 0 | 0 | 0 | 0% |
| Yield response factor | 0.4 | 0.4 | 1.3 | 0.5 | 1.25% |
| Yield reduction | 0 | 0 | 0 | 0 | 0% |
| Cumulative yield reduction | 0 | 0 | 0 | 0 | 0% |

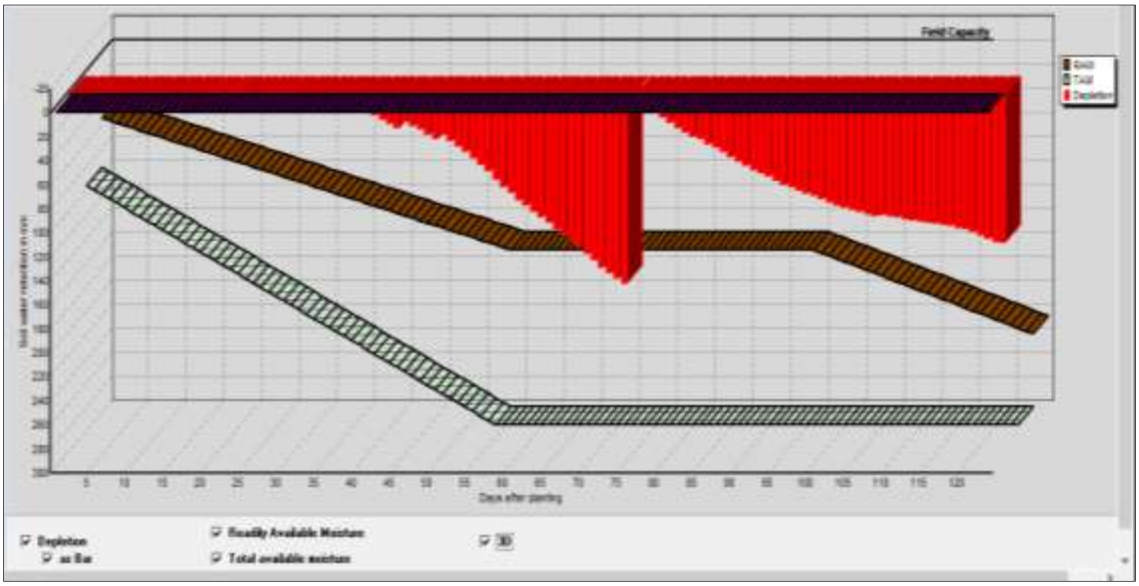


**Fig 4:** Irrigation scheduling

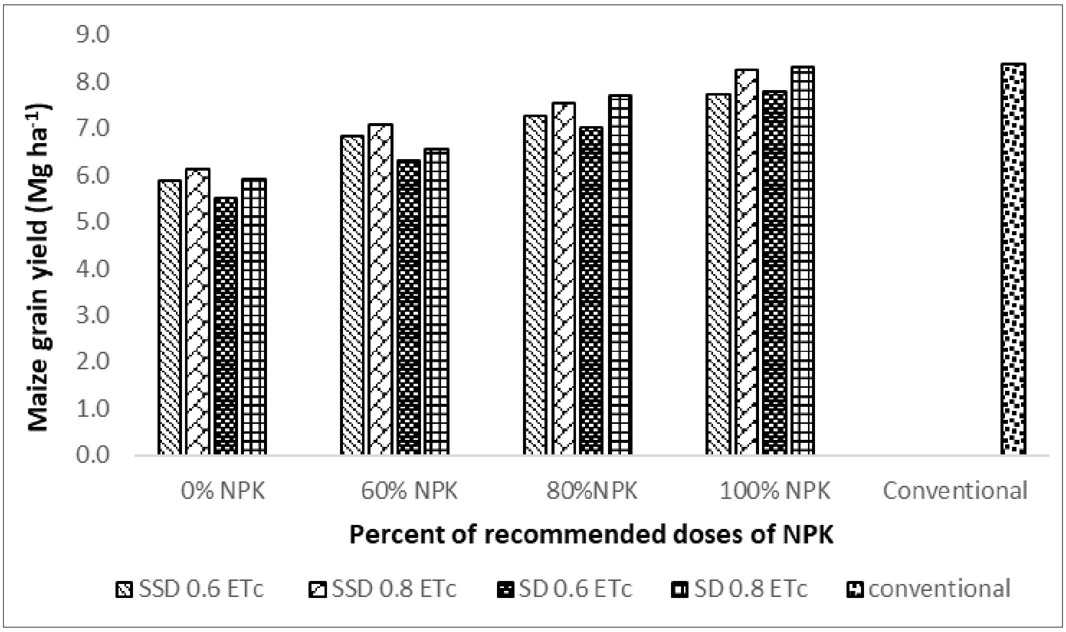


**Fig 5:** Maize grain yield (Mg $ha^{-1}$)

Maize grain yield ranged from 5.52 to 8.32 Mg $ha^{-1}$ as shown in Fig. 5. The maximum maize grain yield (8.32 Mg $ha^{-1}$) was obtained with 100% recommended dose of NPK. Crop fertigated with 60, 80 and 100% NPK had 14, 26 and 37% higher grain yield compared to control (no NPK). The increment in grain production decreased with increasing NPK levels. The increase in yield with increasing nutrient doses might be due to higher photosynthetic efficiency, effective absorption and utilization of available nutrients and better proliferation of roots resulting in fast development of canopy (Sivanappan, 2004; Malve et al., 2017) [15, 12]. The yields obtained from the plots receiving 100% NPK doses either through conventional method or drip were almost similar. Maize grain yield produced with 80 and 100% NPK levels applied through fertigation were comparable thus showing a saving of 20% of NPK. The yields of maize irrigated with surface and subsurface drip were also found at par. The differences in grain yield of maize irrigated at 0.6 ETc and 0.8 ETc were also meagre. The yield results were statistically similar because of maize taken as *kharif* crop and most of the irrigation water requirement was fulfilled by effective rainfall. The maize stover yield varied from 6.2 to 9.6 Mg $ha^{-1}$ and showed the similar trend as found in case of grain yield. Drip irrigation at 0.6 and 0.8 ETc saved 44 and 25% of irrigation water compared to the conventional surface method of irrigation. The irrigation water use efficiency in surface and sub-surface drip irrigation at 0.6 and 0.8 ETc varied from 0.37 to 0.41 kg $ha^{-1}cm^{-1}$.

## Conclusions

The crop water requirement for maize crop was calculated by the use of the FAO CROPWAT 8.0 Model. The crop water requirement for maize crop was found to be 365.2 mm and irrigation requirement 275.3 mm. Proper and optimal scheduling of irrigation using CROPWAT 8.0 enabled the efficient water use to 70%. The preliminary results showed that fertigation using surface and subsurface drip at 0.8 ETc may save 25% of irrigation water and 20% of NPK fertilizer compared to conventional surface irrigation and fertilizer application. The results obtained on ETc and net irrigation requirement provided a practical assessment on irrigation scheduling for the crop grown in semi-arid environment and thus can be used to enhance water use efficiency by better managing irrigation water withdrawal and application amounts so as to optimize crop production.

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