Shiraz
University

Iran Agricultural Research (2017) **36**(**1**) 17-24

Planting Scenarios for Maize Cropping Under Drought Conditions

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ARTICLE INFO

***Article history*:**

Received **25 October 2013**
Accepted **29 May 2016**
Available online **27 November 2016**

***Keywords*:**

Deficit irrigation,
Maize
Planting method
Planter
Water productivity

ABSTRACT-Water management is an essential concept for water intensive crops such as maize dealing with water shortage under drought conditions. Maize production is ranked after wheat and barley in Fars province, Iran. Therefore, the present study was conducted to investigate the effects of planting methods by conventional and modified planters on maize growth and yield at different irrigation regimes under semi-arid conditions. Irrigation treatments were full and deficit irrigation (100 and 80% of crop evapotranspiration (ET_c), respectively), and planting methods of on-bed and in-furrow bottom. Experiments were conducted and analysed in a split plots design (planting methods as main plot and irrigation as sub-plot) with three replications. Though planting methods did not significantly affect the yield, total dry matter yield increased by 3.7% for in-furrow bottom planting as compared with that obtained in on-bed planting. Water productivity (WP) was significantly affected by irrigation treatments. Maximum WP for total dry matter was obtained at 80% of ET_c and in-bottom of furrow planting by 4.6 kg m^{-3}. Considering the soil moisture content during the growing season, planting in-furrow bottom and deficit irrigation as 80% of ET_c is recommendable for drought conditions.

INTRODUCTION

Maize as one of the oldest crops with a history of about 7000 to 10000 years is one of the three main world cereals. It is a tropical and subtropical crop; however, it is widely cultivated in other climates with a lower rate of growth (Emam, 2007). Maize grain production is ranked at fourth place after wheat, barley and rice in Iran. The largest maize cultivation areas belong to Khuzestan and Fars provinces with about 38.2 % and 13.8% of total cultivated area, respectively and 37.6 % and 16% of total domestic maize grain production (Anonymous, 2013). According to the FAO report, the production of grain maize in Iran has been doubled from 2000 to 2014 (Anonymous, 2015).

Maize is a water intensive crop and should be produced at moderately high irrigation levels (Ko and Piccinni, 2009). Therefore, under water deficit conditions, evapotranspiration (ET) of the maize is dependent on the regional climate. Some studies have reported about 624 mm water for silage maize (Majnooni-Heris et al., 2007a), and about 848 mm for grain maize (Majnooni-Heris et al., 2007b). Naroua et al. (Naroua et al., 2014) reported that water use for maize is about 585 mm for a 150-day growing season in a region with an annual rainfall average of 400 mm. It was reported 535 mm for a 142-day growing season in a semi-arid region (Li et al., 2005), and 453 mm for a 122-day growing season in an arid area in Egypt (Amer, 2010).

Some research has been conducted for assessing the optimum water use with low reduction in yield at different irrigation regimes. In some studies, different methods of irrigation i.e., fixed and variable alternate furrow, and conventional furrow (Du et al., 2005; Sepaskhah et al., 2006) were studied. Zand-Parsa and Sepaskhah (2001) noted that under water limiting conditions, the optimum value of applied water is 736 mm to produce over 10 ton ha^{-1} maize with 206 kg ha^{-1} soil nitrogen content (applied and residual). Sepaskhah and Khajehabdollahi (2005) and Sepaskhah and Parand (2006) expressed that maize grain yield and top dry matter considerably decreased when the plant was irrigated by variable alternate furrow throughout the growing season as compared to conventional furrow methods with a 7-day interval. Ko and Piccinni (2009) stated that irrigation management of maize at 75% ET_c is feasible with 10% reduction in grain yield and increasing WUE as compared to 100% ET_c treatment. The greatest WUE (1.6 kg m^{-3}) was achieved at 456 mmof water input. However, maximum grain yield was obtained at less than 600 mm applied water. Du et al. (2010) suggested that mild water deficit in early seedling stage is beneficial for maize grain yield and WUE. They reported that alternate furrow irrigation maintained similar photosynthetic rate; however, it reduced transpiration rate, and thus increased leaf WUE of maize. The WUE can also be altered by planting methods. Wang et al. (2011) and Zhou et al. (2009) found that maximum WUE can be obtained in furrow planting method for maize. Shabani et al. (2013) reported that in-furrow planting of rapeseed increased on average 10.1% WUE compared with on-ridge planting for two successive years.

Kang et al. (2002) reported that when water consumption was reduced by 20 and 40% through extending the irrigation intervals, alternate watering produced the same amount of biomass production under moderate soil drying (20% water reduction). In addition, the values of WUE and root to shoot ratio improved by alternate watering. Zand-Parsa et al. (2006) found that water stress had a significant effect on grain yield of single-cross 704 maize cultivar. Ko and Piccinni (2009) reported a significant difference in volumetric soil water content for maize crop between 100% and 50% ET irrigation treatments. A linear relationship ($R^2 \geq 0.95$) was found between maize grain yield and the amount of irrigation from 0.6 ET to 1.0 ET as reported by Amer (2010). Maximum yield was observed at 1.0 ET applied irrigation water. The same results were also reported by Nassiri et al. (2016), when maize crop was treated with a different amount of applied water.

Zhang et al. (2007) carried out an experiment to evaluate the effect of different methods of tillage and planting on wheat yield. It was found that planting in-bottom of furrow increased the yield about 7.8% compared with that planted on flat plots. Furthermore, it was found that water consumption decreased by 20% for in-bottom planting. Nassiri et al. (2016) found that the amount of applied irrigation water and planting in-bottom of furrow increased maize grain yield as well as biomass. The highest yield (8193 kg ha^{-1}) was observed in plots in which 80% ET$_c$ irrigation was applied with the WUE of about 1.05 kg m^{-3}. They suggested that if water is scarce, planting in furrow bottom is an appropriate practice for water management. However, root development was slightly limited by furrow hard pan due to the dynamic pressure of furrower. The same trend was reported by Wang et al. (2011) for in-furrow planting of maize. Zhang et al. (2012) found that ridged bed planted maize yielded more grain and biomass as compared to flat planted maize at the mean value of soil water content (gravimetric) of 20%. Ridge bed planting method has the benefit of mitigation of soil temperature and moisture limitation for crop growth (Song et al., 2013).

The present study was conducted to improve furrow opener function to provide a tilled planting bed at the bottom of furrow. Furthermore, this study evaluated the interaction of planting methods of maize i.e. on-bed and in-bottom of furrow and different irrigation water regimes (80% and 100% of ET$_c$) in a semi-arid region.

MATERIALS AND METHODS

Field experiments were carried out in a 1200-square-meter area in the College of Agriculture, Shiraz University, Shiraz, Iran, located at 29°50` latitude (N), 52°46` longitude (E), and 1810 m altitude (MSL). The field was tilled initially by a moldboard plow and then was worked twice by a disk harrow. Between two disk operations, 100 kg ha^{-1} triple superphosphate was spread on the soil and mixed by disking. The soil texture of the study area wassilty-clay-loam with an average bulk density of 1.43 g cm^{-3}. Maxima maize seed (a short season) was used for planting. Seed distance on each row (with 75 cm apart) was 12 cm in all 3 m×6 m plots. Seed was planted on-bed and in-furrow bottom (in-furrow, shortly) on June 18, 2010.

There were four treatments for planting, consisting of; 1) planting with a manual cone digger with 7 cm height for controlling a uniform planting depth similar to the one used by Majnooni-Heris et al. (2007b) on bed (Fig. 1a); 2) conventional planting method with 4-rowKeverneland planter using vacuum-seed plate seed metering on-bed (Fig. 1b); 3) a 2-row planter with vacuum-seed plate seed metering planting in-furrow (Fig. 1c); and finally 4) 2-row planter with vacuum-seed plate seed metering planting in-furrow equipped with a shovel in front of furrow opener for loosening the hard pan formed at the bottom of furrow by furrower (Fig. 1d).

All three planters were equipped with runner type furrow opener. Planting depth was adjusted about 7 cm for the planters. Irrigation as the second experimental factor was applied at two different levels of 80 and 100% of crop evapotranspiration (ET$_c$) by a 7-day interval. ET$_c$ was determined by multiplication of K$_c$ and ET$_0$, where K$_c$ (K$_{cini.}$=0.35, K$_{cmid}$=1.2, K$_{cend}$=0.35) and ET$_0$ are the crop coefficient and reference evapotranspiration, respectively, determined by using weather station data and the Penman-Monteith method (Allen et al., 1998).

The first irrigation was applied on June 22, 2010 with the amount of 100 mm for all treatments. The same amount was applied for the second irrigation event for better seed germination. Onward, the amounts of water at irrigation events were measured according to the irrigation treatments by volumetric water meter.

The flow of water was calibrated using a stopwatch and a volumetric container five times before the first irrigation. Fifteen weekly irrigation events were applied till harvest on October 13, 2010. The last irrigation water was applied eleven days before harvest. Cumulative seasonal applied irrigation water for 80 and 100% treatments were 765 and 955 mm, respectively.

Urea fertilizer was distributed twice (21/7/2010 and 24/8/2010) after seed planting at the rate of 155 kg ha^{-1} each. Weeds were manually eradicated, twice.

Soil water content was measured before the first irrigation from 0-15 cm, 15-30 cm and 30-45 cm depths with the standard procedure of gravimetric method. Soil sampling during the growing season was carried out six times till harvest at the same depths.

Fig. 1. Different types of planting devices used in the study, a) Hand tool, b) Keverneland planter, c) in-furrow bottom planter, d) in-furrow bottom planter equipped with shovel

Experiments were carried out and analyzed in split plot design with three replications. Main and split plots were assigned to the planting method and irrigation water treatments, respectively.

Plant attributes such as top dry matter (biomass) and plant height were measured every three weeks till harvest. Three plants were taken from each plot, a total of nine plants were taken for replicated treatments. The height of each plant was measured from the first node above the root to the top of stem. After tassel appearing, the height was measured to the node below the tassel. After harvest, attributes such as total top dry matter (TDM) and stover dry matter (SDM), grain yield (GY), plant height and grain moisture content were measured. The initial grain moisture content was 57.2±7.0 (wet basis). Maize grain yield is reported based on 15% moisture content (w.b.). Harvested samples were weighed by a digital balance with an accuracy of ±0.01g. Stems and leaves were cut into 30 cm pieces, wired and labeled. For measuring dry mater, the batches were kept in an oven at 70 ^{o}C for 48 hours for dry matter measurements.

RESULTS AND DISCUSSION

In-furrow planted seeds germinated about seven days after the first irrigation, whereas on-bed ones germinated nearly five days later. The faster seed germination is expected to be due to higher moisture availability in furrow. Accordingly, tassels in-furrow plants were observed on 22ndof August 2010, and those of on-bed plants appeared four days later.

Plant Height

The plant height variation followed a sigmoid pattern in the growing season for all treatments as shown in Fig. 2. For the case of in-furrow treatments, plants grew faster and, therefore as expected showed a higher height than those for the on-bed treatment. However, final plant height at the end of the growing season approached nearly the same value. Neither planting method nor applied water showed any significant (P>0.05) effect on the final plant height (Fig. 3). The same results have been reported by Song et al. (2013) for the final plant height of maize planted in-furrow and on-bed.

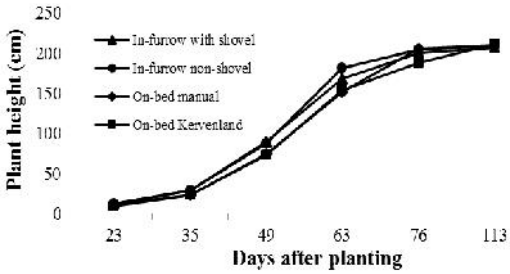

Fig. 2. Variation of plant height during the growing season for various planting methods

The maximum plant mean height was 198 cm for the in-furrow, using runner opener (RP) planter, followed by the plants planted with shovel equipped (SE) planter in-furrow with 192 cm height. The higher plant height for in-furrow planting could be attributed to higher soil water content in furrow and earlier germination in the bottom of furrow as compared to on-bed planted plants. When the planter was equipped with shovel (SE planter), seed placement dispersion increased; therefore, there was a little difference between plant heights for in-furrow planted treatments with different planters. It was observed that the coefficient of variation in plant height was lower for on-bed manual (M) planting (0.03 CV) than machine planted seeds (0.05 CV) because of more control on planting depth in M planting method. The highest coefficient of variation was obtained from plots seeded with SE planter (0.08 CV) that was significantly different from those of others.

According to Fig. 3, the more water was applied, the more plant height was obtained. Nassiri et al. (2016) reported that plant in plots with full water requirement reached the significantly highest height.

Dry Matter and Grain Yield

The highest total (TDM) was obtained from in-bottom planting method (34.7 Mg ha^{-1}) using SE planter, whereas it was 33.2 Mg ha^{-1} for on-bed planting method by Keverneland (K) planter with a nearly 4% higher yield (Fig. 4). The difference was due to different soil water content for on-bed and in-bottom treatments as described in the next section. However, no significant difference was found by ANOVA among planting methods (P>0.05).

(SDM) and (GY) also followed the same trends (Figs. 5 and 6). However, about 6.5% increment in SDM was also obtained for in-furrow planting as compared with that of on-bed planting. Irrigation treatments showed no significant effect on TDM, SDM and GY; however, more yields were obtained for full water requirement (9.9%, 10% and 13% for TDM, SDM and GY, respectively).

Nassiri et al. (2016) stated that the planting method affected the TDM as well as GY significantly, and these values were higher in in-furrow planting. As already mentioned, they used a manual cone digger device for sowing seed; therefore, the planting depth was controlled precisely whereas in this study, none of the planting machines were equipped with depth control devises.

In the present study, though the planting depth was adjusted by openers; the depth of planting could not be controlled compared with manual planting as discussed in the previous section. Wang et al. (2011) reported that about 7% increment in yield can be obtained if maize is cultivated in furrow rather than in flat plots. In the present study, increment in TDM was 3.5% for in-furrow planted maize.

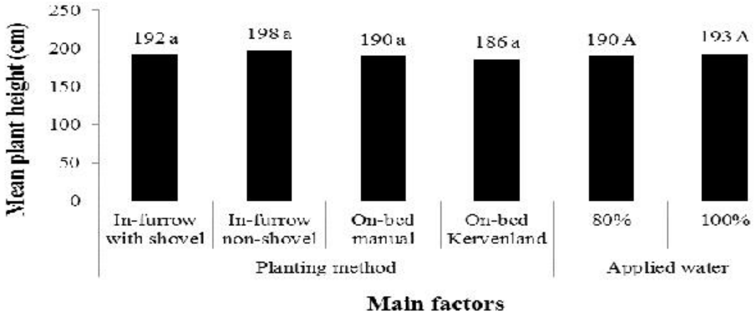

Fig. 3. Plant height affected by experimental main factors

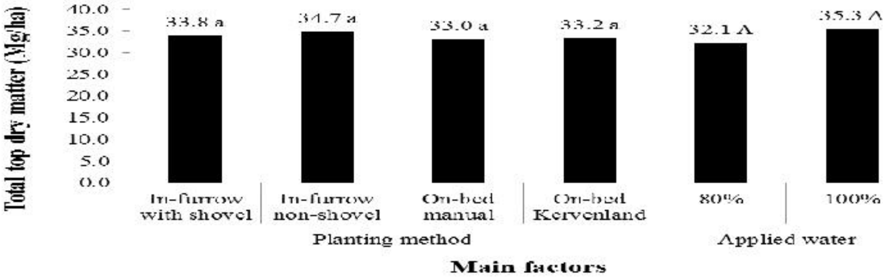

Fig. 4. Total top dry matter at different experimental main factors

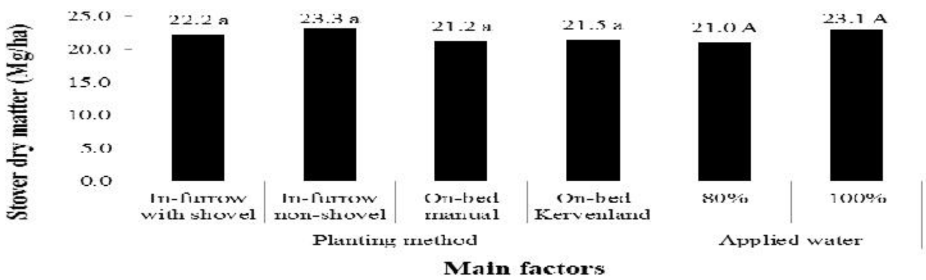

Fig.5. Stover dry matter at different experimental main factors

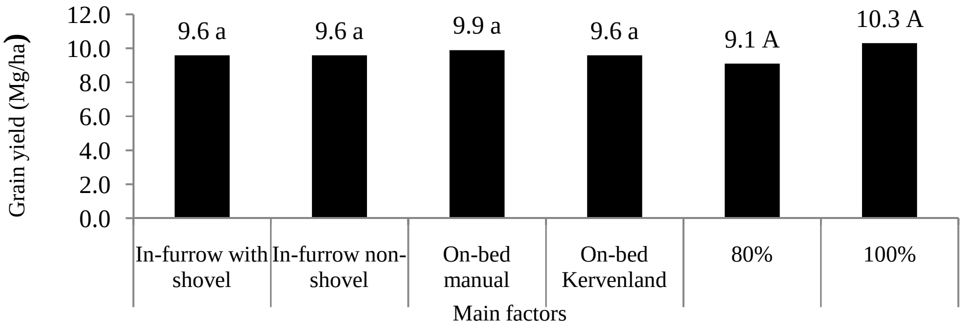

Fig. 6. Grain yield at different experimental main factors

Soil Water Content

Soil water content was measured before field irrigation events from top to 45 cm soil depth in furrow and top seven times during the growing season (Fig. 7). The soil water content of on-bed and in-furrow bottom zones followed the same trends. Similar results have been reported by Nassiri et al. (2016). A significant difference was observed between soil water contents of surface soil and other depths (P=0.015), Fig. 8. The difference in the middle of the growing period is attributed to the increase in ambient temperature and more water requirement for plant growth. However, this difference declined at the end of the growing season because of change in the trend of ambient temperature and water uptake by plants. Low and high soil water contents were measured before the first irrigation and last sampling as 6.5% and 12% (g/g), respectively. These values were significantly different from those in the middle of the growing period.

Higher soil water content occurred in 0-45 cm soil depth as depicted by Song et al. (2013), due to high precipitations. It was reported that soil water content at different planting methods was not significantly different at the post-harvest stage. Fig. 9 depicted that differences in soil water content decreased till reaching the end of the growing season, and it showed that a different planting method had no effect on soil water content at this stage.

Water Productivity

To make a decision on the appropriate combination of planting method and deficit irrigation, the GY and TDM per unit volume of used water, as water productivity (WP), were determined. Seasonal irrigation water for 80% and 100% treatments were 765 and 955 mm, respectively. WP based on GY and TDM are shown as WP_{GY} and WP_{TDM}, respectively (Fig. 10). Analysis of variance on WP_{GY} and WP_{TDM} showed that only TDM was affected by used water (P=0.017); however, they were not affected by the planting method at 5% level of probability (Fig. 10). The WP increments for 20% deficit irrigation were 13.5% and 9.1% for TDM and GY, respectively. It was 5.2% for TDM production for in-furrow planting method. Wang et al. (2011) stated that maize planting in-furrow increased WP by nearly 10%.

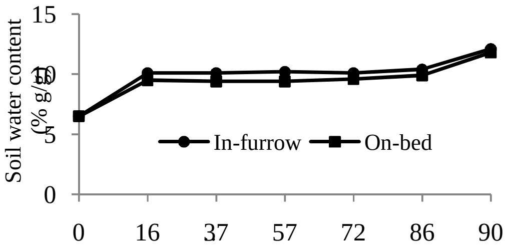

Fig. 7. Variation of soil water content in-furrow and on-bed in 0-45 cm soil depth

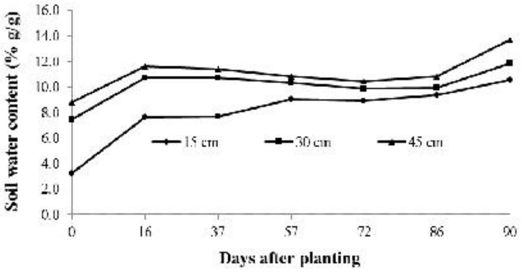

Fig. 8. Variation of soil water content during the growing season at different soil depths

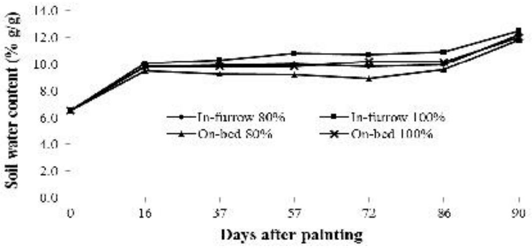

Fig. 9. Variation of soil water content in-furrow and on-bed at different irrigation regimes

English and Nuss (1982) reported that with decreasing applied water, the yield decreased; however, it would reduce water extraction, transfer and distribution costs and finally increase the benefit. Hargreaves and Samani (1984) recommended deficit irrigation as an appropriate alternative to maximize WP.

It was found that maize kernel growth was relatively unaffected by water deficit because of high stalk moisture content and translocation from the stalk to the grain (Quatter et al., 1987). Jaliliyan et al. (2001) in their research on economic benefit of sugar beet production found that, though 20% deficit irrigation of plant evapotranspiration decreased the yield from 53 Mg ha^{-1} to 48 Mg ha^{-1}, this may turn to increase in economic benefit. Sepaskhah et al. (2006) stated that net income per unit water increased as a result of the decrease in the amount of applied water (optimum water) for both land and water limiting conditions.

When drought is prominent in a region, in-bottom planting can be recommended and used as an alternative planting method (Nassiri et al., 2016).

Considering the WP for in-furrow planting, this method saves 4.9% water at the same level of TDM production. For 20% deficit irrigation, saving increased to 11.9% and 8.3% at the same level of TDM production and GY, respectively. From WP point of view, in-furrow planting with shovel did not significantly improve water productivity as compared to non-shovel, which is not in agreementwith Nassiri et al.'s suggestion (2016). This result might be due to proper seed bed preparation and appropriate tillage depth. Therefore, no complicated implementation is required for well-prepared seed beds.

CONCLUSIONS

This research aimed to introduce a new planting method for maize as one of the important cereals as well as water intensive crops. Results revealed that in-furrow planting maintained higher soil water content in root zone and thereby reduced irrigation water requirement compared to the conventional (on-bed) planting method. Moreover, the combination of in-furrow planting and deficit irrigation with 80% ET$_c$ distinguished this combination amongst other treatments for higher water productivity. Therefore, whenever and wherever drought is dominant, in-furrow planting and application of water about 80% ET$_c$ can be recommended as an alternative planting-irrigation method. Furthermore, results emphasized that in-furrow planting method needs a proper tillage depth. This study suggests further research for developing new planting equipment for maize production under water shortage conditions.

ACKNOWLEDGEMENTS

Hereby the authors express their gratitude to National Drought Research Institute, Shiraz University for its financial support.

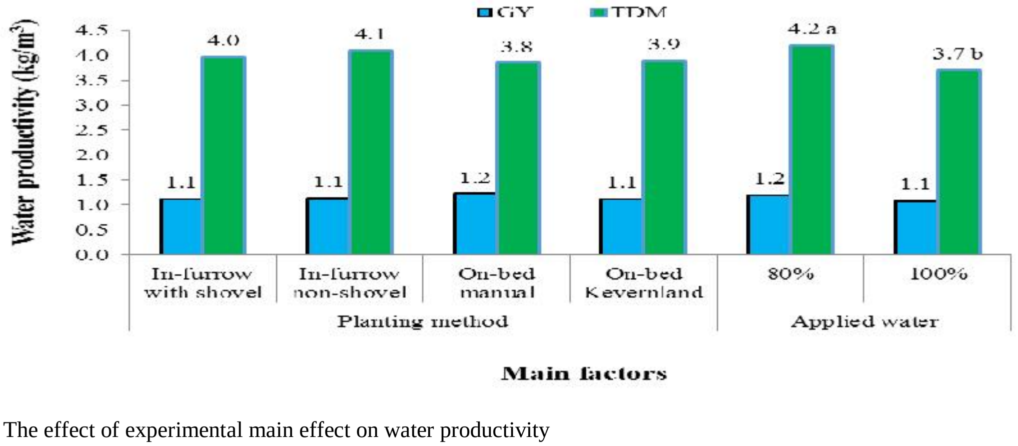

Fig. 10. The effect of experimental main effect on water productivity

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تحقیقات کشاورزی ایران (۱۳۹۶) ۳۶(۱) ۱۷-۲۴

سناریوهای کشت ذرت در شرایط خشکسالی

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اطلاعات مقاله

تاریخچه مقاله:
تاریخ دریافت: ۱۳۹۳/۸/۳
تاریخ پذیرش: ۱۳۹۵/۳/۹
تاریخ دسترسی: ۱۳۹۵/۹/۷

واژه های کلیدی:
کم آبیاری
ذرت
روش کشت
ردیفکار
بهروری آب

چکیده- مدیریت آب یکی از اساسی‌ترین مفاهیم برای محصولات نیازمند به آب زیاد مثل ذرت در شرایط خشکسالی است. تولید ذرت در استان فارس در رتبه سوم پس از گندم و جو قرار دارد. بنابراین در این پژوهش اثرات روش‌های مختلف کشت با ردیف کارهای معمول و تغییر یافته بر رشد ذرت و عملکرد آن در رژیم‌های مختلف آبیاری در شرایط اقلیمی نیمه خشک مورد مطالعه قرار گرفت. تیمارها آبیاری کامل و کم‌آبیاری (به ترتیب ۱۰۰ درصد و ۸۰ درصد تبخیر-تعرق گیاه، ET_c)، و روش‌های کشت روی پشته و داخل (کف) جوی بودند. آزمایش‌ها در قالب طرح کرت‌های خرد شده (روش‌های آبیاری در کرت‌های اصلی و مقدار آب آبیاری در کرت‌های فرعی) با سه تکرار انجام شد. گرچه روش‌های کشت بر عملکرد محصول تاثیر معنی‌داری نداشتند، مقدار ماده خشک کل برای روش کشت داخل جوی نسبت به کشت روی پشته به میزان ۳/۷ درصد افزایش نشان داد. بهروری آب تحت‌تاثیر معنی‌دار تیمارهای آبیاری قرار گرفت. بیشینه بهروری آب برای مقدار کل ماده خشک در مقدار آبیاری ۸۰ درصد تبخیر- تعرق و در کشت داخل جوی به مقدار ۶۴ کیلوگرم بر متر مکعب بدست آمد. با در نظر گرفتن محتوای رطوبت خاک در دوره رشد گیاه، کشت در داخل جوی و روش کم آبیاری به میزان ۸۰ درصد تبخیر–تعرق گیاه برای شرایط خشکسالی توصیه می‌شود.