Agricultural Water Management 97 (2010) 1365–1374

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Morphological quality of sweet corn (*Zea mays* L.) ears as response to soil moisture tension and phosphate fertilization in Campeche, Mexico

B. Rivera-Hernández[a], E. Carrillo-Ávila[b,*], J.J. Obrador-Olán[a], J.F. Juárez-López[a], L.A. Aceves-Navarro[a]

[a] *Colegio de Postgraduados, Campus Tabasco, Periférico Carlos A. Molina s/n. C.P. 86500, H. Cárdenas, Tabasco, Mexico*
[b] *Colegio de Postgraduados, Campus Campeche, Carretera Federal Haltunchén-Edzná Km 17.5, C.P. 24450, Sihochac, Champotón, Campeche, Mexico*

ARTICLE INFO

Article history:
Received 1 April 2009
Accepted 6 April 2010
Available online 6 May 2010

Keywords:
Hybrid A7573
Ear characteristics
Drip irrigation
Vertisols
Carstic soils
Tensiometers

ABSTRACT

In Mexico, corn production, part of which is sweet corn, is mainly destined for human consumption. In the present work, the morphological quality of sweet corn ears was assessed in response to four levels of soil moisture tension indicating irrigation start (−5, −30, −55, and −80 kPa) and three levels of phosphate fertilization (60, 80 and 100 kg ha^{-1}) in carstic soils in the south-east of Mexico. A factorial experimental design with three replicates was used. The following variables were determined: fresh weight (*SCFWh*), dry weight (*SCDWh*), diameter (*SCDh*), and length (*SCLh*) of sweet corn ears, all without husk, as well as number of kernels (*NKxE*), number of unfilled kernels (*NUK*), number of rows (*NRxE*), and dry kernel weight per ear (*DKW*). Yield of fresh (*YFSCh*) and dry (*YDSCh*) sweet corn ears, both without husk, and the harvest index (*HI*) were also determined. *HI* did not show significant statistical differences among irrigation or fertilization treatments. Regarding the other variables, the effect of the more humid treatments (−5 and −30 kPa) and the effect of the higher phosphorus doses (80 and 100 kg ha^{-1}) were statistically equal ($P \leq 0.01$) with the lowest *NUK* and the highest values of all other variables; therefore, irrigation start at soil moisture tension of −30 kPa and phosphate fertilization application of 80 kg ha^{-1} are recommended. At this level of soil moisture, the mean values over the three fertilization levels and all the replicates, obtained for *SCFWh*, *SCDh*, *SCLh* and *NKxE* were 198.5 g, 4.39 cm, 26.72 cm and 467 grains, respectively. According to the regression models, moisture tensions from −11.8 to −24.0 kPa, and phosphate fertilization doses from 87.7 to 102.2 kg ha^{-1} minimize *NUK* and maximize the values of the rest of the variables. The highest irrigation water use efficiency was found in the moisture tension treatment of −30 kPa with an increase of 27 kg ha^{-1} ears for each millimeter of applied irrigation water.

1. Introduction

In Mexico, the surface area used for growing sweet corn (*Zea mays* L.) has increased by more than 110% in the last 7 years, from 31 261 ha in the year 2000 to 68 576 ha in 2007 (SAGARPA, 2007). In 2006, the national production of sweet corn was 648 238 t, with a mean yield of 9.48 t ha^{-1} (SAGARPA, 2007). More than 34 800 farmers in the State of Campeche grow corn, which is mainly used for human consumption in the form of dry grain and sweet corn (SAGARPA, 2007). Sweet corn consumption has increased in the urban sector of the state in the last few years; however, the demand is not completely satisfied because of the low yields obtained and the seasonality of its production. The average yield of sweet corn in the state was a mere 3.64 t ha^{-1} in 2004, way lower than the national mean yield of 9.77 t ha^{-1} for the same year, despite the use of irrigation for its production (SAGARPA, 2007). This is because, among other factors, there is no established methodology in the application of irrigation, and a lot of corn is grown in shallow soils with phosphorus deficiency.

Rainfall in Campeche increases from north to south from as little as 950 up to 1946 mm year^{-1} (INEGI, 2007) and is characterized for having very irregular distribution in time and space, which does not guarantee the satisfaction of corn crop water needs, even if most of the surface is planted during the rainiest season, from June to November. Water shortage in the soil during any of the phenological stages of the plant causes diminution in growth, delayed maturity and reduced crop yield (Payero et al., 2006). Traore et al. (2000), Setter et al. (2001), and Çakir (2004) pointed out that a decrease of kernel yield in corn due to water stress depends on the growth state of the crop and the duration of the stress. Singh and Singh (1995) and Panda et al. (2004) indicated that the most important period for corn crops, during which soil water deficiency has the greatest effect on crop yield, is 2 weeks before and 2–3 weeks after stigma emission. Oktem et al. (2003) and Payero et al. (2006) reported a positive linear relation between water con-

---

* Corresponding author. Tel.: +52 981 8 11 21 12; fax: +52 981 8 11 21 12.
E-mail addresses: ecarrilloavila@gmail.com, ceugenio@colpos.mx
(E. Carrillo-Ávila).

0378-3774/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2010.04.001

sumption and kernel harvest in hybrid corn, with determination coefficients over 0.90. Li et al. (2002) reported that, in the reproductive stage, water deficit inhibits elongation and reduces the number of stigmata, number of kernels per ear, kernel yield, and final weight of the ear. Andrade et al. (2002) and Bänziger et al. (2002) stated that under conditions of water stress, the corn plant decreases its leaf area index (LAI), photosynthetic rate and growth rate (Stone et al., 2001a,b), and kernel harvest (Aguilar et al., 2007). However, Shaozhong et al. (2000) and Panda et al. (2004), stated that it is possible to allow moderate soil moisture stress during the phenological stages when the corn plants are less sensitive, using the required amount of water during the sensitive periods (flowering and grain filling), in order to achieve optimum yield and maximum water use efficiency.

Denmead and Shaw (1962) and Novák et al. (2005) indicated that, since transpiration is often limited by the soil water available, the most important environmental factors regulating transpiration and water absorption through the roots are soil moisture content or soil water potential (also called soil matric potential or soil moisture tension). Therefore, soil moisture tension is currently being used in many research works to define the beginning of irrigation in diverse crops. With regard to corn (*Zea mays* L.) crops, Rhoads and Stanley (1973, 1974) observed that if the soil water potential, in the upper 0.3 m, is kept above −10 kPa in sand and −40 kPa in clay, the best yields are obtained.

On the other hand, phosphorus is an essential nutrient for plant growth and development; it is the second most important after nitrogen (Schachtman et al., 1998). Nowadays, the productivity of over 30% of the cultivated surface worldwide is limited by the lack of this element in the soil (Vance et al., 2003). Phosphorus is of utmost importance since it intervenes in energy production in the phosphorylation processes (Tisdale et al., 1999). Grant et al. (2001) stated that phosphorus is crucial in plant metabolism, since it plays an important role in cell energy transmission, respiration and photosynthesis. They point out that phosphorus is a structural component of nucleic acids of genes and chromosomes, as well as of many enzymes, phosphoproteins, and phosphate fats. Therefore, phosphorus deficiency in crops at the beginning of their vegetative cycle can result in deficient development from which the plant does not recover, even if phosphorus supply is later increased to adequate levels (Grant et al., 2001).

With respect to the soils where the crop is grown, the water in the aquifers is brackish, with high content of calcium and magnesium carbonates and bicarbonates, because of the carstic origin of the Yucatan Peninsula, and practically all the soils in the state of Campeche have high calcium concentrations. This affects the nutrimental state of the crops due to the interaction of calcium and the other nutrients: calcareous soils inhibit the efficiency of phosphorus applied in fertilizers because of the quick fixture of the applied soluble phosphorus to the high calcium content present in the soil (Sharpley, 2000; Hedley and McLaughlin, 2005). Most plants absorb phosphorus as an ortophosphate ion, but the high calcium content in calcareous soils impedes the absorption, forming calcium phosphates, which cannot be absorbed by plants (McBeath et al., 2006), causing deficiency of this element. Colomb et al. (2000), Pellerin et al. (2000) and Fletcher et al. (2006, 2008b) pointed out that phosphorus deficiency in the soil decreases the rate of emergence, expansion, and duration of leaves, thus reducing the leaf area index and the interception of solar radiation. This, in turn, causes a decrease in biomass accumulation in the corn plant, which diminishes the size of the meristem and the final number of kernels per ear (Fletcher et al., 2008a). de Grazia et al. (2003) stated that both phosphorus and nitrogen are determinants in the photosynthetic potential of corn crop, and that both nutrients must be supplied in adequate amounts to ensure an adequate nutrition of the crop during flowering. Regarding this, Andrade et al. (1996) mentioned that this phenological stage determines the number of grains per surface unit.

Ali et al. (2002) studied the effect of three levels of nitrogen (0, 90 and 150 kg ha^{-1}) and four levels of phosphorus (0, 60, 90 and 120 kg ha^{-1}) on corn growth and yield, finding the greatest values for plant height (289.9 cm), number of ears per plant (1.72), number of kernels per ear (344), dry weight of 1000 kernels (320.9 g), and kernel yield (3.81 t ha^{-1}) with doses of 150 kg N ha^{-1} and 90 kg P ha^{-1}. de Grazia et al. (2003) found significant effects when applying different doses of phosphorus and nitrogen to sweet corn crop. The highest yield was found with the highest doses of both nutrients (200 kg N ha^{-1} and 80 kg P_2O_5 ha^{-1}). However, the effect of phosphorus addition was significant only for the variables leaf length, unit leaf area, ear diameter, and aerial biomass. They conclude that phosphorus becomes a limiting factor only with high doses of nitrogen. On the other hand, Hochmuth and Cordasco (2008) mentioned that in Florida, research into sweet corn fertilization was carried out for more than 30 years, and they reported that since most soils used for sweet corn production in Florida are rich in phosphorus, no statistical differences were found in yield when using different doses of phosphate fertilization, ranging from 0 up to 224.17 t ha^{-1} P_2O_5. Ear quality has not improved either at increasing the doses of phosphate fertilizer. A similar result was reported by Crnko et al. (1993) who found no effects on sweet corn, adding phosphate fertilizer, in histosols with high phosphorus content. However, Hochmuth et al. (2009) stated that sweet corn grown in organic soils responds to phosphate fertilization. These authors summarized in their article the results of almost 70 years of fertilization research into sweet corn: they pointed out that the greatest yield is obtained for doses ranging from 168 to 224 kg ha^{-1} P_2O_5 when the fertilizer is broadcasted on the crop, and for doses from 56 to 112 kg ha^{-1} P_2O_5 when the fertilizer is applied in bands. They mentioned that the crop response to phosphate fertilization greatly depends on the phosphorus content of the soil itself. For sweet corn crop, they recommend a maximum dose of 179 kg ha^{-1} P_2O_5 when planting, applied in bands, at a distance of 5–8 cm from the plant file and 5–8 cm depth, with decreasing doses as a function of the increasing content of phosphorus in the soil.

In Mexico, numerous studies have documented the negative effect of water deficit in the soil on grain production in corn crop (Amado and Ortíz, 1998; Reta and Faz, 1999; Montemayor et al., 2006; Ojeda-Bustamante et al., 2006). Nevertheless, there is little research with respect to the effect of soil moisture tension as indicator of irrigation beginning on yield and morphological quality of sweet corn. On the other hand, although several studies pointed out the importance of phosphorus in sweet corn yield and quality (Colomb et al., 2000; Plénet et al., 2000a,b; Ali et al., 2002), in the State of Campeche the information related to the effect of phosphate fertilization on the morphological quality of sweet corn, is limited. This implies that the fertilization doses the producers apply to the sweet corn crop are mostly based on empiric recommendations, or, in the best of cases, the producer uses fertilization doses recommended for dry kernel production in areas established for sweet corn production.

In a previous article (Rivera-Hernández et al., 2009), the results obtained, evaluating the effect of moisture tension at the beginning of irrigation and phosphate fertilization on yield components of sweet corn, were presented with emphasis on: plant height, leaf length and dry weight, stem diameter and dry weight, and plant dry weight, including also the characteristics of ears with husk (diameter, length, fresh and dry weight) considering them as components of corn yield.

Due to the importance of phosphate fertilization and irrigation for the morphological quality of sweet corn, the research described in this second article had the main objective of evidencing the effect