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Irrigation rate and plant density effects on yield and water use efficiency of drip-irrigated corn

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ABSTRACT

The efficient use of water by modern irrigation systems is becoming increasingly important in arid and semi-arid regions with limited water resources. This study was conducted for 2 years (2005 and 2006) to establish optimal irrigation rates and plant population densities for corn (*Zea mays* L.) in sandy soils using drip irrigation system. The study aimed at achieving high yield and efficient irrigation water use (IWUE) simultaneously. A field experiment was conducted using a randomized complete block split plot design with three drip irrigation rates (I_1: 1.00, I_2: 0.80, and I_3: 0.60 of the estimated evapotranspiration), and three plant population densities (D_1: 48,000, D_2: 71,000 and D_3: 95,000 plants ha^{-1}) as the main plot and split plot, respectively. Irrigation water applied at I_1, I_2 and I_3 were 5955, 4762 and 3572 m^3 ha^{-1}, respectively. A 3-day irrigation interval and three-way cross 310 hybrid corn were used. Results indicated that corn yield, yield components, and IWUE increased with increasing irrigation rates and decreasing plant population densities. Significant interaction effects between irrigation rate and plant population density were detected in both seasons for yield, selected yield components, and IWUE. The highest grain yield, yield components, and IWUE were found for I_1D_1, I_1D_2, or I_2D_1, while the lowest were found for I_3D_2 or I_3D_3. Thus, a high irrigation rate with low or medium plant population densities or a medium irrigation rate with a low plant population density are recommended for drip-irrigated corn in sandy soil. Crop production functions with respect to irrigation rates, determined for grain yield and different yield components, enable the results from this study to be extrapolated to similar agro-climatic conditions.

1. Introduction

In recent years, drip irrigation has become increasingly popular to reduce the amount of water and fertilizer that are applied to the crop, and also to reduce the amount of labor (Tan, 1995; Hanson et al., 1997; Fekadu and Teshome, 1998). Because the drip irrigation is capable of applying small amounts of water where it is needed and to apply it with a high degree of uniformity and frequently, these features make it potentially much more efficient than other irrigation methods. However, the lateral line of drip system for most field row crops, such as corn, is laid out at intervals of about 0.7 m with an emitter spacing of 0.2 m (Mohamed, 1999). Using such design, the initial installation cost has not been considered a viable economic option for field row crops. Among the various components of a drip irrigation system, the

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cost of laterals is the major factor, which influences the total system cost. Most vegetable crops in Egypt such as muskmelons (*Cucumis melo*) and watermelon (*Citrulus lanatus*) are grown at lateral spacing of 1.4 m or more with an emitter spacing of 0.3–0.5 m. Using such design would be one of the most significant factors in reducing the high overall investment costs of drip irrigation when it is used for field crop production. Furthermore, such design may be considered for corn production through crop rotation with vegetable crops.

Under drip irrigation, the ponding zone that develops around the emitter is strongly related to both the water application rate and the soil properties (Assouline, 2002). Consequently, the water application rate is one key factor determining the soil water content around the emitter (Bresler, 1978) and the water uptake pattern (Phene et al., 1991; Coelho and Or, 1999). However, excessive or inadequate water application has a significant impact on either drip irrigation efficiency or final grain yield. For instance, very high rates of water application can eliminate crop water stress, but it will also lessen drip irrigation efficiency by increasing the amount of water and nutrients that leach below the root zone (Morton et al., 1988; Jordan et al., 2003). Very low rates of water application, by contrast, can cause water stress, especially in sandy soils, by failing to meet the water requirement of the plants. Therefore, a proper drip irrigation rate is one that both minimizes the amount of water leached from the root zone and maintains a high soil matrix potential in the rhizosphere to reduce plant water stress.

Corn is the major irrigated crop in Egypt. It is very responsive to the amount of irrigation water applied: positive when irrigation is sufficient and negative when not. Rhoades and Bennett (1990) and Lamm et al. (1995) both reported that it is difficult to plan for deficit irrigation for corn without simultaneously causing yield reduction. Corn plants are especially sensitive to water stress because their root system is relatively sparse. Laboski et al. (1998) found that corn root distribution assessed at tasseling showed an average of 94% of total root length within 60 cm of the soil surface and 85% within 30 cm. This sensitivity to water stress can lead to dramatic fluctuations in corn yield in light of frequent drought and poor irrigation management often found in Egypt. Therefore, precise drip irrigation management is essential to ensure optimal corn yield because water storage under drip irrigation conditions is generally less than that for surface and sprinkler irrigation techniques, and because most roots are concentrated in the damp soil near each emitter or along each lateral line. Accurate information on yield responses in light of the amount of water applied by drip irrigation is therefore essential to achieve the best drip irrigation management.

Increasing the plant population density usually increases corn grain yield until an optimum number of plants per unit area is reached (Lang et al., 1956; Holt and Timmons, 1968). Fulton (1970) also reported that higher plant densities of corn produce higher grain yields. Plant densities of 90,000 plants ha^{-1} for corn are common in many regions of the world (Modarres et al., 1998; Al-Kaisi and Yin, 2003). However, under surface irrigation conditions in Egypt, population densities from 50,000 to 56,000 plants ha^{-1} are considered optimal because greater plant densities result in reduced yields because of competition between plants (Mohamed, 1999; Griesh and Yakout, 2001). Population densities under drip irrigation could possibly be increased because of smaller plant statures accompanied by decreased leaf numbers and sizes. Little information is available about optimum plant population densities of corn when grown in drip systems of vegetable crops.

The design of drip irrigation system make it potentially enabling plant population densities of up to 90,000 plants ha^{-1}. However, optimum plant population densities are related to soil water availability (Holt and Timmons, 1968; Karlen and Camp, 1985), N fertility, and other environmental factors. For corn, yield increases with increasing available soil water content and nitrogen levels until plant densities reach about 50,000 plants ha^{-1} (Eckert and Martin, 1994). Al-Kaisi and Yin (2003) reported that the combination of 0.80–1.00 estimated evapotranspiration (ET) and 57,000–69,000 plants ha^{-1} population produced optimum corn yield, with irrigation treatments 0.80 ET at these densities being the best management system for optimum water use efficiency in loamy soil under a center-pivot sprinkler system.

The objectives of this study were to evaluate the impacts of various drip irrigation rates and plant population densities on corn production and irrigation water use efficiency (IWUE) when grown in drip systems of vegetable crops and to evaluate production functions in light of drip irrigation rates and yield and its components to enable extrapolation of the results to similar agro-climatic conditions.

2. Materials and methods

2.1. *Experimental site description*

This study was conducted on the Experimental Farm of the Faculty of Agriculture at Suez Canal University, Ismailia, Egypt (30°58′N, 32°23′E, and 13 m above mean sea level) during the 2005 and 2006 growing seasons. The soil of the experimental site is sandy throughout its profile (75.9% coarse sand, 19.7% fine sand, 2.7% silt and 1.7% clay). Selected chemical properties and soil water contents of the experimental soil are given in Table 1. Detailed climatic parameters for Ismailia are given in Table 2. Soil bulk density was determined with a classical method, using cylinders 100 mm wide and 60 mm in height according to Grossmann and Reinsch (2002). Soil field capacity and wilting point were determined in the laboratory using the method described by Cassel and Nielsen (1986).

2.2. *Agronomic practices*

Nitrogen fertilizer was applied at a rate of 288 kg ha^{-1} in the form of ammonium sulphate (20.5%) as fertigation. Nitrogen fertilizer was added 2 weeks after sowing in four equal doses with one dose every 10 days. Phosphorus fertilizer was applied at a level of 350 kg ha^{-1} as calcium super phosphate (15.5% P_2O_5). Whole of phosphorus was applied basally before sowing in all treatments. Potassium fertilizer was applied at a level of 100 kg ha^{-1} as potassium sulphate (48% K_2O) in two equal doses every 2 weeks after sowing. Weed, pests, and diseases control were done in a timely manner. Hand harvesting was performed about 120 days after sowing.