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Tomato yield, nitrogen uptake and water use efficiency as affected by planting geometry and level of nitrogen in an arid region

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ABSTRACT

Water has always been the main factor limiting crop production in arid and semi-arid regions where rainfall is insufficient to meet crop demand. The invite to improve water use efficiency and crop productivity, to ensure future food security, has never been more urgent. Tomato yield performance was studied under different planting methods combined with different nitrogen (N) levels to evaluate the potentials and constraints of plant arrangement under drip irrigation for sustaining crop yield, N uptake, N use efficiency (NUE) and water use efficiency (WUE). Three planting methods were tested included arrangement of tomato plants in single rows, 100 cm apart (SR), normal twin rows at 40/160 cm alternately (NT) and dense twin rows at 40/100 cm alternately (DT), which resulted in rising total plant population by 150% as high as SR and NT. This was done along with four N levels (120, 180, 240 and 300 kg N ha^{-1}), applied continuously by drip irrigation system. Drip laterals were laid out along each single row or in the center of the twin rows; consequently the relative number of laterals and water applied were reduced by 50% and 75% for NT and DT, respectively compared with SR. Dense twin planting produced 24% higher tomato fruit yield over SR although 75% of irrigation water was applied. Otherwise, NT with 50% saving in irrigation water and cost of drip laterals can be realized by loss only 15% fruit yield as compared with SR. Nitrogen supply tended to increase tomato fruit yield significantly up to the highest level of N with all planting methods. The interaction effect of planting method × level of N was significant for almost yield components. Nitrogen supply increased tomato N uptake linearly with maximum N removal from the field 193 kg ha^{-1} under DT and N_{300} treatment combination, which contributed to higher fruit yield and total dry biomass. The lowest N treatment (N_{120}) gave the higher N recovery with all planting methods, despite the sand texture of the soil. NUE was higher under DT as compared with SR but the NUE consistently decreased with increase level of N supply with all planting methods. WUE of both twin planting were higher (69% for NT and 64% for DT) compared with SR indicating to efficient use of water applied under this method of planting. The results of this study suggest that dense twin planting can be viable and rational practice to increase crop yield and saving substantial amount of irrigation water as well as cost of drip laterals.

1. Introduction

Optimum use of irrigation water and nitrogen is one of the most important agricultural management in balancing crop yield and water use efficiency in arid region. Moreover, shortage water availability and escalating irrigation costs along with high prices of fertilizers have caused attention to adopt practices to improve water and N use efficiency. Under this situation, drip irrigation is the most efficient irrigation method with the aim to address many of the problems facing irrigated lands (Kumar and Singh, 2002; Gardenas et al., 2005). Drip irrigation does not wet the entire surface of the soil, making the possibility of reducing evaporation and thereby increase crop water use efficiency (Simonne et al., 2007). Moreover, Cetin and Uygan (2008) observed 42% higher WUE in tomato when one lateral was placed between two plant rows. The use of drip irrigation also facilitates frequent fertilizer application via injection in the irrigation system, which allows improving the conjunction between nutrient application and crop nutrient uptake (Zotarelli et al., 2009). A better understanding of the

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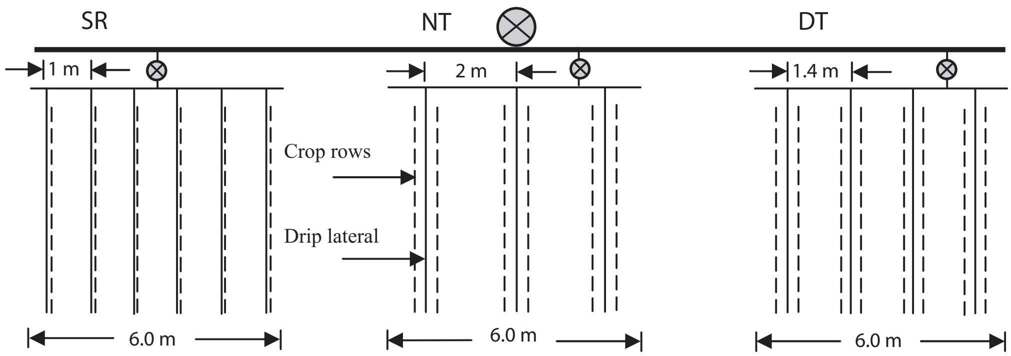

Fig. 1. Layout of the experimental plots and location of drip laterals under different planting geometries, single row (SR), normal twin (NT) and dense twin planting (DT).

interactions of irrigation method, soil type, crop root distribution, and uptake patterns and rates of water and nutrients provides improved means for proper and efficient water management for drip irrigation (Hopmans and Bristow, 2002).

In the design of a drip irrigation system for improving water use and optimizing crop production, factors to be considered include plant spacing and plant canopy cover as well as soil texture, potential evaporation, water quality and topography (Cetin and Uygan, 2008). The greatest problem of drip irrigation system is the higher initial cost of the net work, especially with the vegetable crops that are grown on narrow spaces. However, lateral line spacing is always a compromise between optimal water distribution and the costs for the laterals which imposed specific arrangement for drip irrigated plants. For that reason, drip irrigation systems must be carefully designed and installed so that they operate with proper efficiency for water and fertilizers, which can be applied in a uniform manner. A rational management of drip irrigation needs a proper combination of drip laterals spacing and crop row spacing. The lateral line of drip system for most vegetable crops, should be laid out at intervals of about 60 cm with an emitter spacing of 40 cm. Considering this, the initial installation cost has not been a viable economic option for many row crops. However, increasing the spacing of drip lines would be one of the most significant factors in reducing the high overall investment costs of drip irrigation (Lamm et al., 1997). Some vegetable crops such as cantaloupe and watermelon are grown at lateral spacing of 140 cm or more with an emitter spacing of 40 cm. 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 tomato production through crop rotation but the drip laterals may be placed in the middle of the two crop rows, to reduce high initial costs of drip irrigation.

Crop yields generally increase, with application of N and higher rates of this element is often considered essential to gain higher yield production (Wang et al., 2008; Badr et al., 2012). Applying the correct N rate to maximize crop production is not easy, as the optimum N rate can vary greatly both within soils and among varieties for the same soil due to mineralization of soil organic matter and variable leaching and denitrification of soil nitrate (Jaynes et al., 2011). Providing soil N during crop growth cycle should be available to obtain high yields and maximum income. There are many results that dealt with this topic to optimize the fruit yield of tomato, both in terms of crop N uptake, which ranges from 200 to more than 450 kg ha^{-1} (Scholberg et al., 2000; Blaesing et al., 2006; Erdal et al., 2006), and of N fertilizer requirements, which range from 100 to 224 kg ha^{-1} (Hochmuth, 1988; Hartz and Bottoms, 2009; Zotarelli et al., 2009). The wide disparity of these data can be referred to the large variability of the environmental and crop management factors, from one site to another, and also with genetic diversity exists between the different varieties. However, the use of irrigation strategies that limit the wetted volume in the root zone may improve water and nitrogen fertilizer use efficiency (Han and Kang, 2002), as well as reducing nitrate leaching.

Field tomatoes are a long season crop with high water requirements and the need for moisture increasing until full fruit load is developed. Tomato is a relatively resistant to water stress, hence deficit irrigation could be managed because it can tolerate drought to some degree (Baradas, 1994; Hanson and May, 2004). Maximum productivity for tomato occurs when the soil is kept consistently moist and with N available during periods of high demands (Scholberg et al., 2000). However, the use of drip irrigation may creates a limited wetted soil volume and consequently reducing the crop root development (Mmolawa and Or, 2000). Under this situation, roots grow in a radial shape around the wetted area and concentrate within the top 40 cm of the soil profile (Oliveira et al., 1996; Machado et al., 2003). Maximum root growth has been shown to occur when adequate mineral nitrogen is present (Bloom, 1997), which indicates that lack of inorganic nitrogen in the restricted root zones is critical to root growth.

Therefore, greater emphasis is being placed on water and N management for dry conditions with the aim of crop yield maintenance, which is highly dependent on improving water and N use efficiency. The present study was carried out to describe the performance of tomato yield, N uptake and water use efficiency under different planting geometries included single and twin rows design at different levels of N through drip irrigation system.

2. Materials and methods

2.1. Site and soil description

The field experiment was conducted at the Main Research Station, National Research Centre located at Nubaria province west of Nile Delta of Egypt during the late summer (August–December) growing season of 2013. The research field is situated in an arid climate at an altitude of 24 m above mean sea level and is intersected by latitude of 30°30-N and longitude of 30°20-E. The area has a hot and dry summer months with some ineffective rains in winter which usually bright, sunny days with mild cold nights. The mean monthly evapotranspiration ranged from 6.8 to 2.6 mm in the respective cropping season. The climate parameters recorded from August-December during the growth season of tomato are summarized in (Table 1). The soil of the experimental site was deep, well-drained sandy profile which was classified as an (*Entisol-Typic Torripsamments*) composing of 85.5% sand (2.0–0.02 mm), 11.7% silt (0.02–0.002) 2.8% clay (less than 0.002 mm) and 0.4% organic matter in the topsoil (0–80 cm depth) with an alkaline pH of 8.2, EC of 0.85 dS m^{-1}, CaCO3 1.5%. The average soil water content at field capacity from surface soil layer down to 80 cm depth at 20 cm intervals was 0.18 (v/v) and the permanent wilting point for the