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Soil moisture distribution and root characters as influenced by deficit irrigation through drip system in cotton–maize cropping sequence

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ABSTRACT

Field experiments were conducted during 2007–2009 to study the effect of deficit irrigation practices through drip irrigation system on soil moisture distribution and root growth in cotton–maize cropping sequence. Creation of soil moisture gradient is indispensable to explore the beneficial effects of partial root zone drying (PRD) irrigation and it could be possible only through ADI practice in paired row system of drip layout, that is commonly practiced in India. In the present study, PRD and deficit irrigation (DI) concepts (creation of soil moisture gradient) were implemented through alternate deficit irrigation (ADI) at two levels of irrigation using drip system. Experimental treatments comprised of six irrigation levels (full and deficit) through drip system with surface irrigation for comparison. Maize was sown after cotton under no till condition without disturbing the raised bed and drip layout. Roots confined to the shallow depth and recorded the lowest values for both the crops under conventional drip irrigation at 100% ETc. Among the deficit irrigation treatments, mild deficit irrigation produced longer lateral roots from both the sides of the plant. Contrary to rooting depth, severe water stress affected the lateral root spread and recorded lower values than other drip irrigation treatments. Soil moisture content (SMC) was low nearer to the plant (at 30 cm across the lateral) and far away (at 30 cm along the lateral) from the plant, irrespective of treatments. The reduction in SMC was increased at all locations as applied water level decreased. It is concluded that alternate watering imposed through ADI at 100% ETc produced longer lateral roots with higher values for root dry mass Alternate deficit irrigation (ADI) resulted uneven distribution of soil moisture content. Among the ADI treatments, ADI at 100% had less uneven distribution than ADI at 80% ETc.

1. Introduction

The goal of deficit irrigation is to increase crop water use efficiency by reducing the amount of water in irrigation or by reducing the number of irrigation events (Kirda, 2002). Under deficit irrigation, crops are deliberately exposed to water stress, which may consequently affect the crop growth (Prichard et al., 2004; Zhang et al., 2004). Drip irrigation has been practiced for many years for its effectiveness in reducing soil surface evaporation, increasing the crop yield and WUE. But now, it is used widely in horticultural and wide spaced agricultural crops in order to address the problems of water scarcity. In addition to deficit irrigation (DI), partial root zone drying (PRD) is also a promising practice for inducing stress tolerance in few agricultural and horticultural crops. DI and PRD systems require high managerial skills. Micro-irrigation technology facilitates the application of DI and PRD. Under PRD, when part of the root zone dries out, the levels of abcissic acid (ABA, a plant growth regulator) in the plant increases as drying increases. This sends a message to the leaves to close the stomata as a response to water stress, reducing shoot growth and evaporation from the leaf surface. However, because other roots still have access to water, the plant continues to grow without affecting crop development.

PRD and DI involve manipulating the placement of irrigation water and the moisture deficit maintained in the root zone, respectively. This type of small frequent irrigation applications is achievable only with either drip irrigation or Large Mobile Irrigation Machines (White, 2007). Du et al. (2008) outlined the positive impact of alternate drip irrigation in cotton. They compared the cotton crop under conventional drip irrigation wherein both sides of plant row are watered, and alternate drip irrigation wherein both sides of plant row are alternatively watered. Several scientists studied the effect of water stress by reducing the irrigation amounts from 100 to 80 or 75% ET and reported the yield was not significantly

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affected at these irrigation levels. Dagdelen et al. (2009) reported that seed cotton yield was not significantly affected by drip irrigation application rates of 100 and 75% ET. Darusman et al. (1997) reported that near maximum grain yield was obtained under irrigation amount of 75% ET compared with 100% ET. El-Hendawy et al. (2008) also demonstrated the effect of different irrigation rates on maize grain yield and concluded that comparable grain yield was obtained in both 100% and 80% ET.

Water stress had some negative effects on crop rooting system and prolonged exposure of roots to dryness as soil moisture deficit might cause some anatomical changes in roots. These roots have reduced the ability to sense soil drying (North and Nobel, 1991). Skinner et al. (1998) reported that implementation of PRD through alternate furrow irrigation where in the non irrigated furrows began to dry, root biomass increased as much as 126% compared with irrigated furrow and the greatest increase was at lower depths where moisture was still plenty. Sharp et al. (1988) also reported that drought or moisture stress produced thinner roots than well watered plants in maize. Pace et al. (1999) found that drought treated cotton plants gained significantly greater tap root length than that of well watered ones.

The dry weight of water stressed plant root was lesser and very thinner than the control plants. Root weight was less than that of conventional drip irrigation, but more secondary roots were stimulated in alternate drip irrigation at higher level of water application. This response apparently enhanced the absorptive capacity of plant in alternate drip irrigation (Du et al., 2008). Soil water affected plant growth not only during the soil water stress period but also after relief of the stress. Kang et al. (2000) reported that root development in maize was significantly enhanced by the deficit irrigation through alternate furrow irrigation.

The rate of applying water in drip irrigation is an important factor which governs moisture distribution in soil profile. Sivanappan et al. (1987) studied the water movement pattern for a discharge rate of 8 lph and observed it upto 30–40 cm distance in horizontal and vertical directions, respectively. The moisture content after 48 h at the surface (below the emitter) decreased from 37.8 to 27.8% for discharge rate of 4 lph. The moisture content after 48 h at 30 cm depth below the dripper was found to be stabilized at 23.9% in 0–30 cm depth and at 40 cm distance away from the dripper was 21.8–22.7% for discharge rate of 4 lph. Higher available soil moisture was observed in drip irrigation plots compared to furrow irrigation in two soil depths of 0–15 cm and 15–30 cm (Veeraputhiran, 2000). Igbadun et al. (2008) demonstrated deficit irrigation in maize crop through varying irrigation regimes by withholding irrigation at some growth stages of the crop. The level of moisture stress that the crop was subjected to in each growth stage can be related to the moisture depletion from the effective root zone.

PRD was implemented in orchards and other field crops by using two drip laterals per crop row in order to create alternate wet and dry soil profile. In practice, it is not an economically viable technology due to more investment on drip laterals. Presently a paired row system (one drip lateral for two rows of crop) was recommended in most of the field crops as an economically viable layout. Creation of soil moisture gradient is important to explore the beneficial effects of PRD irrigation and it could be possible only through ADI practice in present situation. Hence in this study, it was planned to use the PRD and DI approaches through drip irrigation in existing paired row lay out and soil moisture gradient was created through application of alternate deficit irrigation (ADI) at two levels of irrigation (100 and 80% ETc). In India, little attempt has been made to assess the effect of deficit irrigation implemented through drip system on soil moisture distribution and root characters of cotton–maize cropping sequence. The main objectives of this research were to (i) study the soil moisture distribution under drip irrigation system in cotton–maize cropping sequence and (ii) rooting characters of cotton and maize under sequential cropping system.

2. Materials and methods

2.1. Seasons and weather data

Field experiments were conducted at the Department of Agronomy, Agricultural College and Research Institute, Coimbatore from 2007 (winter) until 2009 (summer). The region is characterized as semi-arid tropical (SAT) climate, located at 11° 8′ N latitude and 77° 8′ E longitude. The mean annual rainfall (83 years) at Coimbatore is 648 mm distributed over about 50 rainy days with a 30% annual coefficient of variation. The rainfall is monsoon type, with a south-west monsoon from June to September and a north-east monsoon from October to December. The annual mean maximum and minimum temperatures are 31.58 °C and 21.28 °C, respectively.

Cotton crop was raised during winter (August, 2007–January, 2008) and maize was raised during summer (February–May, 2008) under raised bed lay out of drip system. Maize was sown after hybrid cotton under no till condition without disturbing the drip layout. A confirmation study with the same set of treatments was conducted in the same seasons during 2008–2009. The pre-sowing composite soil samples collected from the experimental soil was analyzed for physical–chemical characteristics. The experimental soil was sandy clay with 1.36–1.42 (2007) and 1.34–1.41 (2008) g cc^{-1} of bulk density, field capacity of 25.2–26.3 (2007) and 25.1–26.1 (2008) %, and permanent wilting point of 12.5–13.7 (2007) and 12.4–13.6 (2008) %. The nutrient status was low (264–248 kg ha^{-1}), medium (18.1–18.5 kg ha^{-1}) and high (364–372 kg ha^{-1}) for available nitrogen (N), phosphorus (P) and potassium (K), respectively.

Cotton crop raised during first year in winter (August 2007–January 2008) received 483 mm of rainfall in 24 rainy days (Table 1). Weekly mean pan evaporation ranged from 4.6 to 7.2 mm per day. Maximum mean weekly temperature was 33.0 °C and minimum was 16.3 °C. Relative humidity ranged between 74 and 96% and 41 and 71% at 07.22 and 14.22 h, respectively. Maize crop raised during February 2008–May 2008 received 171 mm of rainfall in 11 rainy days (Table 2). Weekly mean evaporation ranged from 3.2 to 7.3 mm per day. Maximum mean weekly temperature was 29.0–35.7 °C and minimum was 15.9–24.6 °C. Relative humidity fluctuated from 70 to 92% and 28 to 63% at 07.22 and 14.22 h, respectively.

Cotton crop raised during second year in winter (July'08 to December'08) received 473 mm of rainfall in 30 rainy days. Weekly mean pan evaporation ranged from 2.4 to 7.3 mm per day. Maximum mean weekly temperature was 27.1–33.4 °C and minimum was 16.9–23.5 °C. Relative humidity ranged between 76 to 94% and 38 to 71% at 07.22 and 14.22 h, respectively. The second maize crop raised during January'09 to May'09 received 101 mm of rainfall in three rainy days. Weekly mean evaporation ranged from 4.8 to 6.8 mm per day. Maximum mean weekly temperature ranged between 29.1 and 36.4 °C and minimum ranged between 18.0 and 24.4 °C. Relative humidity fluctuated from 79 to 88% and 19 to 45% at 07.22 and 14.22 h, respectively.

2.2. Lay out and experimentation

The experiment was laid out in a randomized block design and the treatments were replicated thrice. Treatments comprised of six irrigation treatments through drip irrigation, with one furrow irrigation for comparison. Drip irrigation system was operated once in three days and water was applied as per the treatments based on estimated ETc. In the event of rain during the cropping period, the