COTTON ROOT SYSTEMS IN A CLAY LOAM SOIL: EFFECTS OF GROWTH STAGE, IRRIGATION AND NITROGEN TREATMENT

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Abstract

Root distribution is influenced by many soil and environmental factors in addition to the influence of genetics on crop morphology and overall plant vigor. The crop growth stage impacts the relative importance of root versus shoot development. Soil nutrient status and relative levels of nutrients in different parts of the soil profile conceivably could impact root distribution. In semi-arid environments, soil water availability is largely determined by irrigation practices once limited water from rainfall is depleted. Irrigation methods differ in the uniformity of water applications, ranging from nearly full surface application in solid-set sprinklers, dead-level basin, border checks to drip and furrow systems which may apply the water to a more limited portion of the soil. A three-year study was initiated under subsurface drip and furrow irrigation in cotton to evaluate the influence of growth stage, nitrogen fertilizer placement, irrigation method (furrow versus subsurface drip (SDI)), and amount applied per irrigation on root length density (RLD) and distribution within the soil profile. Furrow irrigated plots receiving 100% ETc had RLD values significantly lower than SDI plots in within-plant row cores, but much higher values within cores from the furrow area. Under full irrigation, the root system of SDI plants were more concentrated (higher RLD and root mass) near the emitter (within 35-45 cm) than near the soil surface or at greater depths or distances from the emitter. Amounts of applied fertilizer N and location of placement was found to impact root distribution and root length density.

Introduction

Work done in Israel in several studies over the past ten years suggests that higher frequency drip irrigation/fertigation tends to restrict the root zone to a more limited volume of wetted soil and concentrated zone of nutrient placement when compared with lower frequency fertigation. These studies were generally done in soils with sandy loam or similar textures, where lateral water distribution from a point source (drip emitter) is generally more restricted than in heavier soils. Our previous work in sweet corn (which has a fibrous root system) indicated that measurements describing root system depth and density were largely unaffected by irrigation frequencies ranging from multiple irrigations per day to once every 3 to 4 days.

A study was initiated in cotton grown in a clay loam soil in California's San Joaquin Valley to: (1) determine cotton root system responses (rooting depth, lateral distribution and density) to irrigation frequency and amounts; (2) determine the influence of nitrogen fertilizer application amount and placement location (with the same net water application amounts) on the depth, density of cotton root systems at different times of the growing season; and (3) evaluate the impact of a two irrigation amounts (60 versus 100 percent of estimated crop evapotranspiration (ETc)) on lateral water movement and root distribution in subsurface drip-irrigated cotton.

Materials and Methods

Cultural Conditions. The experiment was conducted in a clay loam soil (Panoche clay loam) at the University of CA West Side Research and Extension Center near Five Points, CA. Cotton (*Gossypium hirsutum*, cv. "GC510") was planted in mid-April in 1991, 1992, and 1993 on corrugations (low beds) spaced 76 cm apart. The cultivar "Maxxa" was used in studies done in 1996 and 1997. All treatments received a pre-plant application of 11-52-0 and potassium sulfate fertilizer equivalent to 30 kg N ha-1 and 140 kg K ha-1. With the exception of a furrow irrigated comparison treatment, all treatments received 67 kg P per ha via fertilizers injected through the drip system. In the furrow plots, the fertilizers were applied as a dry, banded application. All plots were germinated and established using 140, 140, 90, 110 and 140 mm of sprinkler irrigation in 1991, 1992, 1993, 1996 and 1997 respectively.

Drip System / Furrow Irrigation. The subsurface drip irrigation (SDI) system consisted of in-line, turbulent-flow emitters with 2 liter per hour output on 0.91 m emitter spacing. Lateral spacing was 1.52 m, with the laterals placed 40 cm below the average soil depth and centered under alternate furrows. Estimated crop evapotranspiration (ETc) was calculated using a locally-derived crop coefficient multiplied by grass refererence evapotranspiration (ET_o). ET_o was determined by the modified Penman method using an adjacent (100 m distant) weather station. Irrigation amounts equivalent to 60% and 100% ETc were applied in the two SDI trts. The furrow irrigated plants were watered on a 12 to 14 day schedule, with one treatment receiving water applications equal to 60% ETc and another 100% ETc.

Treatments. Root system development was evaluated as a function of time (monthly samples in late-June, late-July,

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and late-August or early-September), irrigation frequency and irrigation amount. Irrigation frequencies evaluated included: (1) SDI irrigation after each 2 mm of accumulated ETc (three to four irrigations per day under peak ETc); (2) SDI irrigation after 25 mm accumulated (every four to six days) ETc; and (3) furrow irrigation every 12-14 days (with 100% of estimated ETc applied). The effects of reduced water application amount (60% ETc) on root systems was evaluated under SDI at the 2 mm frequency and under furrow irrigation (12-14 day frequency).

Root System Measurements. Root length density and root fresh and dry weights were measured in samples collected from a 5.1 cm diameter soil core in 15 cm increments to a depth of 1.2 m, then 22.5 cm increments from the 1.2 through 2.92 m depths. All samples analyzed represent a composite collected from two sampling locations within each field block. Three field blocks were sampled in all treatments. Roots were separated and prepared by: (1) soaking soil cores for 1-1.5 hours in a dilute acetic acid solution; (2) washing several times to separate soil and organic materials; (3) hand-separating viable roots from dead roots and soil organic matter; (4) staining roots in dilute methyl violet to enhance contrast; (5) float roots on water and estimate length using a Delta-T video camera system with light table and image analyzer. Core bulk density, water content and soil dry weights were determined on subsamples from each core. Root length density was expressed per unit dry weight of soil and root fresh and dry weights were determined on each sample.

The six sampling locations used within each plot and their relationship to the plant rows and emitter / lateral locations were as follows: (1) sample locations A1, A2 and A3 were located 10, 40 and 70 cm away from and perpendicular to an emitter (away from the drip emitter, across the furrow); (2) sample locations M1, M2 and M3 were located 10, 40 and 70 cm perpendicular to the midpoint between emitters (same distance from drip lateral as A1, A2, A3 respectively, but further from the emitters. These grid sampling locations were selected to represent a cross-section of the root system from close to the plant row and emitter to the maximum distance from emitters. It is important to note that the drip lines were 1.52 m apart (in alternate furrows), so the increasing perpendicular distance from the emitters (40 cm and particularly 70 cm distance) represented a much drier location almost in the middle between laterals.

Results and Discussion

Baseline measurements of root length density (RLD) were taken pre-plant in weed-free areas of fields to identify potential errors in RLD based on "carryover" roots difficult to distinguish from current season roots. These plots had either: (1) cotton grown the prior year; or (2) were fallow. Data showed baseline RLD values averaging 0.08 cm/g in fields previously in cotton, vs. 0.03 cm/g under fallow.

Effects of Soil Sample Location. The six soil core locations (relative to plant row and emitter locations in SDI plots) had a significant effect on root distribution and RLD (Figs. 1,2) in SDI plots. Samples near the drip lateral (A1, M1) and within 30-40 cm of the emitters (A2) had higher RLD than at greater distances from emitters. Differences across locations were smaller in furrow-irrigated plots, with slightly higher RLD in within-row locations as compared with in-furrow locations (data not shown).

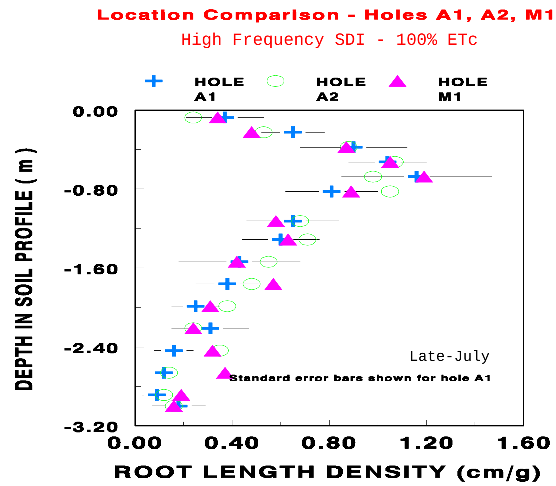

Figure 1. Root length density as affected by location of sampling (holes A1, A2, M1) in subsurface drip irrigation treatment (SDI-100%).

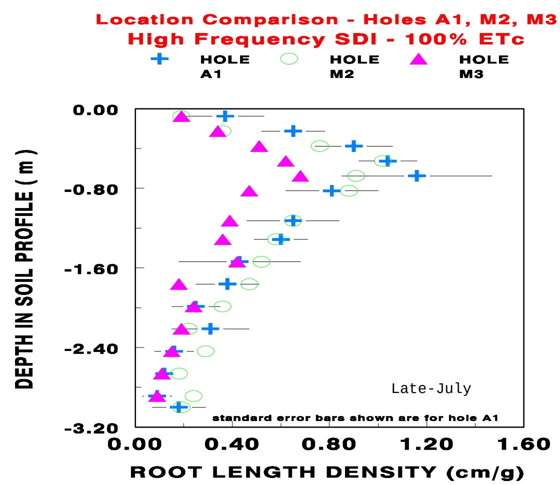

Figure 2. Root length density as affected by location of sampling (holes A1, M2, M3) in subsurface drip irrigation treatment (SDI-100%).

Nitrogen Application Amount Effects. Under SDI irrigation, variable amounts of nitrogen were applied as soluble fertilizer (Calcium Ammonium Nitrate). Injected N applications were spread over a 10-week period, with peak applications during squaring through mid-bloom. Amounts applied were 0, 60, 120 or 180 kg N/ha during the growing season. Differences in root mass across N trts. were largely confined to reduced root mass in 0 and 60 lbs trts. below about 90 cm depth in the soil profile (Figure 3). The data shown was in a year (1996) and location with low residual soil N. Reduced root growth in the lower soil profile reflects lower shoot N uptake and reduced growth in those low N treatments.

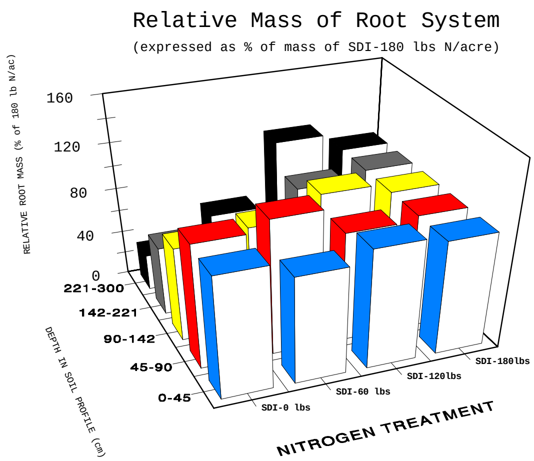

Figure 3. Root mass by depth in soil profile as a function of nitrogen treatment in 1996 experiment with cotton, cv. "Maxxa"

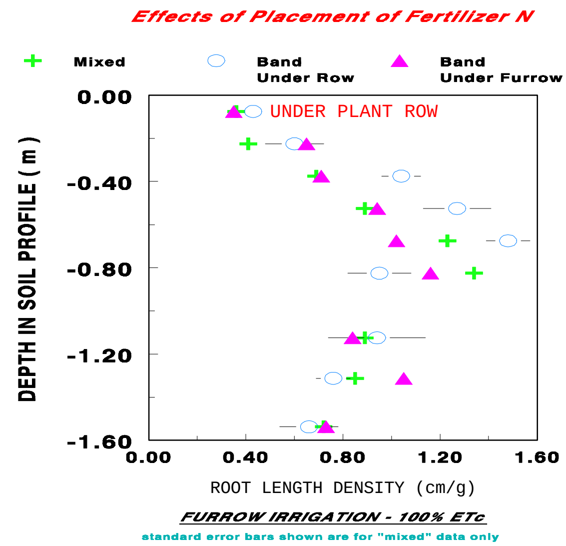

Figure 4. Impact of fertilizer N placement on root length density, for location under plant row in cotton grown in 1996 experiment.

In a separate experiment, RLD was measured to a depth of 1.6 m at locations under the plant row and the center of the furrow in furrow-irrigated cotton. Three N application trts. were evaluated (all of which applied 130 kg N/ha as liquid urea): (1) urea broadcast applied immediately prior to rotavation; (2) shank application 35 cm deep below bed center; (3) shank application below every furrow. In all plots, the surface 35 cm of the soil was mixed prior to planting with a rotavator, and a shank blade was pulled through all treatments to a depth of 40 cm both below the bed center and furrow center. In this way, mechanical disruption of the upper soil was identical in all treatments.

Whether urea was shanked under the plant row or furrow, RLD was significantly increased in the 40-70 cm zone by the presence of applied N in the shank zone (Fig. 4, 5). This difference in RLD was not evident in other depths in the profile.

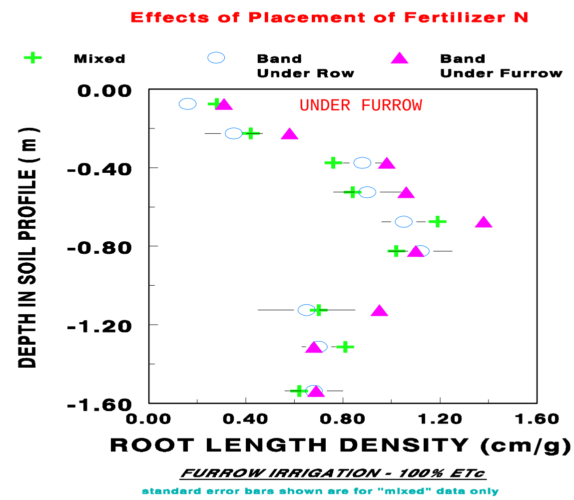

Figure 5. Impact of fertilizer N placement on root length density, for location under furrow in cotton grown in 1996 experiment.

Time of Year / Location Effects. RLD generally increased greatly during the period of rapid leaf area development during June and July (Fig. 6). By the July sampling date, the root system increased greatly in mass (Fig. 6), RLD and depth in the soil from from late-June levels. By late-August, RLD declined moderately in the upper 1m of the soil profile in most cases from late-July levels, but increased during the same period in the 1-2 m depth. The strong effects of low irrigation amount and distance from the emitters was evident in measurements shown in Fig. 7.

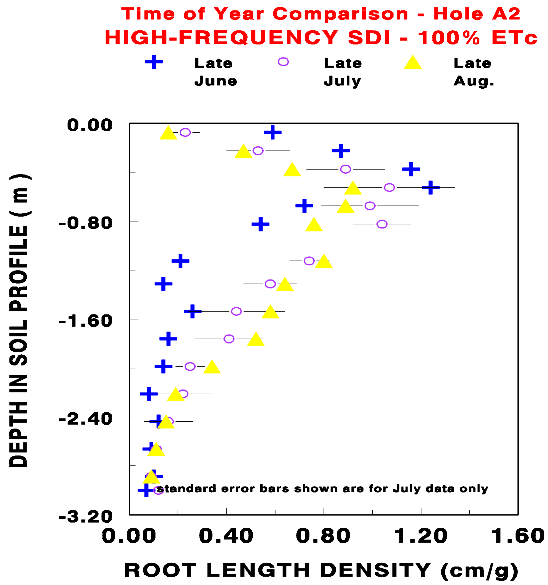

Figure 6. Influence of growth stage (time of year) on root length density of SDI-100% Etc plots for hole location A2 in cotton.

Root Distribution - Generalizations. When comparing total root mass in late-August across treatments, the long-term effects of deficit irrigation in 60% Etc plots were evident. RLD and root mass tended to be higher in deficit-irrigated plants (when compared with full irrigation treatments) below the 1.4 m depth in the soil profile. Surface soil root mass was reduced only in the 60% irrigation treatment under furrow irrigation. This agrees with the greater soil water depletions measured with depth in the low water application treatments (data not shown).

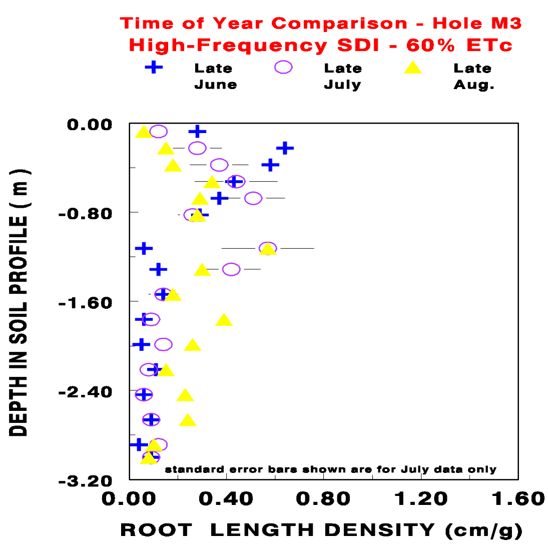

Figure 7. Influence of growth stage (time of year) on root length density of SDI-60% Etc plots for hole location M3 in cotton.

Lint yields in all treatments (including those getting 60% Etc) were good to excellent (exceeding 1600 kg lint/ha in all treatments). Yields were higher in full irrigation treatments, but the significant soil water uptake throughout the soil profile allowed continued growth and good yields even under deficit irrigation in this high water-holding-capacity soil.

Acknowledgments

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