Drip Irrigation Effect on Soil Function, Root Systems and Productivity in Organic Tomato and Corn

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Abstract

Attempts to improve agronomic water use efficiency by introducing subsurface drip irrigation have met with mixed results in organic systems. Growers point to unavailability of nitrogen from organic inputs as a potential cause of poor performance when crops are grown under drip irrigation, but little information exists on organic nutrient cycling under different irrigation schemes. The objective of this study was to examine the effects of irrigation scheme on soil and plant characteristics in an organic production system. We examined the following aspects of carbon and nitrogen cycling as they relate to soil water movement under two different drip irrigation arrangements and compared them to furrow irrigated plots in organic tomato and corn rotations: 1) crop root growth, 2) plant available nitrogen, 3) soil water content, and 4) crop yield. Other aspects in progress but not included in this report include microbial activity, plant N uptake, and cover crop decomposition. Our results have implications for the feasibility of implementing drip irrigation systems in organic agriculture with regard to crop production and water and nitrogen use efficiency.

Introduction

Seventy percent of California's total tomato crop is now under drip irrigation (National Agricultural Statistics Service 2007), which has resulted in greater fruit yield, fruit quality, and water savings in many conventionally managed systems (Hartz and Bottoms 2009). Less is known about the impacts of drip irrigation on crop performance in organic systems, where nutrient mineralization processes are substantially different.

The addition of drip irrigation could alter plant-soil-water interactions essential for the productivity of organic agroecosystems. For example, the more localized water distribution patterns in a drip irrigation system may affect organic nutrient availability from compost and cover crop residues, root growth, and subsequent crop yield. Crop plants lacking sufficient plasticity in root developmental traits to acquire nutrients from a smaller wetting pattern may suffer from water or nutrient stress during the growing season (Lipiec et al. 2013; Machado, Oliveira, and Portas 2003). Furthermore, many organic systems use cover crops in the off-season, and drip irrigation may impact the decomposition and subsequent mineralization of plant-available nutrients.

The Russell Ranch Century Experiment at UC Davis, initiated 24 years ago, examines the long term effects of crop rotation and management system on yield, profitability, and sustainability of 10 different farming systems. This experiment involved plots of organic corn and tomato under a two-year corn/tomato/winter legume cover crop rotation. In 2015, three irrigation treatments were set up in the

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organic plots to assess the long-term impact of irrigation management on soil functioning and crop productivity in organic systems. We hypothesized that the main limiter of organic crop productivity under drip irrigation is nutrient mineralization and mobilization due to the small, discrete wetting pattern around a drip line, and that redistributing water using a double, parallel line—while using equal amounts of water—could improve performance. At Russell Ranch we compared two configurations of sub-surface drip irrigation – a single line and a parallel double line – to furrow irrigation. Our goals were to characterize:

1) Water and nitrogen distribution throughout the bed;
2) Root growth density relative to location of available water at different depths;
3) Weed pressure of 9 common weed species;
4) Crop productivity as yield in tons/acre.

Methods

Layout and crop management: We partitioned each of six 1-acre plots planted as 3 tomato plots and 3 corn plots into 6 rows of single-line drip irrigation, 6 rows of double-line drip irrigation, and the remainder furrow irrigation. Prior to planting, the winter cover crop mixture of oat, vetch and beans was cut and incorporated and 2 tons/acre of composted chicken manure were trenched into the drip treatment rows or spread on top of bed in the furrow treatment.

Yield: Corn yields were calculated following a machine harvest of three adjacent 100 m strips. Dry yields were recorded after grain was threshed and dried to stable weight. Tomato yields were determined following a machine harvest of one 200 m strip and reported as fresh weight (tons/acre) of red fruit.

Weeds: We surveyed ten 0.25 m^2 quadrats per treatment/plot for the 9 most common weed species 1-2 days after irrigation events.

Water: Gravimetric water content was determined for 25 g soil subsamples taken from a grid of three depths and three distances relative to the water source in the bed. The sampling scheme is illustrated in Figure 1.

Nitrate: Using the same sampling grid as above, we extracted 5 g field moist soil samples with 25 mL 2.0M KCl. We then performed a colorimetric analysis using a single vanadium(III) chloride reagent for nitrate concentration (ppm) (Doane and Horwath 2003). Absorbance values were corrected for soil moisture content.

Roots: We installed mini-rhizotron tubes at a 45° angle 1 week after planting and left them in place throughout the growing season. We took bi-weekly scans with a CI-600 In-Situ Root Imager (CID Bio-Science). Scans were manually mapped for a root/background differentiation and color analysis using WinRhizo Pro 2013.

Analysis: We performed an ANOVA analysis using a linear mixed model approach with treatment, depth, and distance from water source as fixed effects and plot as a random effect, followed by a Tukey's Honestly Significant Difference post-hoc test.

Results and Discussion

Drip irrigated tomatoes showed a trend of higher yield in the drip irrigation treatments compared to the furrow, whereas the opposite was the case in the corn plots (Figure 2). However, this difference was not statistically significant. Drip irrigation treatments differed from furrow irrigation treatments in both lateral ($p<0.001$) and vertical ($p<0.001$) distribution of water and nitrate. However, no significant differences were observed between single-line and double-line configurations of sub-surface drip for water and nitrate distribution (Fig. 3). Nitrate was highly concentrated at the surface near the site of compost trenching in the drip treatment, whereas it was spread more evenly in the furrow treatment. In tomato plots, nitrogen use efficiency was 0.34 tons of harvestable yield/acre/lb nitrogen in the drip irrigation treatment, compared to 0.30 tons/acre/lb N in furrow. Water use efficiency was 0.08 tons/acre/m^3 for the drip treatment compared to 0.02 tons/acre/m^3 for the furrow.

Both corn and tomato root systems showed a trend of greater root proliferation in the drip treatments than in the furrow treatment (not significant, $p=0.47$), but indications of plasticity of root growth response to resource availability at different depths were weak (Fig. 4). Weed abundance in tomato plots was significantly greater in the furrow treatment compared to the drip treatments ($p=0.02$).

Design and management of irrigation systems affect the spatial and temporal availability of water for crops. In turn, management can interact with agroecosystem processes, especially as they relate to pest pressure and availability of essential nutrients for yields. These preliminary data suggest that weed pressure is an important limiting factor for tomato production, whereas water stress is a more important limiter for corn. These limitations were reflected in the trend of improved yield for tomato as compared to the trend of depressed yield for corn under drip irrigation.

Conclusions and Next Steps

Design and management of irrigation systems affect the spatial and temporal availability of water for crops. In turn, management can interact with agroecosystem processes, especially as they relate to soil biological, chemical, and physical properties. Tradeoffs and externalities resulting from these interactions have implications for agroecosystem carbon and nitrogen cycling, carbon sequestration, and nitrogen mineralization over the longer term. Characterization of larger-scale parameters of interest, such as greenhouse gas mitigation and soil health, will require research on the effects of drip irrigation on soil physical parameters in addition to the chemical and biological elements examined here.

Preliminary results on the effect on soil physical properties, especially the formation of stable aggregates and related carbon storage capacity emerging from this experiment, offer additional considerations to appreciate long-term effects of drip irrigation in organic systems and broader implications for agroecosystem sustainability. Interactions among these parameters will have implications for infiltration and soil water release, soil organic matter accumulation and carbon sequestration, and consequently for the capacity to build soil natural capital in organic, drip-irrigated systems. For organic systems to remain sustainable, efforts to improve water- and nutrient-use efficiency in drip systems must consider short- and long-term goals, economic feasibility, and differences in crop physiological requirements.

These are preliminary data from a single field season; they will be expanded to include 1-2 more field seasons by 2017. Several analyses are in progress that will be elaborated in later reports on this research, including microbial activity based on colorimetric FDA enzyme analysis and total carbon and nitrogen content of corn and tomato biomass samples along with characterization of shifts in soil properties on the longer term.

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References

Doane, T A, and W R Horwath. 2003. “Spectrophotometric Determination of Nitrate with a Single Reagent.” *Analytical Letters* 36 (12): 2713–2722.

Hartz, Timothy K., and Thomas G. Bottoms. 2009. “Nitrogen Requirements of Drip-Irrigated Processing Tomatoes.” *HortScience* 44 (7): 1988–1993.

Lipiec, J, C Doussan, A Nosalewicz, and K Kondracka. 2013. “Effect of Drought and Heat Stresses on Plant Growth and Yield: A Review.” *International Agrophysics* 27 (4): 463–477.

Machado, Rui M A, Maria do Rosário G Oliveira, and Carlos A M Portas. 2003. “Tomato Root Distribution, Yield and Fruit Quality under Subsurface Drip Irrigation.” *Plant and Soil* 255 (1): 333–341.

National Agricultural Statistics Service. 2007. “Quick Stats Agricultural Statistics Database.” United States Department of Agriculture. http://www.nass.usda.gov/Quick_Stats/.

Appendix

Figure 1

Schematic of soil sampling grid giving subsample positions in relation to drip line. Three replicate grids were sampled at 1 ft. intervals along the bed to account for emitter position.

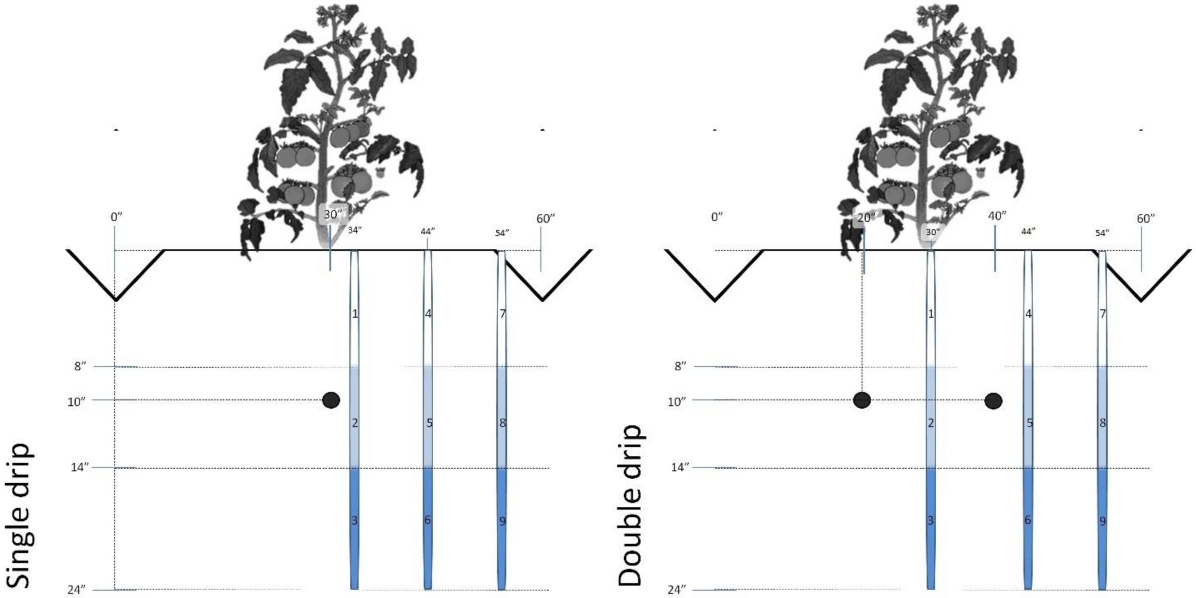

Figure 2

Tomato yield (fresh weight US tons/acre) derived from machine harvest of ~200 x 5 ft. strip. Corn yield (dry grain weight US tons/acre) from machine harvest of 3 adjacent 125 x 5 ft. strips

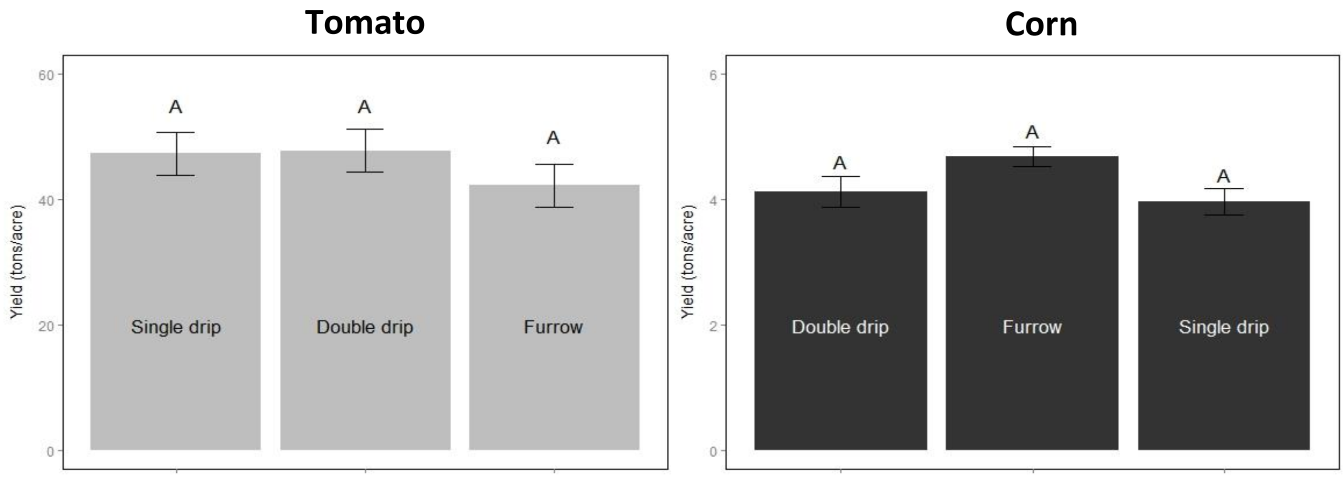

Figure 3

Cross-section of bed showing heatmap of LEFT NO_3^- concentrations (ppm, corrected for water content) and RIGHT gravimetric water content in drip and furrow irrigated tomato plots, averaged across all sampling dates.

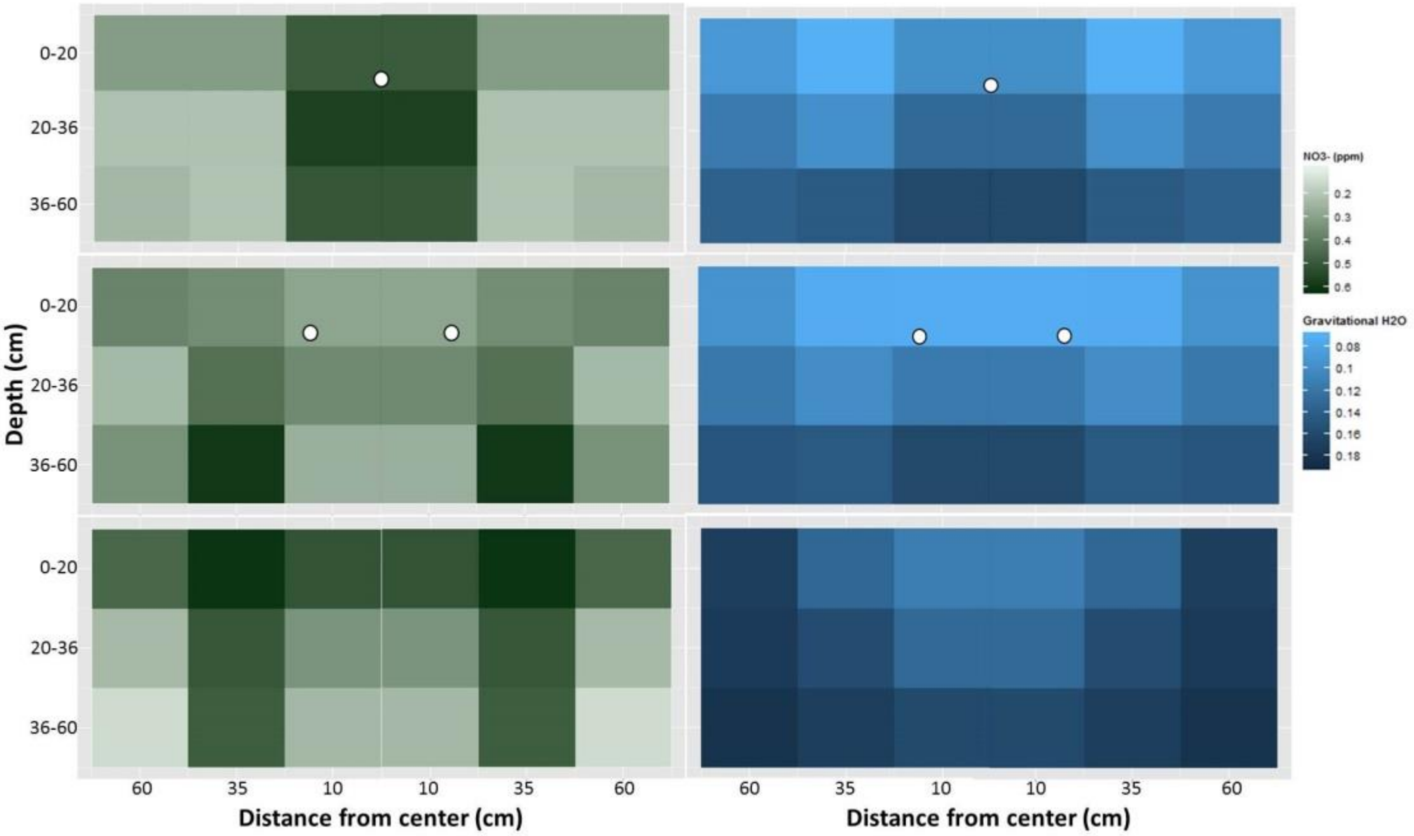

Figure 4

Average total root length by scan depth on the final sampling date for tomato (7/21/2015) and corn (9/7/2015).