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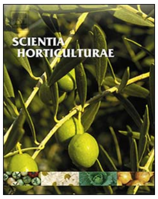

Optimization of irrigation and N-fertilizer strategies for cabbage plasticulture system

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ABSTRACT

Florida cabbage production is dominated by a bare ground production with sub optimal plant populations under seepage irrigation system. Previous studies used plasticulture to increase the plant population and maximize cabbage production per area. The present research was conducted to; determine the optimum nitrogen fertilizer application rate range, determine the transport and fate of applied nitrogen fertilizer and to examine the effects of two irrigation strategies for the proposed plasticulture system with high plant population. The soil moisture sensor based irrigation treatment used 11% and 33% less irrigation water in 2013 and 2014, respectively compared to the evapotranspiration based irrigation with no significant difference in cabbage yield. In 2014, the soil moisture sensor based irrigation also led to an increased retention time of nitrogen fertilizer in the crop rootzone. The optimum fertilizer rate range was determined to be between 400 and 570 $kg\,ha^{-1}$ of N (5–7 g $plant^{-1}$ of N), respectively. Cabbage yields obtained using fertilizer rates within the optimum range under high plant population plasticulture were on average 71% greater than the average bare ground yield under seepage irrigation.

1. Introduction

The average annual fresh market cabbage (*Brassica oleracea* var. capitata) production in the United States between 2005 and 2015 was 1 billion tons. In the same period, cabbage imports were about 60 million tons (USDA-ERS, 2017). California, Florida and New York states are the three top cabbage producers in the U.S. and together supply about 58% of the cabbage produced in the country (USDA-NASS, 2016). Cabbage is grown in Florida during the Fall and Winter months, typically from September to May. During this period, there are considerable weather-related risks that are compounded by the use of seepage or subirrigation. Seepage irrigation in a bare ground production system is the dominant cultural practice for cabbage production throughout Florida. While this system is preferred because of its ease of use and relatively low maintenance costs; seepage requires large volumes of fresh water (Dukes et al., 2010) and is highly susceptible to nutrient losses through leaching and runoff (Sato et al., 2012; Sato et al., 2009). The manipulation of a shallow water table in seepage irrigation results in non-uniform soil moisture in the root zone because water is distributed using water furrows spaced at 18 m apart. The crop rows closest to the water furrows have a more dynamic soil moisture regime in the root zone compared to the crop rows further from the furrows (Reyes-Cabrera et al., 2016; Smajstrla et al., 2000). Florida cabbage producing regions are also characterized by an irregularly distributed semi-impermeable soil layer between 1 and 3 m depth, making the drainage process very slow (Scholberg et al., 2013). During intense periods of precipitation, the water table level can quickly rise to the crop root zone creating the potential for anoxic conditions (Ferreira et al., 2017; Hendricks and Shukla, 2011).

Aside from weather related challenges, pressure is mounting on agricultural producers to conserve water and reduce nutrient losses in the face of population growth, uncertainties associated with climate change, and concerns over water quantity and quality issues that pose a threat to water resource sustainability (Cantliffe et al., 2006; Sato et al., 2009). Although plastic mulch, drip irrigation and fertigation practices have been used for decades in high value horticultural crops to conserve water and nutrients (Lament, 1993; Locascio, 2005), little research has been conducted on the use of those techniques for cabbage production

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(Barrett et al., 2015). The use of plastic mulch, drip irrigation, and fertigation for high population cabbage production has been referred to as plasticulture. Plasticulture cabbage production for Florida has shown the potential to increase yield over the traditional bare ground system (Paranhos et al., 2016a; Paranhos et al., 2016b). The optimum plant population range in the plasticulture system was 14–60% higher than the traditional bare ground system (Barrett et al., 2015). Barrett et al., 2016 showed using various trial data and crop simulations that marketable yield was increased by 45% in the plasticulture system and was shown to be less affected by weather conditions than the bare ground system. This increase and stabilization in yield aided in the determination that the plasticulture system was less risky as compared to the bare ground system, even with the higher costs of implementation. However, an appropriate N fertilizer application rate should be determined for this new system because of the increased plant population and differences in irrigation management compared to the bare ground system. The objectives of this study were to i) determine an optimum nitrogen fertilizer application rate range for high population plasticulture grown cabbage based on cabbage biomass, N accumulation and yield; ii) monitor, quantify, and describe mineral N in the soil and soil solution throughout the growing season; and iii) examine the effect of irrigation strategy on the aforementioned study parameters.

2. Materials and methods

Field trials were conducted at the University of Florida, Institute of Food and Agricultural Sciences, Hastings Agricultural Extension Center in Hastings, FL. The soil is characterized as a Placid fine sand: sandy, siliceous, hyperthermic, typic, humaquepts, with 0–2% slopes (Readle, 1983). The cabbage cultivar 'Bravo' was transplanted 14 November 2012 (2013 Season) and 2013 (2014 Season). Details about the cabbage high population system are described in detail in Barrett et al. (2015). Briefly, cabbage was grown on 1.2 m wide raised beds with black plastic mulch (1.8 m width, 1.25 mm thickness, VIF film, Polygro, LLC. Safety Harbor, FL) and two drip tapes (Aqua-Traxx model EA5081222, 16 mm diameter, 0.3 m emitter spacing, 0.5 L h^{-1} at 55 kPa, Toro Agricultural Irrigation, El Cajon, CA, USA). Beds were spaced 2.0 m on center. Transplants were planted in four rows per bed with an in-row spacing of 25 cm. The trials were arranged in a split-plot design with four replications.

2.1. Main plot

The main plot factor was irrigation strategy. The two irrigation strategies were designed to replace crop water loss from evapotranspiration, one via manual adjustment of the irrigation volume based on crop evapotranspiration (ET_{based}) and one via automated irrigation control with soil moisture sensor (SMS). Weekly reference evapotranspiration (ET_0) data were collected from a Florida Automated Weather Network (www.fawn.ifas.ufl.edu) weather station located within 500 m of the experiment site. Crop evapotranspiration (ET_c) was computed weekly as the crop coefficient (K_c) was updated to match the crop growth cycle. The K_c for cabbage was adjusted for the initial 0.7, mid 1.05, and end 0.95 crop growth stages based on FAO-56 (Allen et al., 1998). Daily irrigation volumes were split into three irrigation events. The irrigation start times were 7:00, 12:00, and 15:00 for both strategies and were initiated using an irrigation controller (Rain Bird ESP4ME, Rainbird, Tucson, AZ, USA) and solenoid valves (ICV 201G, AC power, Hunter Industries Inc. San Marcos, CA, USA). The second irrigation strategy used a soil moisture sensor that bypasses an irrigation event if the volumetric soil moisture content was above the set threshold. The SMS strategy used a Time Domain Transmissometry (TDT) sensor (SMRT-Y soil moisture sensor kit, Rain Bird, Tucson, AZ) which was placed diagonally in the rootzone of the crop from a depth of 5 to 20 cm (Fig. 1). The sensor was wired to the irrigation controller such that the sensor acted as a circuit interrupter when soil moisture was above the set threshold. The soil moisture threshold was set to the soil field capacity, at 0.12 $m^3 m^{-3}$ soil volumetric water content (VWC). Irrigation water volumes were monitored and recorded weekly using inline flow meters (DLJ 200, Daniel L. Jerman Co., Hackensack, NJ, USA).

2.2. Sub plot

The subplot factor was N-fertilizer application rate. Five N rates were tested both years. The N application rate range was developed to encompass the University of Florida – Institute of Food and Agricultural Sciences guidelines of 196 kg ha^{-1} of N (Olson et al., 2012) and the grower average N fertilizer rate of 269 kg ha^{-1} of N for a plant population of 48,438 plants ha^{-1}. The amount of N applied from those two rates were 4 and 6 g of N $plant^{-1}$, respectively. In 2013 season, the N fertilizer rates tested were 90, 197, 293, 392, and 589 kg ha^{-1} of N at a plant population of 77,500 ha^{-1}. The range of N applied in the first year was 7 and 12 g of N $plant^{-1}$. In 2014 season the same plant population was tested but the N rates were increased to better capture the optimum N fertilizer response range because in the season the optimum N rate was near the maximum rate tested. The N rates became 224, 336, 448, 560, and 672 kg ha^{-1}, representing a range of 2 and 9 g $plant^{-1}$. Pre-plant granular fertilizer blend was incorporated into the beds using a 10N–4.4P–8.3K material at a rate of 90 kg ha^{-1} of N the 2013 season and 224 kg ha^{-1} of N rate for the 2013 season. The higher pre-plant fertilizer application rate in 2014 season was carried out to supply all of the lowest application rate at pre-plant, remaining consistent with the 2013 season. Both seasons, additional P was supplied pre-plant using a triple superphosphate 0N-19.7P-0K material for a total of 112 kg ha^{-1} of P_2O_5 for all treatments. Calcium nitrate 15.5N-0P-0K-19Ca and potassium chloride 0N-0P-50K-46Cl were used to supply the remaining N and K fertilizer through the irrigation system (fertigation) keeping K balanced with N. The fertigation schedule supplied fertilizer at increasing concentrations during the exponential crop growth phase and then at reduced concentrations as crop growth slowed near maturity. During the 2013 season there were 12 weekly fertigation events in which fertilizer was distributed at 2, 4, 4, 8, 8, 10, 10, 12, 12, 12, 10, and 10% of the injected total, respectively. During the 2014 season there were seven fertigation events in which fertilizer was distributed at 5, 5, 10, 20, 25, 25, and 10% of the injected total, respectively.

2.3. Soil mineral N

Soil samples were taken prior to transplanting, then every four weeks during the growing season and again after final harvest. A 5-cm diameter soil auger was used to collect soil samples from each plot at three soil depth layers; 0–15, 15–30, and 30–60 cm. Samples were collected from within the plant row (Fig. 1A). The samples were stored at 4 °C for a maximum of two days prior to extraction. A 10.5 g sub sample of soil was extracted using 50 mL of 2 M KCl solution and then submitted to the Analytical Research Laboratory (ARL) at the University of Florida in Gainesville, FL where the extracts were analyzed for nitrate according to the USEPA Method 353.2 (O'Dell, 1993b), and ammonium according to the USEPA Method 350.1 (O'Dell, 1993a).

2.4. Soil solution mineral N

Suction cup lysimeters (Soilmoisture Equipment Corp., Santa Barbara, CA, USA) with a diameter of 5-cm were installed at transplanting to a depth of 36-cm (Fig. 1A). The suction cup lysimeters were modified after Crabtree and Seaman (2006). Samples were collected every two weeks during the growing season and again after final harvest. After collection, samples were stored at 4 °C for a maximum of two days prior to submission to the lab. The samples were analyzed for NH_4-N and NO_3-N as described above.