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Rate and timing of nitrogen fertilizer application on potato 'FL1867'. Part I: Plant nitrogen uptake and soil nitrogen availability

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ABSTRACT

Knowledge of seasonal nutrient demand is necessary to maximize potato (*Solanum tuberosum*) yield and profitability while also minimizing the risk of excess fertilizer leaching into waterways. The objective of this study was to determine the effect of the N fertilizer rate and timing of application on the N use efficiency (NUE) and yield of chipping potato 'FL1867'. This study was conducted with grower collaboration on three commercial farms for two years (2011 and 2012) using subirrigation on course textured soils in Florida. All treatments received 56 kg ha^{-1} of N as ammonium nitrate applied as a band approximately 40 days before planting ($N_{pre\text{-}pl}$). Liquid urea ammonium nitrate was then band applied at 0, 56, 112, or 168 kg ha^{-1} at plant emergence (N_{emerg}) followed by 56 or 112 kg ha^{-1} applied as a side-dress at tuber initiation stage ($N_{tuber\ init}$). The treatments were arranged in a factorial design with four replicates. The total amount of N fertilizer applied ranged from 112 to 336 kg ha^{-1}. Maximum daily N uptake by the potato crop occurred between 55 and 65 days after planting, coinciding with the onset of the tuber bulking stage. Heavy rainfall prior to planting the 2011 crop reduced soil N availability from pre-plant applied N fertilizer indicating the high susceptibility of that application timing to leaching. Average tuber yield ranged from 25.6 to 47.2 Mg ha^{-1}, with the lowest yields occurring when heavy rainfall close to harvest increased yield loss to decay. While higher N_{emerg} rates increased soil inorganic N, tuber yield was either not affected by N application or responded quadratically peaking at N_{emerg} levels between 95 and 125 kg ha^{-1}. N application rates above this range decreased yield and NUE while increasing soil residual N at the end of the season. Plant N uptake and tuber yield did not increase with $N_{tuber\ init}$ rate above 56 kg ha^{-1} and it was associated with lower NUE and also higher residual soil N.

1. Introduction

Several segments of the main waterways of the lower St. Johns River (LSJR) have been classified as an impaired waterway by the Florida Department of Environmental Protection's (FDEP) Total Maximum Daily Load (TMDL) regulations in due to high concentrations of nitrogen (N), phosphorus (P), low levels of dissolved oxygen, high turbidity and/or chlorophyll *a* (FDEP, 2008). Nutrient loading from wastewater treatment is the largest contributor of nutrient pollution in the LSJR (SJRWMD, 2014) from urban, suburban and agricultural areas was also identified as a source of nutrient pollution in the river (SJRWMD, 2014). The Tri-County Agricultural Area (TCAA) in Northeast (NE) Florida is an important vegetable production area within the LSJR Basin. The TCAA accounts for 60% of the potato (*Solanum tuberosum*) production in the state. This region is characterized by high water table Flatwoods soils. The high water table is due to the presence of an impervious clay layer below 40–45 cm depth. This impervious layer allows crop irrigation by raising the water table with ground water to just below the root zone, a practice termed seepage irrigation or subirrigation (Smajstrla et al., 2000). This combination of high water table, coarse texture and low soil organic matter content can lead to offsite

Abbreviations: LSJR, Lower St. John's River; TCAA, Tri-County Agricultural Area; N, nitrogen; P, phosphorus; $N_{pre\ pl}$, N-fertilizer applied at pre-plant; N_{emerg}, N-fertilizer applied at plant emergence; $N_{tuber\ init}$, N-fertilizer applied at tuber initiation as sidedress; NUE, nitrogen use efficiency; BMP, best management practices; UAN, urea ammonium nitrate; AN, ammonium nitrate; DAP, days after planting; NHI, nitrogen harvest index; NUtE, nitrogen uptake efficiency; FDEP, Florida Department of Environmental Protection; TMDL, Total Maximum Daily Load; NE, northeast; FDACS, Florida Department of Agriculture and Consumer Services.

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movement of fertilizers such as N and P. In 2001, the Water Quality Protection Best Management Practices (BMP) Program was established by Florida Department of Agriculture and Consumer Services (FDACS) and FDEP (FDACS, 2005) to reduce nutrient loading into the river from agricultural sources. This initiative involved cost-sharing the implementation of BMPs including water table monitoring and control, sediment control, soil test recommendations and other cultural practices (Way, 2007). In 2011, a cost-share program called TCAA Water Management Partnership was initiated with the objective of improving water quality and water use efficiency within agricultural areas (SJRWMD, 2015). This program identified fertilizer banding as an effective BMP practice. For many years, broadcast application had been the predominant fertilization placement method for potato production in the TCAA. Currently, more than 50% of the potato production in the TCAA has converted to banding fertilizer practices. Although the conversion to banding is an important step toward increasing fertilizer use efficiency and sustainability of potato production in Florida, more information about seasonal nutrient demand, fertilizer rate and timing of application for potatoes are still needed to maximize yield and minimize the risk of nutrient leaching, while also controlling fertilizer input costs.

The fertilizer program most widely used by potato growers in NE Florida includes at least three applications of water soluble N fertilizer. The first N application occurs concomitant with soil fumigation at about 30–40 days prior to planting. Typical N rates for the pre-plant N ($N_{pre\ pl}$) application ranges between 56 and 78 kg ha^{-1}. Subsequently, 112–224 kg ha^{-1} of N is applied at plant emergence. Additional N fertilizer is also applied as a sidedress before the canopy closes the rows which coincides with the time of tuber initiation. Sidedress N application rates range from 33 to 112 kg ha^{-1}, with the higher rates employed after intense rainfall.

Improved N fertilization management must take into consideration plant N demand and root development at different crop development stages and use this information to determine fertilizer rate, application timing and placement. Seepage irrigated potato crops have a limited effective root zone, with the majority of roots restricted to the top 24 cm (Munoz-Arboleda et al., 2006). Matching crop N demand with soil N availability has been challenging for potato growers in NE Florida due to the high susceptibility of the sandy soils to nitrate leaching during the heavy rainfall events common to this area. The effective contribution of $N_{pre\ pl}$ to the nutrition of a potato crop grown on sandy soils was reported to be dependent of rainfall that occurred between N application and seedling emergence (Zotarelli et al., 2014). After intense rainfall events, availability of soil N from $N_{pre\ pl}$ was significantly reduced as result of leaching and/or runoff (Creamer and Baldwin, 2000; Mary et al., 1996). From the time of sprout development until the beginning of vegetative growth, the potato plant's demand for N is low, however some N is required to stimulate plant growth and tuber initiation (Lauer, 1985; Roberts et al., 1982). Application of low rates of N fertilizer rates at planting, supplemented with N applications during tuber development may have the potential to improve early-season tuber growth and to increase nitrogen use efficiency (NUE) (Roberts et al., 1991; Westermann and Kleinkopf, 1985). Plant N demand increases exponentially during vegetative growth and tuber initiation (Alva et al., 2002; Zotarelli et al., 2014). This delay in the maximum crop requirement of N suggests that the crop may make more efficient use of N applied midseason as a sidedress application rather than N applied at planting (Roberts et al., 1991; Westermann et al., 1988). Nitrogen fertilizer strategies must also ensure that some soil N is available during vegetative growth, followed by an increase in soil N availability during the tuber initiation and tuber bulking stages (Alva, 2004; Lauer, 1985; Roberts et al., 1982).

When using seepage irrigation (a form of subirrigation) there is a close relationship between irrigation management and N leaching from sandy soils (Sato et al., 2009). In subirrigation, water is distributed across the field through furrows spaced 18 m apart. Water seeping out of these furrows saturates the soil profile above an impermeable layer. This creates an upward movement of water from an artificially maintained water table (Dukes et al., 2010). The furrows also drain the field after rainfall. The maintenance of a water table level just below the crop root zone and rapid drainage/removal of excessive rainfall water are the greatest challenges when using this type of irrigation system. As the water table is raised, N fertilizer in the effective rootzone is solubilized and available to the plants. When the water table is lowered, the soluble fertilizer can leach below the root zone and subsequently can move laterally by subsurface flow and be transported off-site through the furrows connected drainage ditches (Shukla et al., 2010). As sandy soils with a shallow water table are very susceptible to N leaching, higher fertilizer rates may be required in seepage irrigation systems (Simonne et al., 2010), especially if N fertilizer application timing does not coincide with plant N uptake.

The objective of this study was to determine the effect of rate and timing of N fertilizer application on the NUE and yield of 'FL1867' chipping potato growing on coarse textured seepage irrigated soils in NE Florida. The goal was to determine the combination of proper fertilizer application timing and rate that increased N use efficiency without reducing tuber yield of potatoes.

2. Materials and methods

Trials were conducted during the spring of 2011 and 2012 on three commercial potato fields growing 'FL 1867,' a determinate potato variety grown by farmers under a contract with Frito Lay (Frito-Lay Inc., Purchase, NY). The experimental area consisted of approximately 1.5 ha plots grown within blocks of 20–30 ha in commercial potato fields. The grower-cooperators followed their own crop management practices except fertilization practices and were responsible for all activities associated with cultivation, soil preparation, fumigation, seed treatment, planting, irrigation, and pest, weed and disease management. The researchers were responsible for marking plots, calibrating the fertilizer applicator, applying fertilizer, and plant sampling, monitoring and harvesting.

The predominant soil types were Alaquod Spodosol at Farm 1; Aeric Alaquod at Farm 2; and Arenic Endoaqualf at Farm 3 (USDA-NRCS, 2013). Each 8-row experimental plot was flanked on one side by an irrigation furrow and were 480, 343 and 411 m^2 on Farm 1, 2 and 3 respectively. Seepage irrigation began at or around plant emergence and was maintained by the grower at each farm.

Potato seed pieces of 'FL1867' were planted on 31 Jan, 13 Feb and 5 Feb on Farms 1, 2 and 3, respectively in 2011; and 20 Jan, 2 Feb and 30 Jan on Farms 1, 2 and 3 respectively in 2012. The planting date was used as 0 day after planting (DAP), therefore, any activity that occurred before the planting was expressed as negative DAP. Seed pieces were planted 20 cm apart within rows with 102 cm between rows. All treatments received 112 kg ha^{-1} of P_2O_5 and 168 kg ha^{-1} of K_2O at planting, and 168 kg ha^{-1} of K_2O at emergence.

Rainfall and air temperature were measured by an automatic rain gauge and thermometers installed at each site (Onset, Bourne, MA).

2.1. Nitrogen fertilizer timing and rate application

Nitrogen fertilizer was applied three times during the season, with the timing set to match the application timing commonly used by growers. The first application occurred at pre-plant ($N_{pre\text{-}pl}$), the second application at plant emergence (N_{emerg}) and the third application was a sidedress at tuber initiation ($N_{tuber\ init}$).