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# Optimizing nitrogen fertilizer rates and time of application for potatoes under seepage irrigation

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ABSTRACT

Splitting N fertilizer application is recommended to increase crop N use efficiency by reducing risk of leaching. The objective of this study was to optimize the timing and rate of split N fertilizer applications to maximize tuber yield and quality of chipping potatoes grown using seepage irrigation in Florida. A two-year study was conducted on two commercial farms using cultivars Atlantic and FL1867. A factorial of two N rates applied at pre-plant ($N_{pre\text{-}pl}$) 0 or 56 kg ha$^{-1}$ 30 days before planting followed by four N rates applied at plant emergence ($N_{emerg}$) 0, 56, 112, or 168 kg ha$^{-1}$ were randomized in a complete block design with four replicates. At tuber initiation, all treatments received an additional 56 kg ha$^{-1}$ of N. All applications of N were of granular ammonium nitrate banded. Total N applied for the various treatments ranged from 56 to 280 kg ha$^{-1}$ of N. Soil N was monitored in the 0–20 cm soil depth layer throughout the season. Whole plant biomass peaked at 8.5–8.7 Mg ha$^{-1}$ with $N_{emerg}$ rates between 112–143 kg ha$^{-1}$. Plant N uptake range from 66 to 157 kg ha$^{-1}$. N uptake use efficiency decreased with increasing N rates. Potato yield ranged from 25 to 42 Mg ha$^{-1}$ in both years. In 2013, application of 56 kg ha$^{-1}$ of $N_{pre\text{-}pl}$ produced 2.5–5.1 Mg ha$^{-1}$ higher yield than treatments receiving 0 N. In 2014, there was an interaction between $N_{pre\text{-}pl}$ and $N_{emerg}$ on yield. The higher 56 kg ha$^{-1}$ $N_{pre\text{-}pl}$ resulted in higher yield only when $N_{emerg}$ was at or below 56 kg ha$^{-1}$. For cv. Atlantic when no $N_{pre\text{-}pl}$ was supplied, yield increased linearly in response to $N_{emerg}$ rates, while with 56 kg ha$^{-1}$ of $N_{pre\text{-}pl}$, yield responded quadratically to $N_{emerg}$ reaching a maximum at 114 kg ha$^{-1}$. For cv. FL1867 yield increased quadratically to $N_{emerg}$ peaking at 138 and 126 kg ha$^{-1}$ of when 0 or 56 kg ha$^{-1}$ of $N_{pre\text{-}pl}$ was applied, respectively. The study shows that while the risk of $N_{pre\text{-}pl}$ loss is high, $N_{pre\text{-}pl}$ can result in higher yield, especially when subsequent N rates are low. Application of $N_{pre\text{-}pl}$ was particularly effective in a dry year. By contrast, when soil mineral N from $N_{pre\text{-}pl}$ was largely lost to leaching in a high rainfall year, yield was increased by the $N_{pre\text{-}pl}$ application only when subsequent $N_{emerg}$ rates were less than 112 kg ha$^{-1}$. When early-season soil N was low, the $N_{emerg}$ had a larger impact on tuber yield due to minimum loss to leaching, maximizing yield when $N_{emerg}$ was 128–168 kg ha$^{-1}$. This indicates that applying N fertilizer prior to emergence is necessary to maximize tuber yield.

## 1. Introduction

Potato is an important crop in the United States. The state of Florida is an important supplier of potato especially during the spring, which is the off-season time for northern potato production regions. The state of Florida's total tuber yield in 2016 represented 35% of the U.S Spring production. However, the average tuber yield in the state was 29.5 Mg ha$^{-1}$, while the U.S. average was 31.6 Mg ha$^{-1}$ (USDA-NASS, 2017). Potato production in Florida offers distinctive challenges from the other potato producing regions. Those challenges include Florida soil characteristics (i.e. sandy soil and shallow water table) and irrigation type and practices (i.e. subsurface), which drives the N fertilizer management.

The potato cropping season in northeast Florida is around 95–110 days. The cropping period is limited by the risk of freezing events after planting in Jan and Feb, followed by excessively high air temperatures, accompanied by high rainfall starting in May at tuber maturation. These weather patterns may directly impact tuber yield and quality, increasing the risk of economic losses. In addition, high rainfall events often lead to significant fertilizer leaching events because soils in

*Abbreviations:* N, nitrogen; $N_{prepl}$, N-fertilizer applied pre-plant; $N_{emerg}$, N-fertilizer applied at plant emergence; $N_{tuberinit}$, N-fertilizer applied at tuber initiation as sidedress; AN, ammonium nitrate; DAP, days after planting; N, nitrogen; P, phosphorus

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northeastern Florida are predominantly uncoated fine sands characterized by low cation exchange capacity and high hydraulic conductivity, which induce a rapid infiltration of water and solutes through the upper layers of soil (Errebhi et al., 1998; Stanley and Toor, 2010; Soil Survey Staff, 2015). This high potential for nitrate leaching leads to concerns about the impact of N-fertilization practices in agricultural areas, especially as nonpoint source nutrient loads to the Lower St. Johns River Basin (Way, 2007). The challenge in this area is to supply sufficient fertilizer timed to maximize crop production, without increasing the risk of fertilizer loss to the environment. The confined root system of potato crop and its low nitrogen use efficiency and therefore large quantities of supplemental N fertilizer is usually required (Ojala et al., 1990).

Nitrate leaching can be exacerbated by irrigation management, in particular with irrigation methods that have low water use efficiency due to excessive application volumes. Seepage is a form of subirrigation commonly used by potato growers in FL. This practice is unique from other potato producing regions (Way, 2007). Water application in seepage irrigation occurs through furrows (shallow open ditches) installed along the potato field every 18 m or 16 planted raised rows. Applied water permeates into the soil profile and raises the water table above an impermeable soil layer, located approximately 3.0 m below the soil surface. Typically, the water table is maintained deeper than 55 cm below the soil surface (Dukes et al., 2010) to keep adequate aeration in the root zone. Following irrigation or rainfall the increasing in level of water table creates an upward movement of soil water that supplies the crop root zone. As consequence of water application, N-fertilizer in the effective root zone is solubilized and made available to the plants (Stanley and Toor, 2010). The furrows also drain the field after rainfall. When the water table is lowered, the soluble fertilizer can leach from the root zone and subsequently can move laterally by subsurface flow and be transported off-site through a series of drainage ditches (Shukla et al., 2010).

While maximizing yield is the overall goal, many factors come into play when a grower is making fertilization decisions including time of application, cost of inputs, and availability of resources. Using N rates that optimize profit ability is also be a consideration (Asci et al., 2015). Based on an economic study examining risk perception in BMP adoption, a comprehensive single N-fertilizer recommendation for all potato growers in northeast Florida is not optimal as growers have varying levels of risk aversion leading to decreases in adoption (Asci et al., 2015). There are numerous published trials investigating yield response of potato to N fertilizer managements (Errebhi et al., 1998; Goffart et al., 2008; Vos, 2009). Variability in weather, irrigation management, and production techniques can enhance the utility of recommendations of potato producing regions (Vos, 2009). Growing conditions during the spring season, sandy soil, use of seepage irrigation, and risk of contaminating protected water resources are all important factors that must be considered in deciding on optimal N fertilizer rate for potato production in Florida. The potato crop is known to have low N uptake efficiency ranging between 40% and 60% (Westermann et al., 1988; Errebhi et al., 1999; Rens et al., 2015b; Rens et al., 2016). Thus, splitting N application can increase N uptake by reducing leaching and runoff, especially in years with heavy rainfall on leaching-prone soils (Vos, 1999; Alva, 2004a; Vos, 2009; Kelling et al., 2015).

In northeast Florida, N fertilizer is typically applied at the time of field fumigation, 30–40 days before planting. Previous research has highlighted the necessity to investigate the amount of N applied at pre-planting for potato (Zotarelli et al., 2014). Growers typically apply 26% of the total N at this timing (Asci et al., 2012), and the pre-planting N application occurs far in advance of planting to avoid additional work during the busy time of planting. In combination with the sandy soil and likelihood of rainfall events in NE Florida, the risk of losing N through leaching and runoff is high in the time between pre-plant N application and substantial N uptake by the potato crop. The N fertilizer applied 30–40 days before planting needs to stay in the root zone for 50–70 days to contribute to the nutrition of the potato crop. Zotarelli et al. (2014, 2015) reported that when 56 kg ha$^{-1}$ of N was applied at fumigation, the N could only be detected in the soil at the time of emergence in growing seasons with low precipitation. Consequently the N fertilizer use efficiency for this early application was only 11% (Rens et al., 2016). However, available soil N early in potato development is necessary, as insufficient N at that time reduces leaf area, plant growth and yield (Kleinkopf et al., 1981; Love et al., 2005). The yield benefit from pre-plant N applied in combination with in-season N requires further investigation. Thus, the objective of this study was to optimize the timing and rate of split N fertilizer applications to maximize marketable tuber yield and quality of two chipping potato varieties in seepage irrigation systems under commercial conditions in Florida.

## 2. Materials and methods

The study was conducted in 2013 and 2014 in collaboration with two commercial potato growers located 2.25 km apart in northeast Florida's St. Johns County. Experimental areas of approximately 1.5 ha were selected within commercial potato production fields of 20–30 ha on each participating farm. A total of four trials were conducted at the farms identified as Farm 1 and 2 using the cultivars 'Atlantic' (Webb et al., 1978) and 'FL1867' (Cipar, 2004), respectively, both determinate chipping potato cultivars. At both sites, growers grew a cover crop of sorghum sudangrass (*Sorghum sudanense* Stapf) which was incorporated into the soil in the fall ahead of the potato crop. Aside from the experimental N treatments, growers followed their own crop management plans for the duration of the potato cropping season and were responsible for all activities associated with soil preparation, fumigation, seed treatment, planting, irrigation, tillage and management of pests, weeds and diseases. Soil characteristics and crop management details and respective dates from each site are presented in Table 1. The crops were planted on 24 Jan. and 2 Feb. on Farms 1 and 2 respectively in 2013; and on 16 Jan. and 18 Feb. on Farms 1 and 2 respectively in 2014. Seed pieces were planted 20 cm apart within rows with 107 and 102 cm between rows on Farms 1 and 2, respectively.

Water was either supplied via a seepage irrigation or through precipitation. Seepage irrigation began at or around plant emergence and was managed by the grower at each farm. In this irrigation system, the water table level is adjusted around 55 cm below the top of the raised potato row by adjusting the boards of the water retention structure in

**Table 1**
Potato cultivar, soil type, plant row spacing and dates of planting, N-fertilizer application, and harvest for potato crops grown at Farms 1 and 2 in 2013 and 2014 in northeastern Florida.

| | Farm 1 | | Farm 2 | |
|---|---|---|---|---|
| Potato cultivar | Atlantic | | FL1867 | |
| Soil Type | Ultic Alaquod | | Arenic Endoaqualf | |
| Row spacing (cm) | 107 | | 102 | |
| Plant spacing (cm) | 20 | | 20 | |
| Plot area (m$^2$) | 480 | | 411 | |
| Event | Date | DAP[a] | Date | DAP |
| | 2013 | | | |
| Pre-Plant N application | 12/18/12 | −37 | 1/3/13 | −29 |
| Planting | 1/24/13 | 0 | 2/1/13 | 0 |
| N application at emergence | 2/11/13 | 18 | 2/25/13 | 24 |
| N application at tuber initiation | 3/13/13 | 48 | 3/29/13 | 56 |
| Harvest | 5/9/13 | 105 | 5/20/13 | 108 |
| | 2014 | | | |
| Pre-Plant N application | 12/31/13 | −16 | 1/10/14 | −39 |
| Planting | 1/16/14 | 0 | 2/18/14 | 0 |
| N application at emergence | 2/11/14 | 26 | 3/10/14 | 20 |
| N application at tuber initiation | 3/4/14 | 47 | 4/1/14 | 42 |
| Harvest | 4/23/14 | 97 | 5/29/14 | 100 |

[a] Days before (−) or after planting.