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Impacts of irrigation scheduling on pore water nitrate and phosphate in coastal plain region of the United States☆

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ABSTRACT

Agriculture is one of the largest sources of nutrient contamination, mainly inorganic nitrogen (N) fertilization of intensive crops, such as maize (*Zea mays* L). Proper irrigation management can reduce nutrient leaching while maintaining crop yield, which is critical in enhancing the sustainability of agricultural crops on soils with low water and nutrient holding capacities. A three-year (2012–2014) field study was conducted to evaluate the effects of three irrigation scheduling methods (ISM): Irrigator Pro (IPRO); Normalized Difference Vegetative Index (NDVI); and Soil Water Potentials (SWP) and two rates of N applications (NM) on pore water nitrate and phosphate in four soil types (ST) with maize production in Coastal Plain Region, USA. Soil pore water nitrate varied significantly with ISM and NM, but not with ST. The IPRO method had the lowest soil water pore nitrate followed by SWP and NDVI. The low N application rate resulted in lower nitrate concentration (13.4 mg L^{-1}) than the high N rate (17.0 mg L^{-1}). Soil water pore phosphate was not affected by ISM, NM and ST. The use of IPRO reduced the concentration of pore water nitrate by about 39% and 33% when compared with NDVI and SWP, respectively. Using IPRO method resulted in lower soil water pore nitrate and phosphate concentrations, results indicate scheduling method may be a way to reduce nutrient losses. Results of our study suggest that irrigation management decision may affect nitrogen and phosphorus availability for achieving optimum yield of maize while potentially minimizing nutrient losses via leaching.

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1. Introduction

Adequate supply of water and nutrients results in higher water and nutrient use efficiency, better crop production control and avoidance of stress conditions. High-yielding crops, such as maize (*Zea mays*, L.) and wheat (*Triticum asestivum* L.) require large application rates of nitrogen fertilizer to reach optimal yields (Blackmer and Voss, 1997). Leaching of these nutrients in the form of nitrate-N and phosphate-P can negatively impact water quality (Sumanasena et al., 2004). Irrigation may result in increased downward soil water flux and, as a consequence, greater nutrient loss below the root zone (Sigua et al., 2010; Zotarelli et al., 2007; Sigua et al., 2005; Vazquez et al., 2005; Diez et al., 2000; Nguyen et al., 1996; Schneekloth et al., 1996). Heckrath et al. (1995) reported that dissolved reactive phosphorus (P) is the largest P fraction in drainage water in permeable soils. Shuman (2001) from his work on leaching of phosphate showed that P leaching is a potential problem only at high rates of soluble sources and high irrigation, whereas N is more readily leached. However, it may be possible that, as a result of improved water and N and P uptake by crops, efficient irrigation will reduce nutrient leaching (Burgess et al., 2002).

Irrigation management for maize (*Zea mays* L.) production in the southeastern region of USA is difficult because of the highly variable climate along with typical low water holding capacity and low fertility of the soils. Different types of soils in southeastern coastal USA have different water holding capacities and hydraulic conductivities; therefore may require different depths and rates of water application to reach field capacity and minimize potential runoff and/or groundwater leaching of nutrients (Omary et al., 1996).

Abbreviations: ISM, irrigation scheduling method; IPro, Irrigator Pro; NDVI, normalized difference vegetative index; SWP, soil water potentials; NO_3^-, nitrate; PO_4^{-3}, phosphate; ST, soil types; NM, nitrogen management; SD, soil depths; VRI, variable rate irrigation; ANOVA, analysis of variance; GLM, Generalized Linear Model; SAS, statistical analysis system; WUE, water – use efficiency.

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In an attempt to improve crop production and protect water quality, some farmers have started using irrigation scheduling based on soil moisture and calculations of crop evapotranspiration commonly performed by means of an energy balance method (Rode et al., 2009; Gooday et al., 2008; Michael et al., 2008; Donatelli et al., 2006; Allen et al., 1998). This endeavor involves a commitment by the producers to optimally manage water, labor and equipment.

Interest in site-specific irrigation management system has emerged over the past decade in response to successful commercialization of other site-specific application technologies in irrigated agriculture (Stone et al., 2015). This interest can be attributed to the desire of improving water use efficiency (WUE) as well as complement management of other crop inputs such as nitrogen for groundwater protection. Variable-rate irrigation systems used for site-specific irrigation are capable of spatially allocating limited water resources while potentially increasing profits for farmers. Spatial water applications attempt to overcome site-specific problems that include spatial variability in topography, soil types, soil-water availability and landscapes features (Stone et al., 2015; Stenger et al., 2002; Ilsemann et al., 2001). Currently, there are no readily identified decision support systems for site-specific water management.

There is still limited information on the effects of irrigation scheduling and its interaction with nitrogen management on nitrate and phosphate leaching in humid regions such as the southeastern Coastal Plain. Additionally, site-specific irrigation management system has the potential to reduce leaching of nitrogen and/or phosphorus from the crop root zone, but this has not yet been fully demonstrated in the field. There is a need to find scheduling method to precision-apply water for maximum agronomic and environmental utility. A three-year (2012–2014) field study was conducted to evaluate and compare the effects of three irrigation scheduling methods (ISM): Irrigator Pro (IPRO); Normalized Difference Vegetative Index (NDVI) and Soil Water Potentials (SWP) and two levels of N applications (NM): 157 and 224 kg N ha^{-1} on pore water nitrate (NO_3) and phosphate (PO_4) in four soil types (ST) under maize production using variable-rate irrigation in the southeastern Coastal Plain region of the United States.

2. Materials and methods

2.1. Site description, experimental treatments and experimental design

2.1.1. Site description

From 2012–2014, maize (*Zea mays* L.) was grown under conservation tillage on a 6-ha site under a variable-rate center pivot irrigation (VRI) system near Florence, South Carolina. The study site has long-term historical data set on soil physical and chemical properties because of different types of researchers conducted since 1999. Each year, field preparation started with an application of glyphosate to control winter weeds. Field tillage at maize planting consisted of in-row sub-soiling. The maize (Dekalb 66–97 in 2012 and 2013, and Dekalb DKC66-97 in 2014) was planted in 76 cm rows, with a planting population of 79,000 seeds per hectare. The planting dates for the three years were 3/30/2012, 4/9/2013, and 4/4/2014. The maize field received an annual lime application of 1.7 tons ha^{-1} in 2013 and 2014. Phosphorus and potassium fertilizers were also applied at the rate of 118 kg P_2O_5 ha^{-1} and 135 kg K_2O ha^{-1} in 2012, 2013 and 2014, respectively. Fig. 1 shows the different dates of nitrogen fertilizer application in the study site during the growing season of maize. The monthly average rainfall and irrigation amount in the study site during the growing season of maize are also presented in Fig. 1.

2.1.2. Experimental treatments and experimental design

The layout of our experimental plots (9.1 × 9.1 m plot) was based on split-split–split plot in complete block design (Fig. 2). Experimental treatments were consisted of four factors: four soil types (ST); three irrigation scheduling methods (ISM); two nitrogen management (NM); and two soil depths (SD). Fig. 2 shows the different locations of ST (main treatment) within the 6-ha site under a variable rate irrigation (VRI) system. The three sub-treatments consisting of ISM, NM and SD were randomly distributed under each ST. A total of nine plots were marked at the center of each ST (Fig. 2).

2.1.2.1. Soil types treatment (ST). Soils under the center pivot irrigation system are highly variable. Some of the selected properties of the soils used in our study are shown in Table 1. These soils consisting of four soil types are as follows: i) Bonnaeau, BnA; loamy, siliceous, subactive, thermic Arenic Paleudults; ii) Norfolk, NkA; fine loamy, kaolinitic, thermic Typic Kandiudults; iii) Dunbar, Dn; fine loamy, kaolinitic, thermic, Aeric Paleaquults; and iv) Noboco, NcA; fine loamy, siliceous, subactive, thermic Oxyaquic Paleudults (Fig. 2). Each experimental plot (9.1 × 9.1 m) represented by four soil types was instrumented with suction lysimeters and soil moisture tensiometers. Suction lysimeters were installed at two depths (i.e., 30.5 cm and 91.4 cm) while soil tensiometers were installed at 30 cm soil depth. Additional descriptions on the installations of suction lysimeters and soil tensiometers can be found in Section 2.3 below.

2.1.2.2. Irrigation scheduling method (ISM). Three methods of irrigation scheduling treatments were evaluated for our study. Irrigation scheduling methods under the center pivot irrigation system was replicated three times and was randomly arranged on every quadrant as shown in Fig. 2. The first irrigation treatment was based on the Irrigator Pro for Corn expert system (IPRO) that was developed by the USDA-ARS-National Peanut Research Laboratory, Dawson, GA. This expert system has been tested extensively in uniformly irrigated fields (Davidson et al., 1998a,b; Lamb et al., 2004, 2007). In this research, IPRO for maize was implemented using spatial management zones corresponding to variable soil types. Irrigator Pro uses soil texture and soil water potential measurements to estimate the soil water holding capacity in the root zone for water balance calculations.

The second irrigation treatment (Soil Water Potential, SWP) treatment was based on using soil water potential sensors to maintain soil water potentials (SWP) above −30 kPa (approximately 50% depletion of available water) in the surface 30 cm of soils within a plot. Soil water potentials were measured from 12 sites within each soil type. In each treatment and replication, tensiometers (Soilmoisture Equipment Corp, Santa Barbara, CA) were installed in the individual soil types within each plot at two depths (0.30 and 0.60 m). Measurements were recorded at least three times each week. The 0.30-m tensiometer in the SWP treatment was used to initiate irrigation applications. When the soil water potential of the SWP treatments decreased below −30 kPa, a 12.5-mm irrigation application was applied to that plot. Additionally, if soil water potentials decreased below −50 kPa, an additional 12.5 mm of irrigation was applied if the rainfall forecast was less than 50%.

The third irrigation treatment was based on remotely sensing the crop normalized difference vegetative index (NDVI treatment). The NDVI treatment was used to estimate crop coefficients using methods similar to those used by Bausch (1993) and Glenn et al. (2011). These estimated crop coefficients will then be used in the FAO 56 dual crop coefficient method for estimating crop evapotranspiration (ET_c) and irrigation requirements. Initially in 2012, the crop coefficients were based on the FAO 56 crop coefficients for field maize (K_{cbini} = 0.15, $K_{c\ mid}$ = 1.15, and K_{cbend} = 0.5). After crop establishment and NDVI measurements were collected, the crop