Title: Nutrient Management and BMP efficiency of Center Pivot Crop Rotations

Introduction

Groundwater and surface water quality is a paramount concern for Florida. The quality of these waters can greatly affect the flora and fauna living within and around them. In addition, these waters are the primary source of drinking and irrigation for Florida. A common contaminant affecting water quality is nitrate (NO^{3-}) nitrogen (N). Nitrate leaching and runoff can disrupt nutrient balances in water systems and cause blooms in algae and vegetation previously nutrient-limited. Nitrate is a particular concern for groundwater contamination because of its solubility in water and ability to travel far from agricultural or residential sites. N is a crucial macronutrient for high production agriculture and can come from natural or synthetic sources. Agricultural production is the primary contributor to non-point source water nitrate nutrient pollution (FDACS, 2014); therefore, agricultural practices can be improved to make more sustainable and environmentally sound farming systems while still meeting production demands.

Non-point source nutrient pollution could be contributing to the degradation of Florida's groundwater and natural springs. Some aspects of the springs that have been affected in recent years are a decrease in water flow, an accumulation of algae, and a change in vegetative species around the head of springs (Borisova et al., 2014). As a result of this degradation, there has been a push for further advancement and implementation of agricultural Best Management Practices (BMPs) to improve groundwater quality (Borisova et al., 2014) (FDACS, 2014).

Along with nitrate losses, agriculture is a large consumer of surface and groundwater resources (Borisova et al., 2009; Marella et al., 2018). This, along with other water withdrawals, can alter groundwater recharge rates and, in turn, groundwater discharge (Borisova et al., 2014).

Pursuing section 373.813(2)(b) F.S., the University of Florida Institute of Food and Agricultural Sciences is conducting research and demonstration projects to develop and improve nutrient management systems as part of the state's Best Management Practices (BMPs) program. BMPs are individual practices or a combination of practices that, based on research, field-testing, and expert review, have been determined to be the most effective and practical means to maintain and or improve nutrient management and water quality (FDACS, 2014). There has been a push for more widespread adoption of BMPs in urban and agricultural settings. A proposed BMP is sod-based Rotational Production (RP).

The degradation of the spring quality in North Florida poses an underlying threat to the springs' immense natural, recreational, and economic value (FDACS, 2014), (Borisova et al., 2014). The threat of eutrophication and low water flow in these springs has led to the implementation of Total Maximum Daily Loads (TMDLs) and agricultural BMPs to reduce groundwater consumption and nutrient leaching (FDEP., 2018). The Florida Watershed Restoration Act and the Florida Department of Environmental Protection (FDEP) set a Suwannee River TMDL level on November 17th, 2008, at 0.35 mg/L for nitrate (N) despite agricultural nutrient pollution showing minor adverse effects on the system (FDEP., 2018). The FDEP has adopted a Basin Management Action Plan (BMAP) to meet the desired TMDL. The BMAP was laid out in five-year increments with specific goals along the way to reach the targeted load reduction. To help meet the TMDL goal within 20 years, there is a push to implement 100% of current BMPs in agriculture settings within the first five years of the project. This is expected to yield a 10-30% reduction in the groundwater nutrient loading needed to meet the TMDL. Between years 5-10 and 10-15 of the project, the remaining 80% and 100% of the total reduction are expected to be met. More advanced BMPs and new projects are needed to achieve the remaining load reduction goals. Despite this TMDL, it has shown that groundwater discharge rates have had a greater effect than N concentration on the quality of springs (FDEP., 2018).

Changes in agricultural practices and rotations can positively affect the quality of springs in North Florida. Currently, growers in the area are using a variety of rotations. However, additional long-term research on the effectiveness of a bahiagrass (*Paspalum notatum* Flüggé) rotation's ability to reduce nutrient losses over time would fill knowledge gaps. There is also limited knowledge on the effect that a high nutrient demanding deep-rooted carrot (*Daucus carota* L. subsp. *Sativus)* crop can have on the ability to uptake any residual N left deeper in the soil. The more diverse Rotational Production (RP) cropping system, including grazed bahiagrass and carrots, is being assessed for its feasibility of being adopted as a BMP because of deep root systems, lower inputs intensity, and the incorporation of a grazed sod-based component. These components could reduce N leaching, erosion, and pest cycles while improving soil quality, agricultural productivity, and diversity.

A crucial part of nutrient management considered in this project is the four Rs of nutrient efficiency. The four Rs of nutrient efficiency are the right source, right rate, right timing, and right placement of nutrients, with an optional fifth R of right irrigation practices applying to the sandy soils throughout Florida (Hochmuth et al., 2018). The right source R practice relates to selecting the right source of fertilizer to ensure that it is available for crop uptake as needed. The right rate practice encompasses soil testing to determine potential nutrient deficiencies in the soil and apply fertilizers for optimal return. The right timing R practice relates to matching nutrient applications with crop nutrient demands at the various growth stages. The right place R practice relates to placing the nutrients in areas where the plant has the best access to the nutrients for the highest efficiency. The right irrigation R practice encompasses using efficient irrigation application and schedule to meet crop demands without increasing the potential for nutrient leaching (Hochmuth et al., 2018). All rotations are being assessed, given equal consideration, and applied to the 4R nutrient management practices.

Rotational Production and BMP impacts on soil quality and nitrogen (N) movement in North Florida

N movement is hard to track in agroecosystems because of its high environmental mobility and various pathways of inputs and losses (Prasad et al., 2020; Nevins et al., 2020). Especially in Florida, nitrate is hard to monitor and retain because of the coarse-textured soils with low anion exchange capacity and large annual rainfall (Atkin et al., 2011). N transformations are controlled mainly by soil taxonomy, moisture regime, soil pH, OM content, N source, temperature, microbial activity, and C:N ratios. N inputs in an agricultural system can come in synthetic fertilizer, mineral N from organic matter, atmospheric deposition, or already be present in the soil (Prasad et al., 2013). Field N outputs consist of crop uptake, residual soil mineral N, leaching, volatilization, denitrification, and runoff (Prasad & Hochmuth, 2013). As a result of the complex relationship of N in agricultural soils, Rotational Production and BMPs aim at minimizing the inputs and tracking the losses of N pathways through management practices and sampling. These practices also aim toward utilizing a higher percentage of inputs in crop uptake to minimize environmental damage while building soil quality.

The rotational production system being studied is the rotation of bahiagrass, corn, peanut, and carrots. In comparison, a standard grower practice is common only to include a corn-peanut or similar rotation. In 2012, corn production consisted of 10,670 harvested acres in Suwannee County, whereas peanuts consisted of 17,379 harvested acres the same year (Athearn et al., 2017). In the same study, harvested vegetable crops, including carrot production, consisted of 11,243 acres, whereas hay and other forage crops consisted of 26,085 acres in production (Athearn et al., 2017).

Implementing a more diverse RP cropping system has benefits from nutrient management and soil quality (Wright et al., 2015). A better understanding of nutrient cycling within a farm and improved soil quality makes it possible to increase nutrient input efficiency crop yield and reduce water requirements because of increased soil water retention (NRCS., 2004; Bhadha et al., 2021). RP is a less input-intensive farming practice that includes a grazed pasture or sod-based component to reduce leaching, erosion, and pest/disease cycles while at the same time increasing soil quality (NRCS, 2004).

A critical aspect of soil quality that RP improves is soil organic matter (Bhadha et al., 2021) (NRCS., 2004; Wright et al., 2015). Historically, croplands not under rotational production only have 50% of the organic matter previously supported by native vegetation (NRCS., 2004). Typical soils in North Florida have a low soil organic matter (SOM) content of around 1%. Because of this poor soil quality, increasing organic matter can significantly improve nutrient and water retention (Bhadha et al., 2021). With the inclusion of a grazed sod-based component, organic matter in cropland soils can be maintained or increased (Wright et al., 2015, 2018). Results from studies in North Florida found that these practices can increase organic matter content by 0.1% each year; however, improvements taper off after a time (Wright et al., 2015).

Improving soil organic matter makes higher, predictable yields possible and increases soil water retention (Bhadha et al., 2021). RP systems can include a livestock component and a wider variety of crops; therefore, there is more biodiversity in the system and increased resilience to events such as hurricanes or extreme pest events that could wipe out an entire crop (NRCS., 2004; Wright et al., 2015). Biodiversity in agricultural lands is a key component in making production more sustainable and adapting to climate change extremes (Wright et al., 2016). Another important soil quality enhanced with RP is microbe populations, nutrient cycling, and soil aeration (Wright et al., 2016). These factors improve soil health and the cycling of C, N, P, and S so that they are more available for plant uptake (Wright et al., 2015). Increased microbe populations also improve the N fixation capability of the legume peanut rotation. These decaying residues can count towards N credits for subsequent crops (Mulvaney et al., 2017). More natural N sources reduce the need for synthetic N inputs and increase the farm's sustainability.

Best Management Practices aim to improve water quality through improving nutrient management (FDACS 2014). BMPs that do so are banding of fertilizers and matching fertilizer application to the demands of the crop (Sanchez et al., 1990). Pertaining to the right place and right timing R practices, banding is the application of fertilizer directly to the root zone in concentrated bands. A study in the Everglades on lettuce found that in four trials, banding of P fertilizer achieved a 98% maximum yield with an average of one-third the P rate required by broadcasting (Sanchez et al., 1990). When banding N, applications are made periodically to meet only the nutrient demands of the crop’s growth stage and maximize the potential for crop uptake (Hochmuth et al., 2018).

Over time, decreased water use per acre is another improvement often realized with RP and best management practices. This decrease in water use is often realized because of the increased soil organic matter and less intensive sod rotation that requires fewer water inputs to remain productive (Wright et al., 2015). The 5th R of nutrient stewardship, as mentioned earlier, is proper irrigation because of the sandy soils common in Florida, which have little water retention capability. This BMP incorporates irrigation scheduling and practices to minimize water use, such as soil moisture sensors or precise application (FDEP.,2018). One environmental benefit of reducing irrigation is more groundwater recharge to improve spring discharge and a decreased possibility of nutrient leaching or sediment runoff (FDEP., 2018).

Conservation tillage is a BMP to reduce sediment loss and soil degradation (Bergtold et al., 2019). Although effectiveness varies between applications, N loss is decreased when there is a reduction in sediment and organic matter loss (Mulvaney et al., 2017). A potential downside to sod-based RP is the greenhouse gas emission associated with cattle production. Cows release methane gas, a potent, long-lasting greenhouse gas that can contribute to climate change. Despite this downside, BMPs have improved farm nutrient management and soil quality when implemented correctly.

Comparison of N use Efficiency and Agricultural Productivity Across the Various Rotation Components

Agriculture as an industry is tasked with feeding a growing world population while trying to do so in a more sustainable manner at the same time. By 2050, the world population is expected to reach almost 10 billion (United Nations., 2019). As a result, yield and input efficiency are important aspects to consider. Establishing crop rotations that work in unison to make these goals possible is extremely important. Evaluating N and irrigation efficiency under cropping systems helps determine if rotations meet these goals.

RP offers a different cropping method than monoculture or less extensive rotations. Since an input-intensive cash crop is not grown in every rotation of RP, it is often wrongfully associated with having lower agricultural productivity or potential profitability compared to intensive monoculture (Bergtold et al., 2019). Comparing the agricultural productivity and input efficiency of corn, carrots, peanuts, and grazed bahiagrass determines if RP has helped yield, water quality, and sustainability goals.

N use efficiency is important because as fertilizers become an even bigger part of production costs, replacing N lost to the environment becomes more expensive (Mosheim, R. 2019). If a higher percentage of nutrients are utilized, there can be a higher yield and lower inputs, making the economic return higher per unit input. Composing an N budget is the best way to determine various N-pools and N-losses in an agricultural field (Prasad et al., 2013). Again, the environmental losses are calculated by subtracting N outputs from the inputs. The irrigation efficiency of the rotations is another vital aspect to consider while addressing water quality and input efficiency.

Corn is a common cash crop for center pivot agricultural lands in much of North Florida and typically requires significant N fertilizer and irrigation inputs for high yield (Prasad et al., 2020). Corn has a relatively short growing season with extensive roots and large residue left after harvest. Grain yield and quality are highly responsive to N inputs and can be affected by water stress at various physiological stages (Wright et al., 2018). Having deeper roots allows the corn to acquire N that has leached deeper into the soil profile later in the season. Another important aspect to consider for corn production is that N demands can be accurately predicted (Jayasundara et al., 2007). A corn soil system N budget can determine if nutrient and cultural practices are working correctly (Prasad et al., 2020).

A study was conducted on North Florida farms in sandy soils common to the region (Prasad et al., 2020). In this study, a soil system budget was composed and found 71% of inputs were identified in plant accumulation and residual soil (leftover N after harvest), 14% lost to leaching, and an unaccounted for 15% (Prasad et al., 2020). This is a good indicator that the system utilizes a large portion of the inputs and that not much of the applied nutrients can leach and reach groundwater sources or volatilize. If a higher percentage of the inputs were lost to leaching or volatilization, new BMPs should be implemented to improve nutrient retention, and alternative rotations other than corn should be incorporated to have less impact on groundwater nitrate concentrations.

In a study comparing BMPs and longer rotations to conventional practices for corn production over four years, there was a 51% decrease in cumulative nitrate leaching when BMPs and more extensive rotations were implemented with no yield loss (Jayasundara et al., 2007). Compared to a conventional system, sod-based peanut/corn rotation can improve soil quality and the growth environment, resulting in high crop yields and WUE (Zhao et al. 2008). Corn yield can be increased under RP system because of the decreased pest pressure associated with more diverse rotations and improved soil quality (NRCS, 2004). A natural decrease in pest pressure associated with RP reduces the annual cost of pest management. This increase in yield and reduction of inputs could make up for any loss of productivity from not producing a high-value cash crop on all available lands over multiple seasons.

Corn has significant water demands throughout the growing season. The crop reaches a maximum demand 65 days after planting at a rate of 0.23 inches/day during the R1 reproductive stage to ensure no yield loss. This demands then slowly decrease to 0.11 inches/day 130 days after planting at the time of harvest (Sharma et al., 2020)

An essential part of the RP system is the incorporation of grazed bahiagrass. Bahiagrass has little harvestable value per acre compared to other cash crops. Despite this, it is the common forage for livestock, making it a significant source of income (Athearn et al., 2017). Rotations following bahiagrass often see improvements in multiple aspects of soil quality and yield of subsequent cash crops (Bergtold et al., 2019; Wright et al., 2018). Increased subsequent crop yields and decreased input requirements are common associations with implementing a RP system, giving significant economic and environmental incentives.

Bahiagrass is a low N and irrigation demanding crop, making input costs significantly less when the rotation is implemented two years at a time. This practice is associated with increased agricultural productivity and subsequent crop yield, particularly peanut. As a result, an overall increased economic return of RP with livestock compared to standard rotational practices can be realized (Wright et al., 2018). This component takes extra farm knowledge and equipment; however, having an additional income source could make this rotation more applicable. Government subsidies or incentives to implement this more sustainable rotation could also further the adoption.

Further research needs to be conducted on the economic breakdown of implementing bahiagrass versus a standard cash crop rotation in this application. This rotation can also contribute carbon credits if it is shown to sequester deep soil carbon over time. Overall agricultural productivity increases because the land is used year-round, wherein the ground is bare over winter months in conventional practices.

In scenarios where irrigation is not an option or limited, bahiagrass has more resistance to drought conditions. After bahiagrass has a root system established, it does not require irrigation to remain productive if there is sufficient rainfall. This allows for higher productivity in non-irrigated fields or less stress on water systems where agricultural groundwater withdrawals are a concern. Bahiagrass rotations offer a more economically sustainable farm model for farmers who want to minimize their groundwater impacts and increase their diversity of income sources.

Peanuts are another common crop found in rotation with corn in North Florida. They have been found to have multiple soil quality and economic benefits when incorporated into RP (Wright et al., 2015). Peanuts are a legume crop that allows them to fix N from the atmosphere symbiotically with microbes and transform N^2 into plant-available N. This means in addition to peanuts' value as a cash crop, peanut residue contains a large amount of N from biological fixation reducing the need to apply N fertilizers. The residues can count as a "peanut N credit" and contribute to the N demands of subsequent crops under some circumstances (Jani et al. 2019). This credit could reduce the reliance on synthetic fertilizer use and increase the profit margins if fewer costs went into fertilizer with the same or increased yield. N becomes available as the legume decomposes, making it difficult to match crop N demands with residue decomposition. Further research is needed to account for significant N contribution from peanut residues to subsequent crops (Jani et al. 2019). Management factors that affect the N release of peanut resides are tillage, planting time of subsequent crops, temperature, rainfall patterns, and soil nutrient holding capacity.

Peanut crops also demand a significant amount of water to reach full yield potential. Peanut water use reaches a maximum of 70 days after planting during the R5 physiological stage at 0.20 inches/day. Demand decreases to 0.04 inches/day, 140 days after harvest, during the R8 maturity stage (Sharma et al., 2020). Depending on irrigation efficiency and residue N contributions, peanuts offer a potential profit and environmental incentive to be included in RP systems.

Carrots are a crop commonly found in rotations in North Florida. Carrots are being included in the RP system because production in South Georgia and North Florida has significantly increased since 2015 (Hochmuth et al., 2021). Along with increased production, the purpose of including carrots is to determine the effects that a high N demanding crop with a profound root system could have on nutrient leaching. Carrots are implemented in the rotation after corn so that there is a good opportunity to uptake any nitrates that have leached below the root zone of corn. If a N budget were composed for the carrot rotation, it would be possible to determine if nutrient rates are sufficient or if excessive nitrate leaching occurs and there is a need for revision of nutrients or cultural practices.

Carrots also have a lower irrigation water demand throughout their growth because of their shorter growing season over the fall and winter. If carrots are seeded in October, they reach a maximum daily water use 28 days after planting, during the vegetative growth stage at a rate of 0.09 inches/day. Water use then decreases to 0.05 inches/day after 90 days at the harvest time. (Sharma et al., 2020). Along with offering a lower water use and the potential to uptake any deep soil N, carrots offer another highly productive cash crop that could help offset any profit decrease associated with sod-based RP.

Feasibility of Rotational Production (RP) as a BMP

Maintaining water and soil resources is essential to benefit from them at a high standard for generations to come. As previously described, there are a lot of environmental and production benefits associated with the proper implementation of RP. The benefits of these services can be harder to quantify on a social level. Society benefits from the enactment of BMPs and RP because of the added agricultural productivity and ecosystem services associated with these practices. Rotational Production and BMPs improve water quality and provide more areas to support threatened species. This increase in ecosystem diversity and support of native systems provides support for key recreational activities such as wildlife watching, hunting, swimming, snorkeling, and other aquatic activities (Borisova et al., 2014). These activities are essential drivers of the economy in many North Florida towns that surround affected springs and waterways. Spring recreation is estimated to bring in $83.8 million in annual revenue within the Lower Suwannee and Santa Fe River Basins (Borisova et al. 2014). With this large economic incentive to maintain these natural areas and services, there should be a greater value on RP's potential function as a BMP.

Along with a monetary value, a social value should be put on the RP system because of the potential to improve local water quality and ecosystem function, which is important for farms and the surrounding community that sees these systems. RP should be considered a potential BMP because of its impact on increasing nutrient efficiency and decreased annual water use. These impacts align with the nutrient and water goals of Best Management Practices. If these practices are proven year after year, there could be the need to revise N and rotational practice recommendations for similar applications. A potential roadblock to adopting RP and BMP is the extensive knowledge, time, and upfront costs needed to implement these practices properly. Educating farmers and the public on the impacts that can be made could promote cost-share incentives and help society overcome potential roadblocks. With RP offering a more sustainable food production model, the public and farmers should become more aware of the potential benefits and conduct further research on the impacts of this system on a wide scale.

Objectives/Hypothesis

This paper assessed rotational production and BMP impacts on nitrate movement and compared N and irrigation efficiency between the rotation components. The rotation components being addressed are various rotations, including corn, carrot, peanut, and bahiagrass with cattle grazing. There has been a comparison of the N and irrigation efficiencies of the RP system incorporating a less input-intensive grazed bahiagrass component to a grower's standard corn-peanut rotation. It is hypothesized that the RP system incorporating a bahiagrass component requires significantly less N and irrigation inputs reducing the stress on water resources while increasing agricultural productivity.

Materials and Methods

Location and Treatments

This research location is adjacent to the Suwannee Valley Agricultural Extension Center (SVAEC) in Live Oak, FL (82°,54’20.956” W, 30°18’16.697” N). The site is an approximately 28.3-hectare (70-acre) parcel with a 16.19-hectare (40-acre) center-pivot irrigation system. This 16.19-hectare center pivot irrigation system will be used for a 16-year RP study. In 2013, the land was cleared of timber and converted to row crops and cattle grazing. The experiment start date was February 19th, 2019. Soil samples were taken before fertilization and crop planting to give a baseline of soil fertility. The soil types are mapped as a complex of Hurricane, Albany, Chipley 0-3% slopes and a complex of Blanton, Foxworth, and Alpin 0-5% slopes throughout the field. Two major soil taxonomies consist of a hurricane – Sandy, siliceous, thermic oxyaquic Alorthod: and Blanton – Loamy, siliceous, semiactive, thermic Grossarenic Paleudults. The Hurricane series is comprised of a very deep, somewhat poorly drained, rapidly permeable soil with a water table at depths of 0.61 m to 1.1 m 6 months a year. The Blanton series comprises deep, moderately well-drained soil with a similar water table depth of 0.61 to 1.1 m 6 months a year. As a result of the high drainage and shallow water table, nutrient retention capabilities and erosion are a particular concern for these soils. The mapped variation in soil texture throughout the field is displayed in figure 1.

Figure 1: Field soil texture (North Florida Research and Education Center, Suwannee Valley, FL.)

The land within the center pivot was separated into four 4.06-hectare (10 acres) sections to allow for four separate crop rotations. Each center pivot section has been assigned a four-year crop rotation treatment (Fig. 2).

Two sections have been assigned RP treatments that implement bahiagrass and cattle grazing. The other two sections are control treatments and incorporate standard grower practices. The RP treatments are bahiagrass-bahiagrass-peanut-corn (BBPC) in the southwest section (section 500 in Fig. 2), and bahiagrass-bahiagrass-carrot-peanut-corn (BBAPC) in the northwest section (section 400 in Fig. 2). These sections house the livestock component of the rotation, with 68 cows being present. The control treatments consist of a continuous corn-peanut (CP) rotation in the northeast section (sections 100 and 200 in Fig. 2) and a corn-carrot-peanut (CAP) rotation in the southeast section (section 300 in Fig. 2). The CP rotation section was divided into two 2.02-hectare (5-acre) sections to ensure at least 2.02 hectares (5 acres) of corn and peanuts in each study year. The rotation for the CP section alternates between these two 2.02 hectares (5-acre) sections so that after four years of data collection, each 2.02-hectare (5-acre) section will have completed two full rotations (Fig. 2). The carrot crop in the CAP rotation has been grown before peanuts in the same crop year so that after four years of data collection, the BBAPC and BBPC will have one complete rotation cycle while the CAP treatment will have undergone two complete rotations.

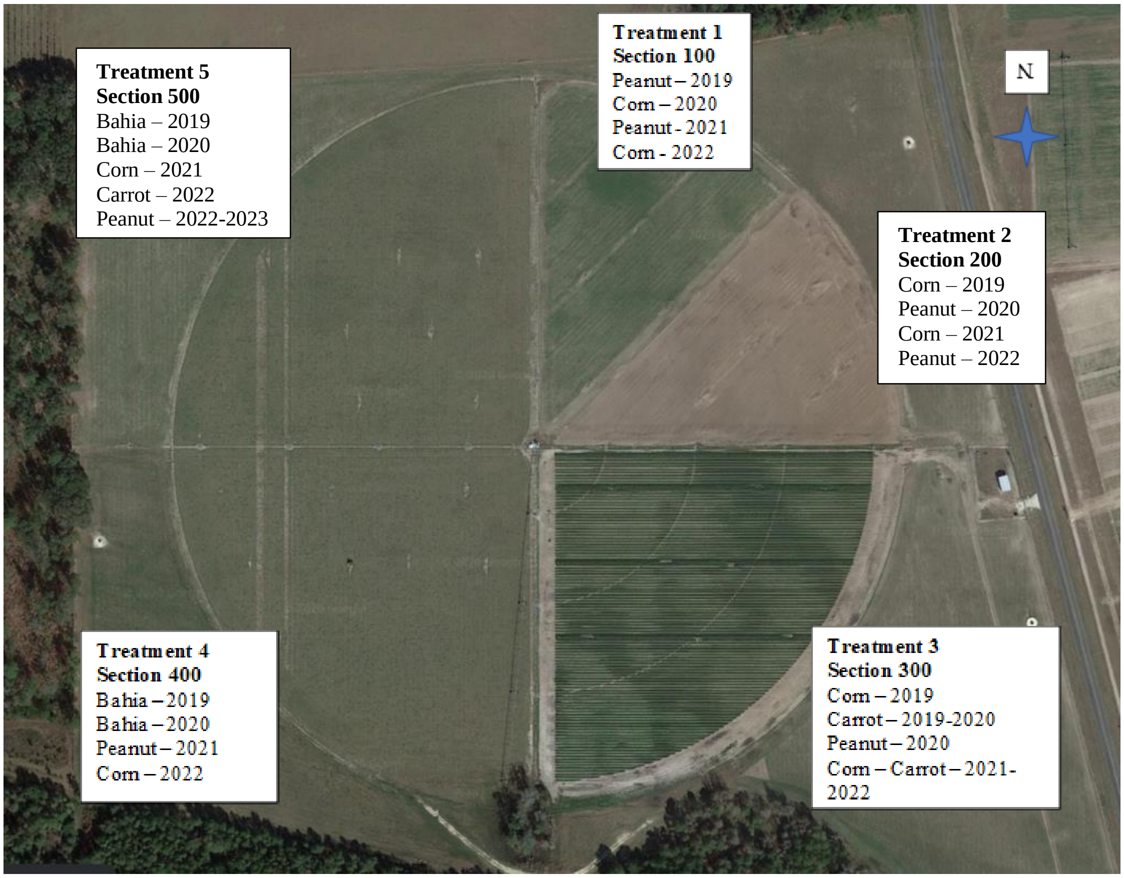

Figure 2: Field Treatment Rotation (North Florida Research and Education Center, Suwannee Valley, FL.)

Soil sampling

Soil samples are taken every other month at 20 random locations within the center pivot system: four within each treatment of the center pivot. Each location is sampled at six depths for a total of 120 soil samples for each sampling event. The six sampling depths are 0-15, 15-30, 30-

45, 45-61, 61-76, 76-91 centimeters. All samples taken are labeled and refrigerated to reduce the chance of any nutrient transformations before analysis. Samples are then delivered and analyzed at the Waters Agricultural Lab (Camilla, GA). Samples are analyzed for nitrate, ammonium (NH_4^+), Total Kjeldahl N (TKN), organic matter content, pH, Mehlich III phosphorus, potassium, cation exchange capacity, and base saturation. Using these samples, it is possible to determine mineral N in the top 15cm of the soil before planting and after harvest for all rotation components.

Plant tissue sampling

Plant tissue sampling has been conducted on every field treatment on harvested material and field representative above-ground biomass at various plant-growth stages. Samples are analyzed for TKN and given as a %. Enough above-ground plant tissue for four 20 g dried samples per treatment section has been collected and submitted to the Waters Agricultural Lab (Camilla, GA). Corn tissue sampling begins at the V4 growth stage and continues through harvest. Carrots and peanuts tissue sampling begins when enough above-ground biomass is available for harvest without killing the crop and continues until harvest. Collecting field representative material in each section was considered in sampling. Analyzing for TKN provides N concentration in the above-ground and the harvested portion of the plant at a given date. This data creates biomass and N accumulation curves (Witty, 1983) and helps determine N exported from the farm as harvested material.

Crop Yield

Yield calculation for corn, peanuts, and carrots is based on sampling a field representative 4 m^2 (= 0.0004 Ha or 1/1000 acre) (Lauer J., 2002). Row width for corn, peanuts, and carrots is 76 cm making it possible to calculate the yield on a 1/1000 sampled scale. Four locations were sampled in each section to enable us to evaluate the variability within and between each section.

Irrigation Data

Irrigation events were tracked by the center pivot system and summarized every year. The center pivot tracks degrees of the system, with true north being at $0^{o}/360^{o}$. Based on this, each treatment section was assigned a range of degrees to determine when an irrigation event occurred. Treatment 1 (0^{o}-45^{o}), Treatment 2 (45^{o}-90^{o}), Treatment 3 (90^{o}-180^{o}), Treatment 4 (180^{o}-270^{o}), Treatment 5 (270^{o}-360^{o}). Along with degrees, the amount of irrigation was tracked when an event took place to give an amount of irrigation applied on each section for each event. To get an estimation of N applied through irrigation, a water sampling of the well was done and analyzed for nitrate N. A summary of irrigation events and N applied through well water over a growing season are displayed for each treatment in Table 2.

Precipitation and N Deposition Data

Precipitation events for the field were recorded and accessed through the Florida Automated Weather Network (FAWN). The weather station is at the Suwannee Valley Agricultural Extension Center (SVAEC) in Live Oak; therefore, readings should represent the adjacent field. Precipitation amount and number of events were totaled within each treatment's planting and harvest dates and displayed in Table 4. Atmospheric inorganic N wet deposition was estimated by the National Atmospheric Deposition Trends Program (NADP., 2016). An estimated 3.36 kg/ha N is deposited annually in North Florida.

N uptake in harvested Grain

Harvested peanut and corn grain N content is estimated from (IPNI., 2014). 1 bushel of corn grain is estimated to contain 0.67 lb. of N, whereas 1 ton of peanut nuts is estimated to contain

70 lb. of N (IPNI., 2014). Using these parameters, along with the yield, it was possible to estimate the N content exported from the field as harvestable grain material (Table 3).

The environmental load for each rotation can be calculated using the equation below:

$N_{env\ load} = N_{soiln} + N_{irrn} + N_{fert} + N_{atm} – N_{crop} - N_{soiFi}$

Where,

N_{soiln} = initial inorganic N in top 15cm of soil before planting

N_{irrn} = N from irrigation water

N_{fert} = N from fertilizer applications

N_{atm} = N from atmospheric deposition (estimated from literature) (NADP., 2016)

N_{crop} = N uptake in harvested grain from crop

N_{soiFi} = Mineral N present in the top 15 cm of soil at crop harvest

$N_{env\ load}$ = Environmental N loading or unaccounted for N

All values are expressed in kg ha^{-1} *season*$^{-1}$ *and are displayed in Table 5*

Data Management and Analysis

Collected data is stored on a shared dropbox folder secure to the University of Florida. The data has met minimum dataset elements, including a control standard deviation, control number of observations, treatment mean, treatment standard deviation, and other statistical endpoints. All analysis has been done on SAS® Analytics Software (SAS Institute, Cary NC). Data with a residual standard deviation greater than five has been dropped from the dataset to minimize contaminated data. Samples with a standard deviation greater than 5 are thought to have been mishandled or labeled incorrectly at the time of sampling. A linear mixed model of tissue sampling concentrations was compiled using the denominator degrees of freedom method (DDFM). Following these methods, comparisons have been made to determine nutrient inputs and irrigation efficiency of the discussed crop rotations. Due to complications during coronavirus, there has been no yield data collected for the 2019/2020 carrot crop making it impossible to create a N budget. There has been no total biomass tissue sampling done at the time of harvest, making an accurate N budget impossible to compile for all the rotations.

Results

In 2019, the bahiagrass component received 7% of the irrigation for corn production (42 mm vs. 238 mm) and 22% for peanut production (42 mm vs. 198 mm). Compared to the carrot rotation, 2019 bahiagrass received 21% of the irrigation received by the 2019/2020 carrot crop (42 mm vs. 203 mm). In 2020, the bahiagrass received 0 mm irrigation due to the established root system and significant rainfall of the year. However, over the same 2020 season, corn sections received 242 mm of irrigation, and peanuts received 13 mm. In 2019, peanuts section 100 received 0 kg N/ha fertilizer, whereas corn sections (200, 300) received 379 kg N ha^{-1} through 6 different timed applications. The same year, carrots section 300 received 289 kg N ha^{-1} over 9 split applications. The bahiagrass rotations established in 2019, sections 400, 500, received 50 kg N ha^{-1} through two separate applications. In 2020, corn section 100 received 377 kg N ha^{-1} through 8 different timed applications. Peanuts, sections 200 and 300, received 13 kg N ha^{-1} through only 1 application in 2020. In the second year of the bahiagrass rotation, after livestock had been added, section 400,500 received 63 kg N ha^{-1}.

2019 peanut tissue sampling reflected the higher yield attained in 2019 than the 2020 crop. In 2019, peanuts yielded 8,111 kg ha$^{-1,}$ whereas, in 2020, peanuts yield averaged 6,010 kg ha^{-1}. In 2019, peanut tissue sampling had an average N concentration of 3.75 % N 120 days after planting (DAP), whereas the lower-yielding 2020 peanut crop had a leaf tissue concentration of 3.25% N at 100 DAP. Due to N relocation within the plant, the 2020 peanut N concentration would be expected to be even lower at 120 DAP. Corn tissue sampling also reflects a similar yield between years. 2019 corn section 200 and 300 tissue sampling had a 3% N concentration of 80 DAP and yielded around 14,450 kg ha^{-1}. Corn grown in 2020 in section 100 had a similar N concentration of 3% 80 DAP and yielded 14,305 kg ha^{-1}. In the later tissue sampling (100 DAP and 135 DAP), it is clear that there is a relocation of N away from the biomass and likely into the harvestable grain portion of the crop. Growers can use these N concentrations at the various DAP to predict potential yields or identify if there is N deficiency at the sampled growth stage.

The partial N budget (table 5) shows a large N environmental load difference between the corn and peanut rotations. In 2019 peanuts had an environmental load of -283 kg N/ha^{-1}. This negative environmental load is because of the lack of inorganic fertilizers and the capability of the leguminous peanut rotation to fix large amounts of atmospheric N. 2019 corn had an environmental load of 196 kg N/ha^{-1} for section 200 while section 300 had an environmental load of 200 kg N/ha^{-1}. The resulting N use efficiency for the 2019 section 200 and 300 corn rotations was 49.5% and 49.2%. In 2020 corn section 100 had an environmental load of 203 kg N/ha^{-1}, leaving a large opportunity for N to reach undesirable places or leach into the water table. The resulting N use efficiency of 2020 corn was 47.4%. In 2020 peanuts, sections 200 & 300, received very little N fertilizer (13 kg N/ha^{-1}) but had an environmental load of -188 kg N/ha^{-1} and – 211 kg N/ha$^{-1,}$ respectively.

Table 1. Cumulative irrigation, N contributions from irrigation water, number of irrigation events, precipitation rates, number of precipitation events, and annual N deposition given by year, crop, and section. Annual N deposition is estimated from literature (NADP., 2016).

			Irrigation			Precipitation		N Deposition
Year	Crop	Section	Amount	N	Events	Amount	Events	Amount
			-- mm --	-- kg/ha --		-- mm --		-- kg/ha/yr. --
2019	Peanut	100	198	0.53	15	518	138	3.36
2019	Corn	200	238	0.40	20	572	147	3.36
2019	Corn	300	238	0.40	20	572	147	3.36
2019/20	Carrot	300	203	0.38	22	570	189	3.36
2019	Bahia	400	42	0.0672	4	997	110	3.36
2019	Bahia	500	42	0.0672	4	997	110	3.36
2020	Corn	100	242	0.46	21	716	148	3.36
2020	Peanut	200	13	0.21	1	801	136	3.36
2020	Peanut	300	13	0.21	1	833	146	3.36
2020	Bahia	400	0	0.00	0	1368	137	3.36
2020	Bahia	500	0	0.00	0	1368	137	3.36

Table 2: N fertilizers applied by source, form, nutrient content, rates, (N) number of applications, crop, section, and year. All values are expressed in kg N/ha^{-1}.

			N Fertilizer Applied										
Crop	Year	Section	Liquid 10-34-0	Granular 12-3-14	Granular 21-0-0	Liquid 23-9-0	Liquid UAN	Granular 3-7-28	Granular 32-0-0	Granular 9-7-28	Organic Chicken Litter	Total	N
			-- kg N ha^{-1} -- -										
Bahia	2019	400			47			3				50	2
Bahia	2019	500			47			3				50	2
Bahia	2020	400		27					36			63	2
Bahia	2020	500		27					36			63	2
Carrots	2019/20	300	13				255	21				289	9
Corn	2019	200				34	209			58	78	379	6
Corn	2019	300				34	209			58	78	379	6
Corn	2020	100				34	208			58	78	377	8

Peanuts	2019	100		0	0
Peanuts	2020	200	13	13	1
Peanuts	2020	300	13	13	1

Table 3: Average Crop Yield, N exported in Harvested Grain, and applied N fertilizer rate. Grain N content was estimated from (IPNI., 2014).

Crop	Year	Section	Average Yield kg/ha^{-1}	Grain N Harvested kg N/ha^{-1}	N Fert Applied kg N/ha^{-1}
Peanut	2019	100	8,111	283	0
Corn	2019	200	14,446	172	379
Corn	2019	300	14,471	173	379
Carrot	2019/20	300	NA	NA	289
Corn	2020	100	14,305	171	377
Peanut	2020	200	5,629	196	13
Peanut	2020	300	6,390	222	13

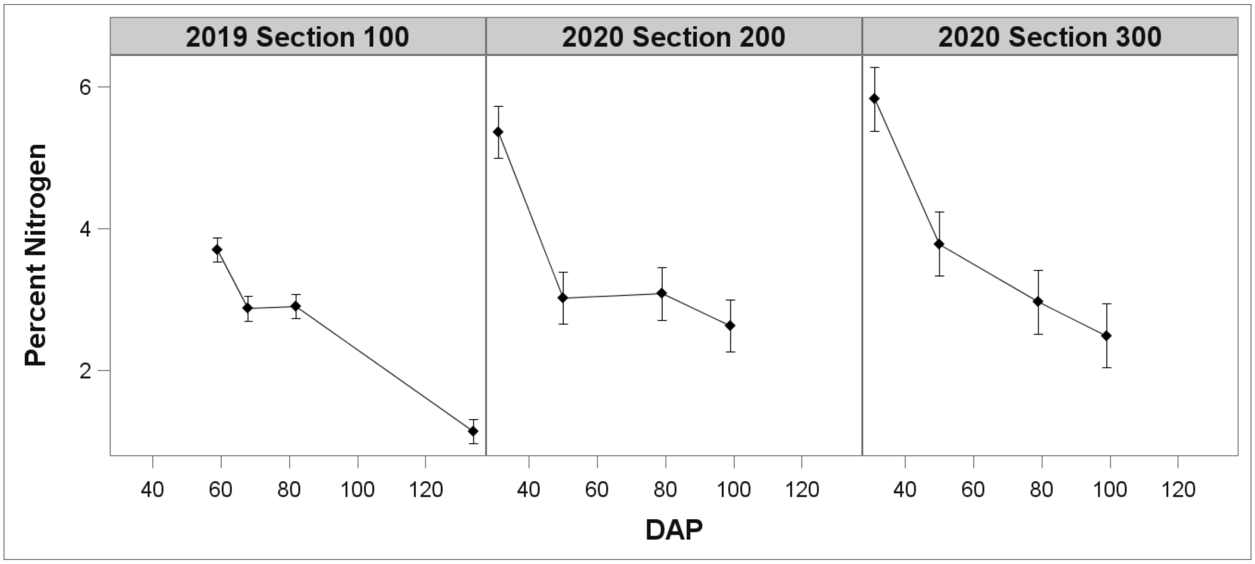

Figure 3: Corn Tissue Sampling N % at various DAP. Error bars are included to show variability between sampling events.

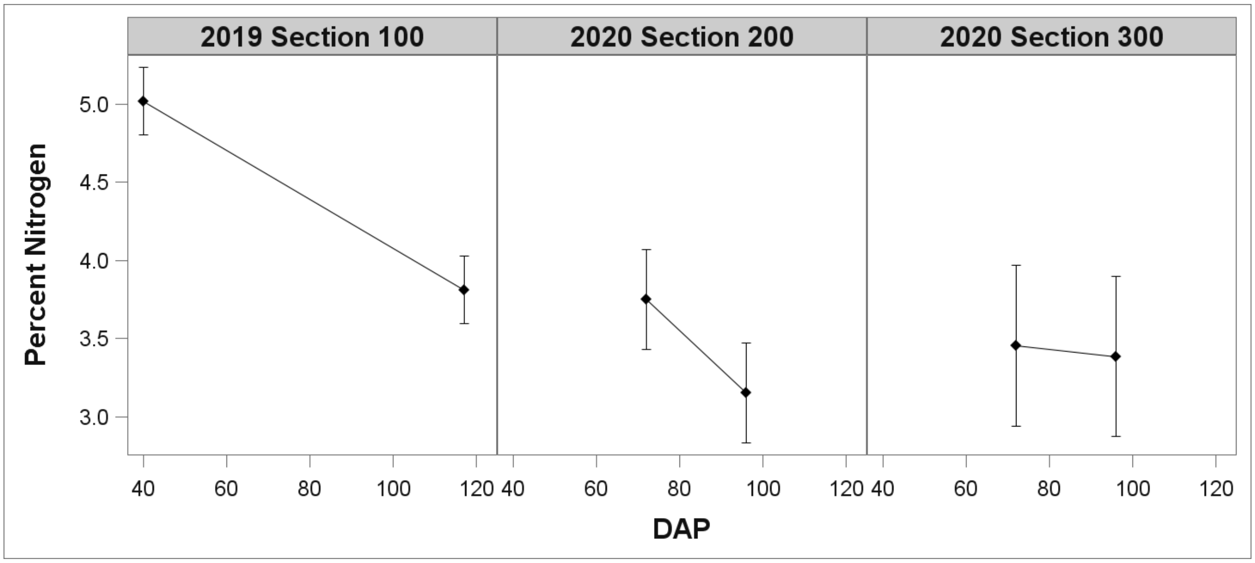

Figure 4: Peanuts Tissue Sampling N % at various DAP. Error bars are included to show variability between sampling events.

Table 4: Crop planting dates, harvest dates, and total days.

Crop	section	Plant	Harvest	Total Days
Peanuts	100	16-May-19	30-Sep-19	137

Corn	200	19-Mar-19	12-Aug-19	146
Corn	300	18-Mar-19	12-Aug-19	147
Carrots	300	24-Oct-19	9-Apr-20	179
Bahia	400	19-Apr-19	6-Jan-21	628
Bahia	500	19-Apr-19	6-Jan-21	628
Corn	100	12-Mar-20	6-Aug-20	147
Peanuts	200	13-May-20	25-Sep-20	135
Peanuts	300	14-May-20	25-Sep-20	134

Table 5: N Budget Parameters and Environmental N load in kg N/ha^{-1}

Where, $N_{env\ load} = N_{soiln} + N_{irrn} + N_{fert} + N_{atm} - N_{crop} - N_{soiFi}$

Crop	**Section**	**Year**	**N_{soiln}**	**N_{irr}**	**N_{fert}**	**N_{atm}**	**N_{crop}**	**N_{soiFi}**	**$N_{env\ Load\ kg\ N/ha}$$^{-1}$**
Peanuts	**100**	**2019**	**1**	**0.53**	**0**	**3.36**	**283**	**5**	**-283.11**
Corn	**200**	**2019**	**5**	**0.4**	**379**	**3.36**	**172**	**20**	**195.76**
Corn	**300**	**2019**	**7**	**0.4**	**379**	**3.36**	**173**	**17**	**199.76**
Corn	**100**	**2020**	**5**	**0.46**	**377**	**3.36**	**171**	**12**	**202.82**
Peanuts	**200**	**2020**	**4**	**0.21**	**13**	**3.36**	**196**	**13**	**-188.43**
Peanuts	**300**	**2020**	**7**	**0.21**	**13**	**3.36**	**222**	**13**	**-211.43**

Conclusion

In Florida, the quality of groundwater and soil is extremely important. These aspects of the environment can be harmed by agriculture, and the best practices possible should be implemented to minimize impacts. RP is addressed as a more diverse cropping system that aligns with these goals. The rotation of corn, carrot, peanuts, and grazed bahiagrass offers a new cropping system that requires significantly less irrigation and nitrogen inputs over an extended period. Each of the various rotations work in unison to utilize natural processes and minimize groundwater or nutrient inputs. As a result, there are minimal environmental impacts and higher returns on nutrient and irrigation inputs. Corn has shown to have a much larger environmental N load compared to other rotations. It can be assumed that there are environmental load benefits from implementing longer, less nutrient intensive, rotations between corn years.

Rotational production has the capability to increase the overall productivity and profitability of farming operations, making this farming model appealing to farmers. Some potential knowledge gaps that could be addressed are identifying the amount of N that is leached below the root zone of each rotation. Through this, it would be possible to quantify the effects that wide implementation of these practices could have on groundwater quality within an entire watershed. Along with this, an evaluation of RP's effect on long-term carbon pools in soils would be beneficial. If these gaps were filled, there could be more reason to provide cost-share to farmers wanting to implement RP or other BMPs.

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