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The Influence of Bahiagrass, Tillage, and Cover Crops on Organic Vegetable Production and Soil Quality in the Southern Coastal Plain

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Abstract

Conventional farming utilizing bahiagrass (Papsalum notatum Flugge) in rotation with crops has been shown to increase yield, improve soil quality, and decrease weed and disease pressure. Organic production systems in the Southern Coastal Plain are challenged with limited soil fertility and a wide array of insect, disease, and weed pests. The purpose of this study was to investigate the influence of sequential years in bahiagrass and tillage (conventional and conservation) on organic vegetable yield and soil indices. After 0-4 years in bahiagrass, a crop rotation of rye and oats (winter cover crop), bush beans (spring vegetable crop), soybean (summer cover crop), and broccoli (fall vegetable crop) was implemented. Vegetable crop yields, plant biomass, plant C and N, and soil C, N, and P were measured for the four crops in the rotation over a three year period. Two years or more of bahiagrass prior to initiating the vegetable crop rotation showed positive effects on vegetable crop yields and soil quality parameters. Tillage treatments did not have a consistent effect on measured parameters. Soil C was not impacted by years in bahiagrass but was influenced by years of crop production. Potential soil N and P mineralization indicated an increase of soil organic fractions with years in bahiagrass. Available N increased after cover crops, and available P decreased with increasing years in bahiagrass.

Keywords: organic vegetables, bahiagrass, yield, soil quality, carbon

1. Introduction

Sustainable organic farming is challenging, compared to conventional farming, when dealing with limited soil fertility and insect, nematode, disease, and weed pest pressures. Weed control is one of the top priorities for organic production (Organic Farming Research Foundation, 2002). Organic management often relies on intensive conventional tillage to control weeds due to the limited availability, effectiveness, and high cost of organically-approved herbicides. Conventional tillage decreases soil quality by breaking up soil aggregation and inducing soil organic matter (SOM) decomposition (Carter & Rennie, 1984; Cambardella & Elliott, 1992; Abid & Lal, 2008; Fuentes et al., 2009). Major impacts of soil quality degradation include decreased soil fertility, soil moisture, and yields and increased soil erosion potential. Other weed control options include plastic row covers or plastic mulches which are not considered sustainable due to the amount of energy used during production and the waste generated when removed after harvest.

In the southeastern United States, the continuous production of cash crops throughout the year increases the potential of soil quality degradation unless integrated with soil conservation practices. Soil organic matter losses induced by intensive soil tillage and removal of nutrients and crop biomass with crop harvest (Mann et al., 2002) are dominant factors contributing to reduced soil quality. Conservation tillage, or strip tillage, only disturbs soil within the planted area, leaving the majority of area intact and plant residue on the soil surface between rows compared to conventional tillage which disturbs the entire area. Decreased tillage minimizes soil organic matter decomposition and promotes surface soil C storage (Lal & Kimble, 1997; Mbuthia et al., 2015), reduces soil erosion (Williams et al., 2009; Prasuhn 2012), increases fertility (Langdale et al., 1997), and improves soil moisture holding capacity (Moreno et al., 1997; Karlen et al., 2013). Conservation management, which includes using cover crops and conservation tillage, improves soil quality. Cover crops add organic matter into the soil (Powlson et al., 1987; Sanchez et al., 2001), improve soil aggregate stability (Tisdall & Oades, 1982; Peregrina et al., 2010), reduce soil erosion (Langdale et al., 1991; Spiertz, 2009) and weed pressure (Zotarelli et al., 2009), and potentially increase available soil N to subsequent crops (Ladd et al., 1981; Sanchez et al., 2001).

Perennial grasses have been shown to improve soil quality (Wright & Anderson, 1999; Baer et al., 2000) compared to cropped ecosystems. Organic C, soil aggregate stability, and available N increased when in perennial grasses (Chan et al., 2001). A land use change from an intensively managed agricultural usage, such as row crops, to a grassland cause an increase in soil C (Guo & Gifford, 2002). Perennial grasses, including bahiagrass, have been found to reduce nematode populations (Rodríguez-Kábana et al., 1988; 1989; Johnson et al., 1999; Katsvairo et al., 2006).

Multi-year bahiagrass rotation systems provide an additional tool for conservation management. A crop rotation utilizing bahiagrass and conservation management has been shown to increase crop yields, soil moisture, and SOM while decreasing weed, disease, and insect pressures (Marois et al., 2002; Wright et al., 2004; Katsvairo et al., 2007a, b). A 4-year rotation of two years of bahiagrass followed by two years of a conventional crop rotation of cotton and peanut, increased crop yields and improved soil quality (Marois et al., 2002; Wright et al., 2004). Vegetable producers have been increasingly interested in sustainable systems (Hutchinson & McGiffen, 2000), and have integrated cover crops into their management systems.

The overall intention of organic farming is sustainability along with being environmentally responsible. Increasing or maintaining soil quality helps to create a sustainable system. Bahiagrass rotations have been shown to increase SOM and control disease and pests in conventional systems. Weed control is paramount in organic production as weeds may inhibit cash crop production by competing for limited soil resources such as moisture and nutrients. Conservation tillage improves soil quality compared to conventional tillage but the consequence of this management practice has not been sufficiently tested in organic systems. The main objective of this study was to examine the effectiveness of a perennial grass rotation using conservation management in addressing the challenges of organic vegetable production in the Southern Coastal Plain.

2. Method

The study was conducted at the University of Florida's North Florida Research and Education Center, Quincy, FL, from 2010 through 2013. The soil is a Dothan sandy loam (fine loamy siliceous, thermic Plinthic Kandiuldult). The climate for northern Florida is humid subtropical with an annual mean minimum and maximum, respectively, of 18 and 26 oC and 150 cm of rainfall (National Climatic Data Center, NOAA). The long-term agriculture history of the study area was a conventional farming of cotton, corn, soybeans and peanuts. Two years prior to the study initiation, one half of the area was planted with bahiagrass with the other half in soybean production.

2.1 Study Design

The study was established as a split plot design, with the main treatment being number of years in bahiagrass (0-4 years) and the subplot as tillage treatment (conservation or conventional). Conventional tillage was defined as the total plot tilled with a rotovator and conservation tillage defined as only strips within the plot tilled with a rip/strip implement, leaving the remaining plot unplowed. The crop rotation included two cool-weather vegetable crops planted in spring and fall (Valentino bush beans (Phaseolus vulgaris L.) and Major broccoli (Brassica oleracea L.), respectively) and two cover crops of Horizon 401 rye (Secale cereale L.) and Horizon 270 oats (Avena sativa L.) in the winter months and Hinson Long Juvenile soybeans (Glycine max L. Merrill) in the summer months. Plots were planted in March/April (bush beans), June (summer cover crop), September (broccoli), and December (winter cover crop). Each year new plots brought into the rotation were planted in November with the winter cover crop.

In Year 1 of the study, plots for vegetable production were implemented into both areas (previously in conventional farming or in bahiagrass for two years) with the remaining area planted with bahiagrass (in the area in conventional farming) or left in bahiagrass. Each following year (Years 2 and 3), additional plots were added to the vegetable rotation from the areas in bahiagrass. Table 1 provides an outline of treatment description. In Year 1, only 0- and 2-year bahiagrass treatments were in rotation. Year 2 included 0-, 1-, 2-, and 3-year bahiagrass treatments with the 0- and 2-year bahiagrass treatments continuing in the vegetable rotation and 1- and 3-year bahiagrass treatments beginning in this year of the study. Year 3 started the final two bahiagrass treatments (2- and 4-year bahiagrass) with all other treatments (0-, 1-, 2-, and 3-year bahiagrass) continued in vegetable production. An additional block of 25-year bahiagrass was divided into plots in Year 1 and continued in vegetable rotation for the entire study. This treatment was outside the main experimental design and used to specifically examine potential soil degradation over time with vegetable production. The 25-year bahiagrass treatment was not included in the statistical analyses except where noted.

Table 1. Study design for timing of bahiagrass treatments going into the vegetable rotation. Two original bahiagrass treatments, 0 years in bahiagrass and 2 years in bahiagrass, either had plots enter into the rotation, planted with bahiagrass (0 years bahiagrass only), or staying in bahiagrass until following years. Each study year, plots in bahiagrass started into the vegetable rotation, continued with the rotation, or stayed in bahiagrass

Year 1		Year 2		Year 3	
Years in bahiagrass	Years in vegetables	Years in bahiagrass	Years in vegetables	Years in bahiagrass	Years in vegetables
0	1	0	2	0	3
Bahia grass planted	--	1	1	1	2
Bahia grass planted	--	1	--	2	1
2	1	2	2	2	3
2	--	3	1	3	2
2	--	3	--	4	1

2.2 Plot Establishment and Crop Management

Plot size was established as 9.1 by 7.3 m (length by width) with eight vegetable crop rows having 0.9 m row spacing. All plots beginning into the rotation were harrowed three times and rotovated twice to break up the bahiagrass and prepare the plots for the winter cover crop. Thereafter, all vegetable plots were tilled with appropriate tillage methods as described above. Each plot was tilled 3 times over a two week period after the cover crop and before planting vegetables. Oats and rye were planted with a Great Plains drill at 5 bu ha-1 oats and 2.5 bu ha-1 rye, bush beans were planted using a Monosem planter at 15 cm spacing, soybeans were planted with a Tye drill at 112 kg ha-1, and broccoli was hand planted at 23 cm spacing from transplants grown in a greenhouse. Organic poultry litter (8-5-5, Nature Safe) at 135 kg N ha-1 was applied to plots before final tillage, within one week before planting. At approximately 2 weeks after planting, vegetable plots were fertilized with certified organic sodium nitrate (16-0-0) at 34 kg N ha-1. After vegetable harvest, standing residue was mowed to allow for planting of cover crops; no plots were tilled for cover crop preparation. Winter cover crops were fertilized with the poultry litter at 67 kg N ha-1 before planting. Each year (Year 1, Year 2, and Year 3) began with the winter cover crop and ended with broccoli harvest.

2.3 Data Collection and Analyses

Yield was collected in the vegetable plots from two inner rows in each plot. Marketable bush beans were hand-picked and weighed. Marketable broccoli was also hand-picked, weighed, and number of heads counted. One-meter square sub-plots were collected from each plot from all crops for biomass weight and nutrient evaluation. Soil samples were collected from each plot for all crops after vegetable harvest or just before cover crop mulching. Ten soil samples per plot from the 0-15 cm depth were composited and refrigerated after collection. Soil was sieved by hand to remove debris comparable to a 2 mm sieve. Fresh soil samples were extracted for available N and P and again after incubation. Fresh soil samples were adjusted for water content (0.01 MPa) and incubated at 25 ^oC for 14 days. Samples were opened every three days and readjusted for water content as needed.

Available N was measured from a 2 M KCl extraction (Mulvaney, 1996) and available P measured from a Mehlich III extraction (Kuo, 1996). Potentially mineralizable N and P were determined by the change in available N and P after a two week incubation. Separate soil samples were incubated similarly for measurement of potentially mineralizable C. Carbon mineralization was measured as soil respiration using sodium hydroxide traps (Anderson, 1982). Total plant biomass was collected with a hedge trimmer 5 cm above the soil surface within a square meter in each plot at the end of each crop. Total plant biomass was defined as the total biomass, including crop plants and weeds. Plant biomass was dried at 42 ^oC until dry and weighed. Percent C and N from the plant biomass were measured by combustion in Year 3 only (Brodbeck et al., 2001). Total C and N were calculated by multiplying percentage by plant biomass weight.

2.4 Statistical Analysis

All statistics were analyzed by ANOVA utilizing SAS (2007). Dependent variables (yield, soil characteristics, total biomass, and biomass C and N) were analyzed as a 2 x 2 split plot design with years in bahiagrass and tillage as the main effects. In addition, data from 0-year, 2-year, and 25-year bahiagrass treatments (plots beginning vegetable rotation in Year 1 and in vegetable production for the entire three years of the study) were analyzed separately to better quantify potential soil degradation as a function of years in vegetable production for all plots that were in vegetable production. Analyses were run for each crop using ANOVA with years in vegetables as the main effect. Yields and soil parameters were sorted by crop within each year and variables were analyzed by ANOVA with date (year) as the main effect to better quantify changes over time. Duncan's mean separation tests were used when appropriate for all analyses. Means and standard errors for all data are presented.

3. Results

3.1 Yield

Statistical analyses with years in bahiagrass and tillage as main effects, and also years in vegetable production and tillage as main effects, showed that years in bahiagrass had the most influence on vegetable crop yields (Table 2). In Year 1, the bush bean yield was significantly higher in the 0-year bahiagrass treatment; however, no differences were found by the end of that year. In Year 2, vegetable yields significantly increased in a stepwise pattern as a function of years in bahiagrass (Figure 1). These significant effects persisted until the last vegetable crop (broccoli, Year 3) where yields were numerically higher, but not significant, with increasing years in bahiagrass. Years in vegetable rotation did not affect bush bean yields in either Year 2 or Year 3. Broccoli yield also was not impacted by number of years in vegetable rotation and was only affected by bahiagrass in Year 2 (Table 2). Significant differences due to tillage occurred in Year 1, with higher yields in the conventional tillage treatment. However, these differences were irregular with no clear pattern in Year 2 and no differences due to tillage were found in Year 3. Yield data were thus presented with tillage treatments combined (Table 2).

3.2 Aboveground Vegetation Biomass

Preliminary factorial analyses showed tillage had minimal effect on biomass and was only significant in the broccoli crop in Year 3; therefore tillage treatments were combined for analyses. Plant biomass from both vegetable crops corresponded to yield results for the first two years of the study, showing the influence of bahiagrass (Table 2). In Year 3, years in bahiagrass significantly reduced bush bean plant biomass but had no significant effect on broccoli plant biomass. In Year 3, the amount of plant biomass was significantly affected by number of years in vegetable rotation. Interestingly, effects were opposite for the two vegetable crops as years in vegetables increased plant biomass in bush beans but decreased broccoli plant biomass.

The number of broccoli heads was only affected in Year 2, with a significant increase due to years in bahiagrass. Although there was an increase in broccoli head size in Year 2, it was not significant. However, in Year 3 broccoli head size was affected by bahiagrass, with increased size due to increasing years of bahiagrass (Table 2). Number of years in the vegetable rotation did not affect broccoli head count or size.

Plant biomass total C and N were only analyzed for Year 3. Tillage had no effect on plant biomass C or N; thus tillage treatments were combined for statistical analyses. Bush bean plant biomass N concentrations, total N, and total C were affected with years in vegetable rotation with differences between 1- and 3-year bahiagrass. Total C and N content in the bush bean biomass was reduced by years in bahiagrass. For broccoli plant biomass, years in bahiagrass significantly increased N concentration and content and C content. Years in vegetables significantly impacted total C and C concentrations but not consistently (Table 2).

3.3 Mineralizable Soil C, N, and P

Tillage had no significant effect on any measured soil parameters; therefore results were combined for tillage treatments. Mineralizable C was significantly affected by years in vegetable rotation and also by years in bahiagrass (Table 3). In Year 2 and Year 3, significant reductions occurred with increasing years in vegetable rotation for the majority of the crops. In contrast, years in bahiagrass only impacted mineralizable C in two crops (Year 1). Less C was available for mineralization with increasing years in the vegetable rotation.

Mineralizable N was not affected by years in bahiagrass or years in vegetable rotation (Table 4). In Years 1 and 2, mineralizable N in the winter cover crop (rye/oats) was influenced by years in bahiagrass but only for the plots in their first year of rotation. Number of years in vegetable rotation increased mineralizable N in the winter cover crop and bush bean crop only in Year 2. Years in bahiagrass or vegetable production did not significantly effect mineralizable N in Year 3.

Mineralizable P was more influenced by number of years in bahiagrass than were mineralizable C or N (Table 5). Mineralizable P in Year 1 was significantly different in both the winter cover crop and the broccoli crop (Table 4). Number of years in bahiagrass was only significant in the bush bean crop in Year 2, but for Year 3, bahiagrass significantly affected mineralizable P in all crops except the broccoli crop. Yearly seasonal trends were evident, with more P immobilized or less mineralizable P as the year progressed. Years in vegetable rotation did not affect P mineralization.

Table 2. Mean yield, plant biomass, and percent nitrogen, percent carbon, nitrogen content, and carbon content of plant biomass for bush beans and broccoli crops for each treatment and year. Lower case letters indicate significant differences between years in bahiagrass. Standard errors are in parentheses. Statistical significance (p value) for years in bahiagrass or years in vegetables are listed for each variable within each Year. If years in vegetables was significant, only bahiagrass treatments started in the same Year were compared (i.e. 1- vs. 3-year bahiagrass)

Years in bahiagrass	Years in vegetables	Yield (tons ha^{-1})	Biomass (g m^{-2})	%N	N content (mg g^{-1} m^{-2})	%C	C content (mg g^{-1} m^{-2})
		Bush Beans					
		Year 1					
0	1	2.8 (0.39) a	315 (7.1) a				
2*	1	1.7 (0.19) b	254 (7.5) b				
Years bahiagrass		p=0.023	p=<0.001				
Years vegetables		NA**	NA				
		Year 2					
0	2	3.0 (0.21) b	245 (26) b				
1	1	2.9 (0.43) b	223 (23) b				
2*	2	3.9 (0.11) b	239 (23) b				
3	1	5.0 (0.46) a	319 (25) a				
Years bahiagrass		p=0.004	p=0.044				
Years vegetables		NS***	NS				
		Year 3					
0	3	4.0 (0.47) bc	247 (22)	2.80 (0.07)	7.20 (0.41)	38 (0.42)	99 (4.4)
1	2	3.3 (0.28) c	294 (21)	2.80 (0.16)	8.08 (0.56)	39 (0.58)	113 (4.4)
2	1	3.2 (0.17) c	176 (6)	2.30 (0.17)	4.69 (0.31)	40 (0.72)	84 (6.2)
2*	3	4.4 (0.50) b	228 (31)	2.83 (0.08)	5.93 (0.50)	40 (0.48)	84 (7.6)
3	2	6.5 (0.34) a	224 (17)	3.01 (0.06)	6.63 (0.39)	39 (0.48)	85 (3.3)
4	1	4.6 (0.31) b	164 (6)	2.24 (0.14)	3.99 (0.21)	40 (0.45)	72 (3.8)
Years bahiagrass		p=<0.001	p=0.002 (1- and 3-yr)	NS	NS	NS	p=0.002
Years vegetables		NS	p=0.002	p=<0.001	p=0.034	p=<0.001	p=0.006 (1- and 3-yr)
		Broccoli					
		Year 1					
0	1	2.8 (0.39)	330 (39)				
2*	1	1.7 (0.19)	338 (33)				
Years bahiagrass		NS	NS				
Years vegetables		NA	NA				
		Year 2					
0	2	0.9 (0.28) b	192 (24)				
1	1	1.5 (0.40) b	260 (28)				
2*	2	1.9 (0.19) b	226 (22)				
3	1	3.1 (0.50) a	340 (27)				
Years bahiagrass		p=0.001	p=0.057 (1- and 3-yr)				
Years vegetables		NS	p=0.002				
		Year 3					
0	2	1.8 (0.32)	205 (18)	3.48 (0.13) b	7.12 (0.68)	38 (1.20)	77 (6.8)
1	1	2.5 (0.55)	321 (45)	3.23 (0.17) b	10.66 (1.83)	33 (1.29)	107 (16.4)
2	2	2.4 (0.30)	317 (43)	3.59 (0.21) ab	11.37 (1.67)	36 (1.74)	112 (14.4)
2 *	3	2.4 (0.28)	279 (24)	3.90 (0.14) a	10.70 (0.74)	36 (0.54)	101 (8.9)
3	2	3.2 (0.18)	292 (14)	3.62 (0.10) ab	10.58 (0.58)	37 (0.25)	107 (5.4)
4	1	2.6 (0.53)	384 (47)	4.09 (0.18) a	15.25 (1.51)	35 (0.85)	132 (15.0)
Years bahiagrass		NS	NS	p=0.007	NS	NS	NS
Years vegetables		NS	p=0.012	NS	NS	p=0.008	p=0.039

*Indicates the 2-year grass treatment that began in Year 1.

**Indicates not applicable.

***Indicates not significant.

Table 3. Means of potentially mineralizable C for each crop and bahiagrass treatment in each study year. Standard errors are shown in parentheses, and significant differences within each crop and study year due to years in bahiagrass are indicated by lower case letters. See Table 6 for significant differences between years in bahiagrass within years in vegetable rotation

Years in bahiagrass	Winter cover crop	Bush Beans	Summer cover crop	Broccoli
	Mineralizable C (mg g^{-1} soil)			
	Year 1			
0	0.19 (0.13) a	0.14 (0.008)	0.25 (0.011)	0.26 (0.024) b
2*	0.15 (0.33) b	0.15 (0.009)	0.27 (0.015)	0.40 (0.017) a
Years bahiagrass	p=0.028	NS***	NS	p=0.001
Years vegetables	NA**	NA	NA	NA
	Year 2			
0	0.17 (0.006)	0.15 (0.006) b	0.14 (0.004)	0.25 (0.010)
1	0.20 (0.006)	0.18 (0.009) b	0.18 (0.005)	0.27 (0.008)
2*	0.18 (0.004)	0.20 (0.011) ab	0.14 (0.011)	0.26 (0.010)
3	0.25 (0.008)	0.23 (0.009) b	0.17 (0.006)	0.28 (0.010)
Years bahiagrass	NS	NS	NS	NS
Years vegetables	p=<0.001	NS	p=<0.001	NS
	Year 3			
0	0.15 (0.006)	0.12 (0.005)	0.15 (0.006)	0.12 (0.006)
1	0.17 (0.005)	0.12 (0.008)	0.17 (0.007)	0.14 (0.003)
2	0.27 (0.007)	0.16 (0.007)	0.19 (0.011)	0.14 (0.003)
2*	0.16 (0.005)	0.12 (0.004)	0.16 (0.007)	0.14 (0.004)
3	0.17 (0.007)	0.12 (0.005)	0.17 (0.010)	0.14 (0.004)
4	0.25 (0.007)	0.15 (0.005)	0.12 (0.012)	0.15 (0.006)
Years bahiagrass	NS	NS	NS	NS
Years vegetables	p=<0.001	p=<0.001	p=<0.001	NS

*Indicates the 2-year grass treatment that began in Year 1.

**Indicates not applicable.

***Indicates not significant.

3.4 Available Soil Nitrogen and Phosphorus

Soil available N was affected by years in bahiagrass for several crops throughout the study (Table 4), but patterns were not consistent. Only the cover crops were affected by bahiagrass during the first two years of the study. Years of vegetable production only affected the winter cover crop in Year 2. Soil available N was similar for all treatments for Year 3.

Soil available P was more affected by years in vegetable rotation rather than by number of years in bahiagrass (Table 5). In the first year of the study, both cash crops were impacted by bahiagrass with more available P in the 0-year bahiagrass treatment. In Year 2 and Year 3, available P was affected by bahiagrass in the winter cover crops, with more available P in the lesser years in bahiagrass. Number of years in vegetable rotation affected soil available P in all crops except in the bush bean crop for Year 2.

Table 4. Means of potentially mineralizable N and soil available N for each crop and bahiagrass treatment in each study year. Standard errors are shown in parentheses, and significant differences within each crop and study year due to years in bahiagrass are indicated by lower case letters. See Table 6 for significant differences between years in bahiagrass within years in vegetable rotation

Years in bahiagrass	Winter cover crop	Bush Beans	Summer cover crop	Broccoli
	Available N (mg g^{-1} soil) Year 1			
0	1.90 (0.08) b	4.26 (0.42)	5.98 (0.50)	4.05 (0.46)
2*	2.89 (0.20) a	2.62 (0.21)	--	2.72 (0.25)
Years bahiagrass	p=0.006	NS***	NA	NS
Years vegetables	NA**	NA	NA	NA
	Year 2			
0	4.56 (0.22) ab	6.10 (0.73)	3.89 (0.31)	4.50 (0.22)
1	3.51 (0.21) b	6.89 (1.03)	4.83 (0.33)	3.40 (0.23)
2*	5.59 (0.36) a	4.41 (0.47)	2.95 (0.23)	5.14 (0.33)
3	6.29 (0.34) a	4.54 (0.46)	3.95 (0.21)	4.59 (0.47)
Years bahiagrass	p=0.012 (1- and 3-yr)	NS	p=0.024 (0- and 2-yr) p=0.037 (1- and 3-yr)	NS
Years vegetables	p=0.003	NS	NS	NS
	Year 3			
0	4.21 (0.42)	2.88 (0.19)	5.22 (0.40)	5.39 (0.27)
1	5.37 (0.39)	3.24 (0.24)	5.84 (0.20)	4.85 (0.31)
2	5.13 (0.41)	2.73 (0.31)	6.17 (0.56)	5.94 (0.83)
2*	4.00 (0.48)	3.93 (0.24)	5.59 (0.34)	4.92 (0.61)
3	5.37 (0.50)	3.24 (0.25)	5.84 (0.42)	4.85 (0.71)
4	4.75 (0.85)	4.37 (0.30)	7.39 (0.52)	6.04 (0.73)
Years bahiagrass	NS	NS	NS	NS
Years vegetables	NS	NS	NS	NS
	Mineralizable N (mg g^{-1} soil) Year 1			
0	2.13 (0.34) a	4.10 (0.60)	--	7.62 (1.15)
2*	-1.73 (0.24) b	3.62 (0.68)	--	6.60 (1.19)
Years bahiagrass	p=<0.001	NS	NA	NS
Years vegetables	NA	NA	NA	NA
	Year 2			
0	7.91 (0.22) a	4.20 (0.93) b	8.04 (0.83)	4.48(0.23)
1	4.40 (0.41) b	-0.68 (1.19) c	6.35 (0.74)	3.48 (0.25)
2*	7.81 (0.63) a	7.29 (1.05) a	6.45 (0.48)	5.14 (0.32)
3	0.54 (0.73) c	0.51 (0.46) c	6.02 (0.56)	4.59 (0.47)
Years bahiagrass	p=0.004 (1- and 3-yr)	NS	NS	NS
Years vegetables	p=<0.001	p=<0.001	NS	NS
	Year 3			
0	-3.30 (0.39)	12.05 (0.72)	8.89 (1.21)	11.24 (1.06)
1	-4.96 (0.38)	15.48 (1.18)	11.32 (0.66)	11.39 (0.73)
2	-5.01 (0.40)	9.25 (1.05)	7.95 (1.23)	9.69 (0.46)
2*	-3.61 (0.46)	9.20 (0.56)	4.75 (0.41)	13.23 (1.57)
3	-4.47 (0.47)	12.53 (0.74)	10.72 (1.45)	12.98 (0.74)
4	-4.91 (0.84)	8.25 (0.58)	4.28 (0.68)	12.26 (0.97)
Years bahiagrass	NS	NS	NS	NS
Years vegetables	NS	NS	NS	NS

*Indicates the 2-year grass treatment that began in Year 1.

**Indicates not applicable.

***Indicates not significant.

Table 5. Means of potentially mineralizable P and soil available P for each crop and bahiagrass treatment in each study year. Standard errors are shown in parentheses, and significant differences within each crop and study year due to years in bahiagrass are indicated by lower case letters. See Table 6 for significant differences between years in bahiagrass within years in vegetable rotation

Years in bahiagrass	Winter cover crop	Bush Beans	Summer cover crop	Broccoli
	Available P (mg g^{-1} soil)			
	Year 1			
0	28.2 (2.5)	34.5 (2.4) a	54.3 (8.1)	37.6 (2.7) a
2*	28.6 (2.5)	22.1 (1.7) b	50.1 (3.5)	20.0 (1.7) b
Years bahiagrass	NS	P=0.010	NS	P=0.005
Years vegetables	NA	NA	NA	NA
	Year 2			
0	41.4 (2.9)	46.5 (2.1)	43.1 (3.4) a	52.6 (4.8)
1	32.8 (2.2)	38.9 (2.8)	32.1 (2.9) ab	41.2 (4.5)
2*	30.3 (2.0)	41.9 (1.7)	30.3 (3.3) b	45.6 (2.5)
3	22.8 (1.4)	31.3 (1.5)	25.0 (1.7) b	35.8 (1.7)
Years bahiagrass	p=0.004 (1- and 3-yr) p=0.004 (1- and 3-yr)	NS	NS	NS
Years vegetables	p=0.038	NS	p=0.006	p=0.047
	Year 3			
0	42.5 (2.9)	49.7 (4.6)	43.1 (3.6)	55.1 (5.7)
1	34.4 (2.6)	42.3 (3.0)	36.3 (3.4)	42.6 (3.8)
2	23.1 (1.1)	30.3 (2.8)	25.9 (2.0)	41.1 (5.6)
2*	25.0 (2.0)	38.9 (1.5)	31.2 (2.4)	49.3 (2.2)
3	34.4 (1.7)	42.3 (1.6)	36.3 (2.2)	42.6 (3.8)
4	11.5 (1.1)	23.6 (1.0)	21.1 (1.2)	24.4 (2.1)
Years bahiagrass	p=0.003 (0- and 2-yr) p=0.005 (1- and 3-yr) p=0.005 (2- and 4-yr)	NS	NS	NS
Years vegetables	p=<0.001	p=<0.001	p=0.002	p=0.005
	Mineralizable P (mg g^{-1} soil)			
	Year 1			
0	-5.48 (1.68) a	-3.44 (1.70)	-15.66 (4.58)	-15.84 (3.93) b
2*	-12.85 (2.83) b	-7.33 (0.83)	-14.95 (2.40)	-2.60 (1.16) a
Years bahiagrass	p=0.003	NS	NS	p=0.003
Years vegetables	NA	NA	NA	NA
	Year 2			
0	1.72 (4.31)	0.22 (2.11) a	-28.32 (7.06)	-38.00 (8.20)
1	-0.17 (1.93)	-4.15 (1.11) ab	-16.11 (6.84)	-26.98 (7.34)
2*	0.96 (1.30)	-9.11 (1.58) b	-29.97 (3.28)	-45.33 (2.48)
3	-0.50 (1.11)	-6.60 (1.65) b	-24.74 (1.67)	-35.47 (1.69)
Years bahiagrass	NS	p=0.026	NS	NS
Years vegetables	NS	NS	NS	NS
	Year 3			
0	-0.41 (1.10) b	-4.70 (1.55) b	-13.68 (3.63) c	-9.56 (7.10)
1	0.83 (1.16) b	-0.61 (1.06) b	-9.57 (2.62) bc	0.89 (3.86)
2	-0.96 (0.83) b	-3.09 (0.83) b	-7.72 (1.52) bc	-15.18 (4.91)
2*	10.33 (1.39) a	5.43 (1.49) a	2.90 (2.51) a	-8.40 (1.950
3	17.12 (2.70) a	7.96 (1.49) a	2.40 (1.41) a	-3.83 (3.35)
4	14.59 (2.74) a	7.23 (1.53) a	-2.23 (0.75) ab	1.74 (1.81)
Years bahiagrass	p=<0.001	p=<0.001	p=<0.001	NS
Years vegetables	NS	NS	NS	NS

*Indicates the 2-year grass treatment that began in Year 1.

**Indicates not applicable.

***Indicates not significant.

3.5 Soil Quality Degradation

A separate set of analyses were performed to more clearly discern changes over time in the initial treatments (0- and 2-year bahiagrass; Table 6) along with a 25-year bahiagrass (Table 7) treatment that was brought into the vegetable rotation in Year 1. By comparing the yield and measured soil parameters over the three years of the study in the 0-, 2-, and 25-year bahiagrass treatments, we determined if bahiagrass impacted soil quality or fertility after being in a continuous vegetable rotation and determined if soil degraded over time with continuous cropping. Many differences were found in soil analyses between 0- and 2-year bahiagrass; however significant differences did not persist through Year 3 (Table 6) even though the 2-year bahiagrass treatment produced higher yields.

In both 0- and 2-year bahiagrass treatments, bush bean yield significantly increased over time; however broccoli yield decreased (Figure 1). Bush bean yields from the 25-year bahiagrass treatment increased over time, but broccoli yields were similar all three years (Figure 1). Potential C mineralization decreased over time in all crops for the 0-, 2-, and 25-year bahiagrass treatments (Figure 2). When comparing potential C mineralization at the beginning of the study (winter cover crop, Year 1) to the end of the study (broccoli, Year 3), both the 0- and 25-year bahiagrass treatments had less C mineralization while the 2-year bahiagrass treatment did not change. Soil N increased over time in the 0- and 2-year bahiagrass treatments within crops and by the end of the study (Figures 3 and 4). In the 25-year bahiagrass treatment, potential mineralizable N increased over time in the vegetable crops (Figure 3), but the available N did not change (Figure 4). The 2-year bahiagrass changed from immobilizing P to having the potential to mineralize P after three years compared to 0-year bahiagrass, which had a net immobilization of P over time (Figure 5). There were no differences between Year 1 and Year 3 in the 25-year bahiagrass, although potential P mineralization decreased by the end of the study. Available P increased over time in the three treatments (Figure 6).

Table 6. Statistical analyses comparing the 0-year and 2-year bahiagrass treatments over time for yield, soil potential mineralizable C, N, and P, and soil available N and P

		Mineralizable			Available	
	Yield	C	N	P	N	P
	Winter Cover Crop					
Year 1	NA*	p=0.028	p=0.000	p=<0.001	p=0.006	NS
Year 2	NA	NS**	NS	NS	NS	p=0.041
Year 3	NA	NS	NS	p=<0.001	NS	p=0.003
	Bush Beans					
Year 1	p=0.024	NS	NS	p=0.072	NS	p=0.010
Year 2	p=0.022	p=0.016	NS	p=0.015	p=0.020	NS
Year 3	NS	NS	P=0.040	p=0.002	p=0.019	NS
	Summer Cover Crop					
Year 1	NA	NS	NA	NS	NA	NS
Year 2	NA	NS	NS	NS	p=0.025	NS
Year 3	NA	NS	P=0.001	p=0.007	NS	NS
	Broccoli					
Year 1	NS	p=0.001	NS	p=0.046	NS	p=0.005
Year 2	P=0.007	NS	NS	NS	NS	NS
Year 3	NS	NS	NS	NS	NS	NS

*Indicates not applicable.

**Indicates not significant.

Table 7. Means of yield, plant biomass, potentially mineralizable C, N, and P, and soil available N and P for each study year for the 25-year bahiagrass treatment. Standard error is shown in parenthesis and statistical differences between years is indicated by lower case letters

Study Year	Winter cover crop	Bush Beans	Summer cover crop	Broccoli
	Yield (tons ha^{-1})			
1	NA*	2.75 (0.14) b	NA	3.04 (0.42)
2	NA	4.51 (0.52) a	NA	3.06 (0.25)
3	NA	3.97 (0.20) a	NA	2.90 (0.18)
	Plant biomass (g m^{-2})			
1	NA	NA	NA	NA
2	NA	283 (20.8) a	NA	270 (24.2) a
3	NA	167 (11.8) b	NA	280 (22.0) a
	Mineralizable C (mg g^{-1} soil)			
1	0.34 (0.005) a	0.16 (0.011) b	0.31 (0.024) a	0.41 (0.009) a
2	0.17 (0.004) b	0.20 (0.005) a	0.12 (0.009) b	0.26 (0.010) b
3	0.28 (0.005) a	0.10 (0.006) c	0.14 (0.008) b	0.13 (0.004) c
	Available N (mg g^{-1} soil)			
1	3.16 (0.23) b	7.20 (0.55) a	--	2.36 (0.18) b
2	6.00 (0.25) a	7.92 (0.60) a	3.82 (0.29) b	5.10 (0.46) a
3	3.84 (0.23) b	5.76 (0.42) b	4.89 (0.31) a	3.01 (0.24) b
	Mineralizable N (mg g^{-1} soil)			
1	-2.22 (0.28) b	0.72 (0.86) c	--	8.33 (0.60) a
2	8.58 (0.38) a	4.74 (0.68) b	7.07 (0.67) a	5.10 (0.46) b
3	-3.40 (0.25) b	10.97 (0.46) a	4.68 (0.41) b	4.84 (1.10) b
	Available P (mg g^{-1} soil)			
1	38.0 (1.8) b	43.1 (2.1) b	161.1 (7.1) a	53.5 (3.4) b
2	68.1 (3.2) a	78.8 (5.1) a	61.5 (3.6) b	105.6 (6.0) a
3	66.2 (3.6) a	85.3 (5.4) a	66.4 (5.0) b	95.1 (7.2) a
	Mineralizable P (mg g^{-1} soil)			
1	7.49 (1.78) a	-8.11 (3.70) a	-83.70 (5.12) c	-5.67 (2.17) a
2	-3.82 (1.77) b	-42.02 (3.02) b	-60.95 (3.54) b	-105.10 (5.96) b
3	7.12 (1.80) a	-8.17 (2.52) a	4.93 (3.81) a	-9.58 (3.49) a

*Not applicable.

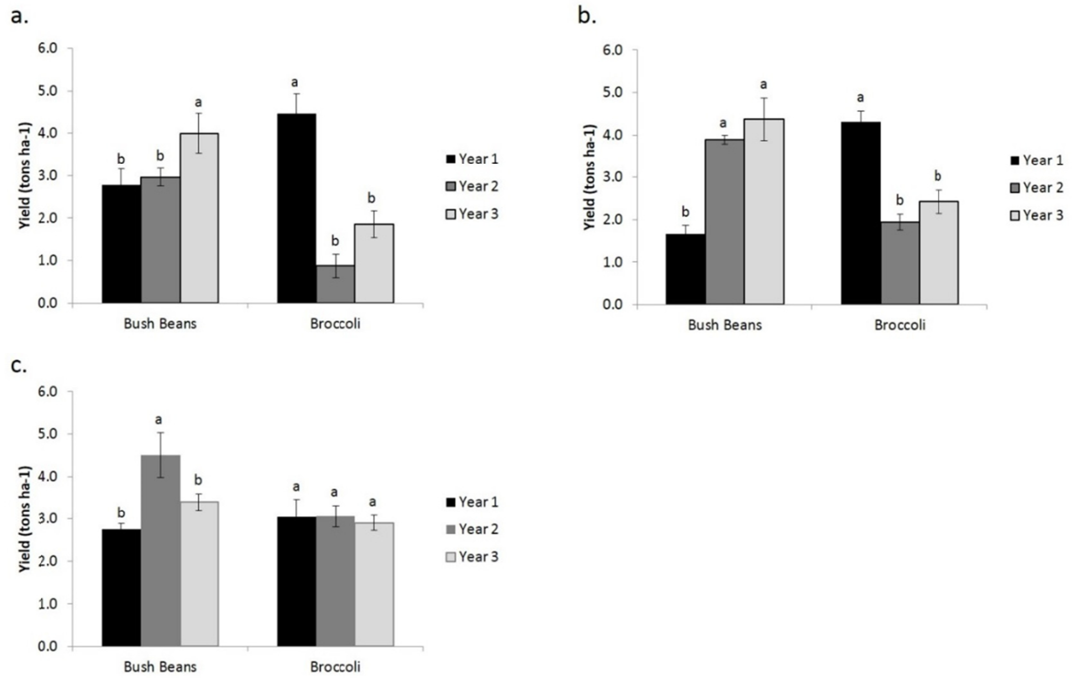

Figure 1. Comparison of bush bean and broccoli yields over time in the a. 0-year bahiagrass, b. 2-year bahiagrass, and c. 25-year bahiagrass treatments. Significant differences between years within each crop are indicated by lower case letters. Data from both tillage treatments were combined

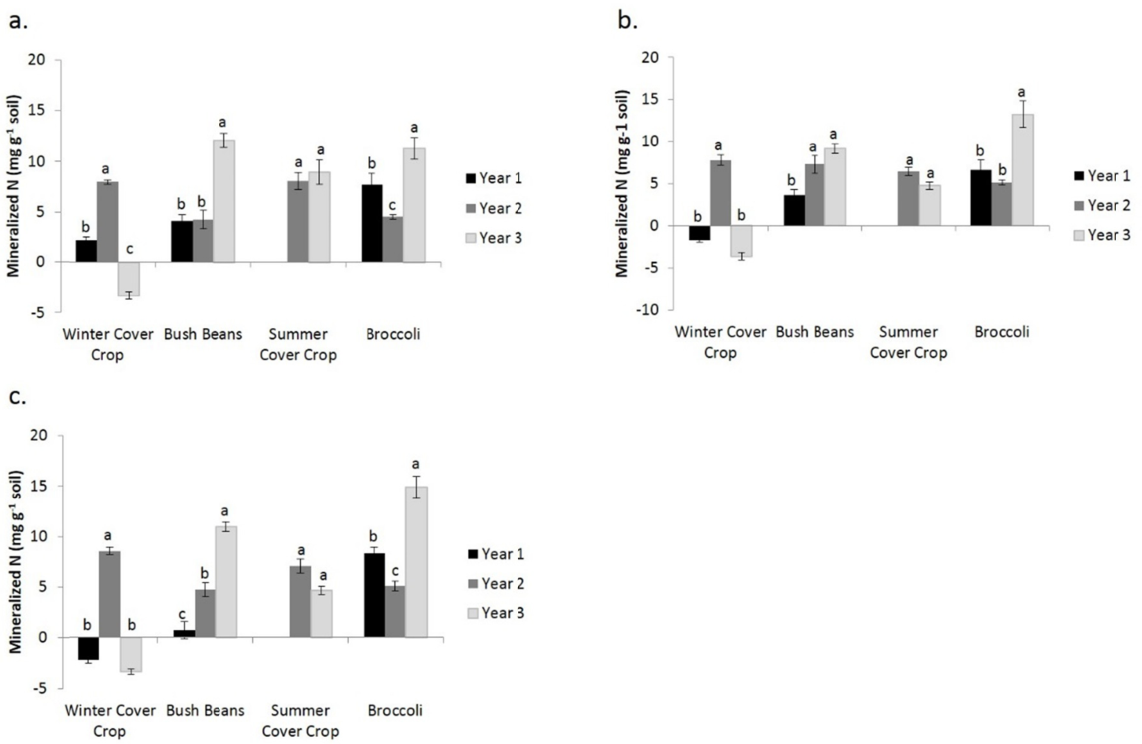

Figure 2. Comparison of potential C mineralization over time for each crop in the vegetable rotation in the a. 0-year bahiagrass, b. 2-year bahiagrass, and c. 25-year bahiagrass treatments. Significant differences between years within each crop are indicated by lower case letters. Data from both tillage treatments were combined

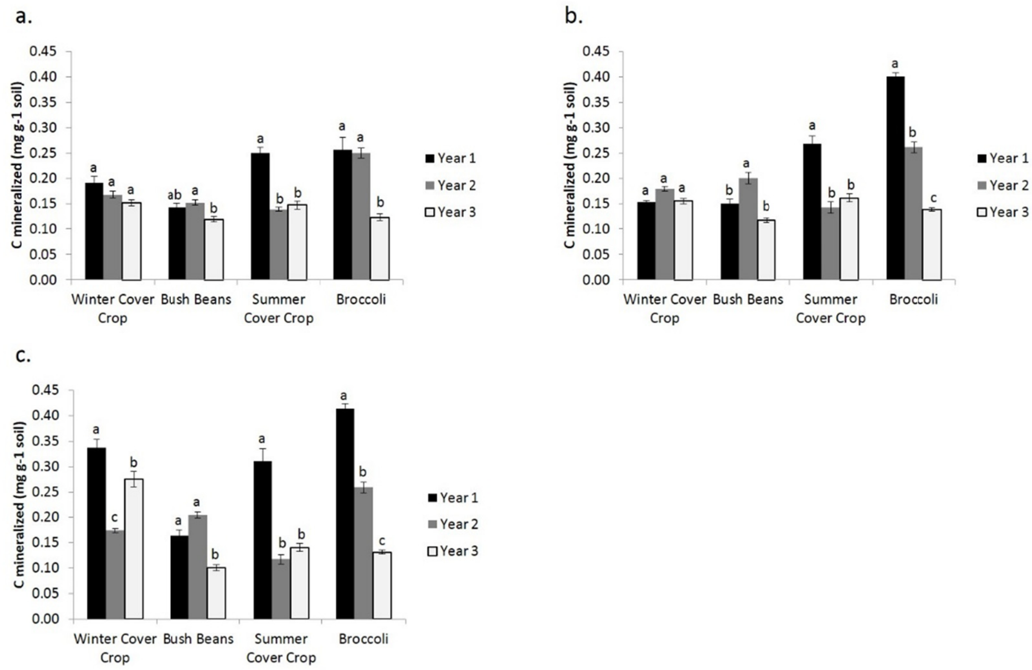

Figure 3. Comparison of potential N mineralization over time for each crop in the vegetable rotation in the a. 0-year bahiagrass, b. 2-year bahiagrass, and c. 25-year bahiagrass treatments. Significant differences between years within each crop are indicated by lower case letters. Data from both tillage treatments were combined

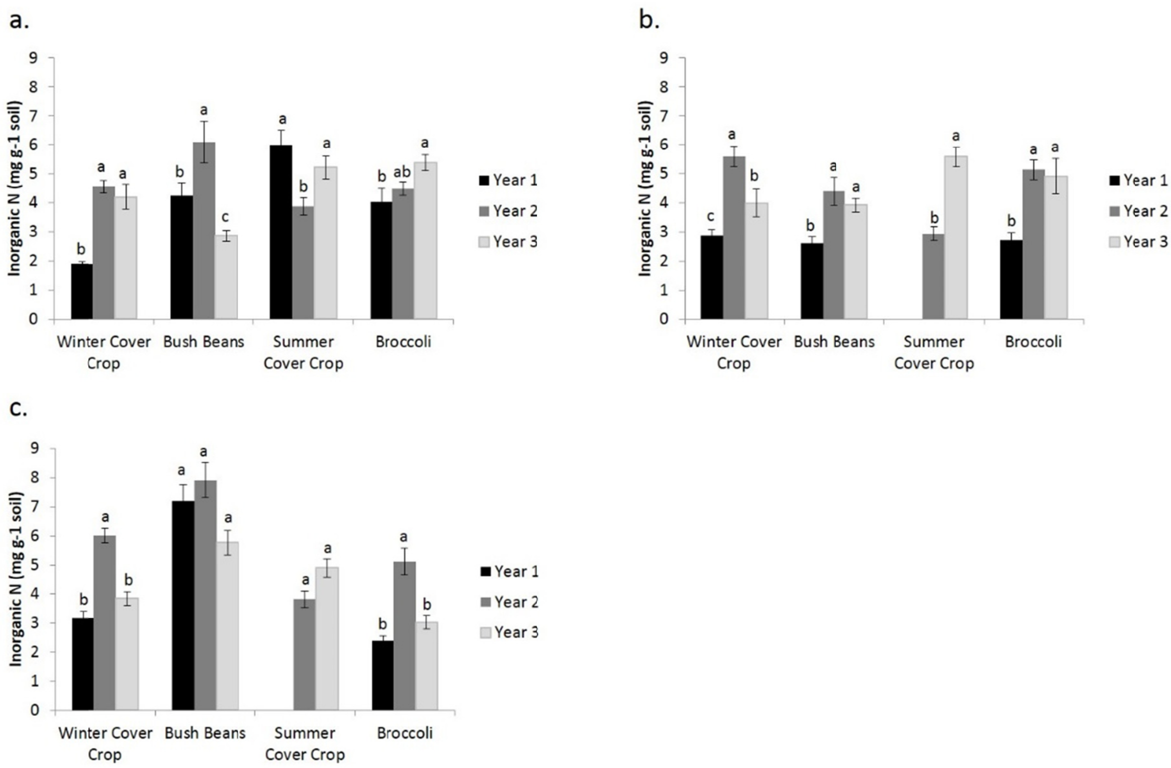

Figure 4. Comparison of soil available N over time for each crop in the vegetable rotation in the a. 0-year bahiagrass, b. 2-year bahiagrass, and c. 25-year bahiagrass treatments. Significant differences between years within each crop are indicated by lower case letters. Data from both tillage treatments were combined.

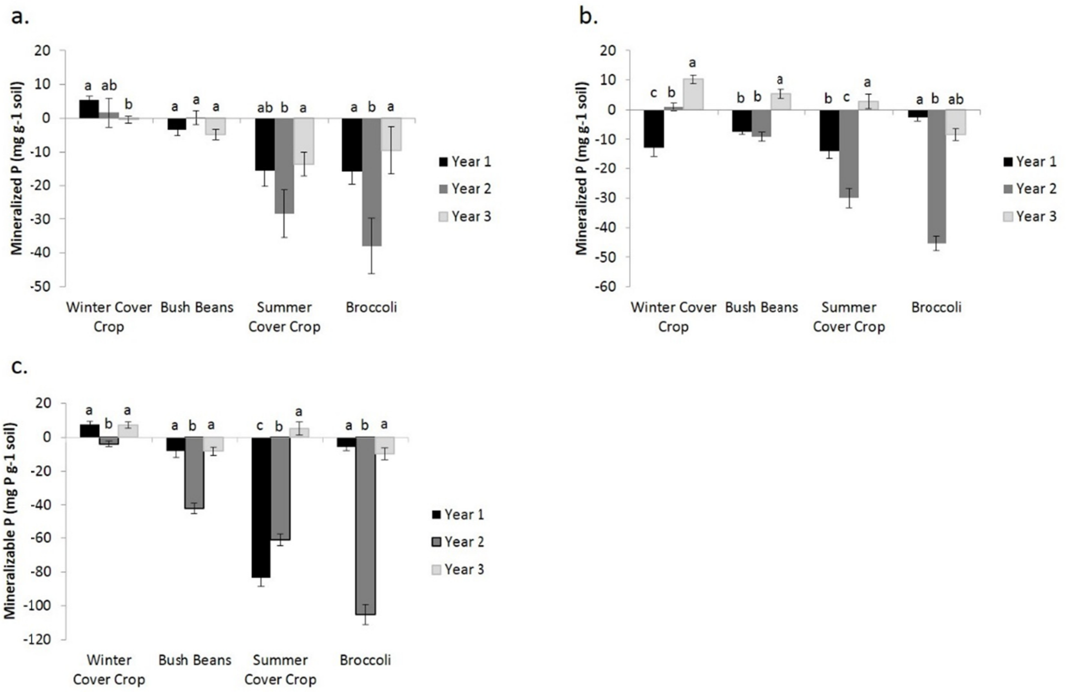

Figure 5. Comparison of potential P mineralization over time for each crop in the vegetable rotation in the a. 0-year bahiagrass, b. 2-year bahiagrass, and c. 25-year bahiagrass treatments. Significant differences between years within each crop are indicated by lower case letters. Data from both tillage treatments were combined

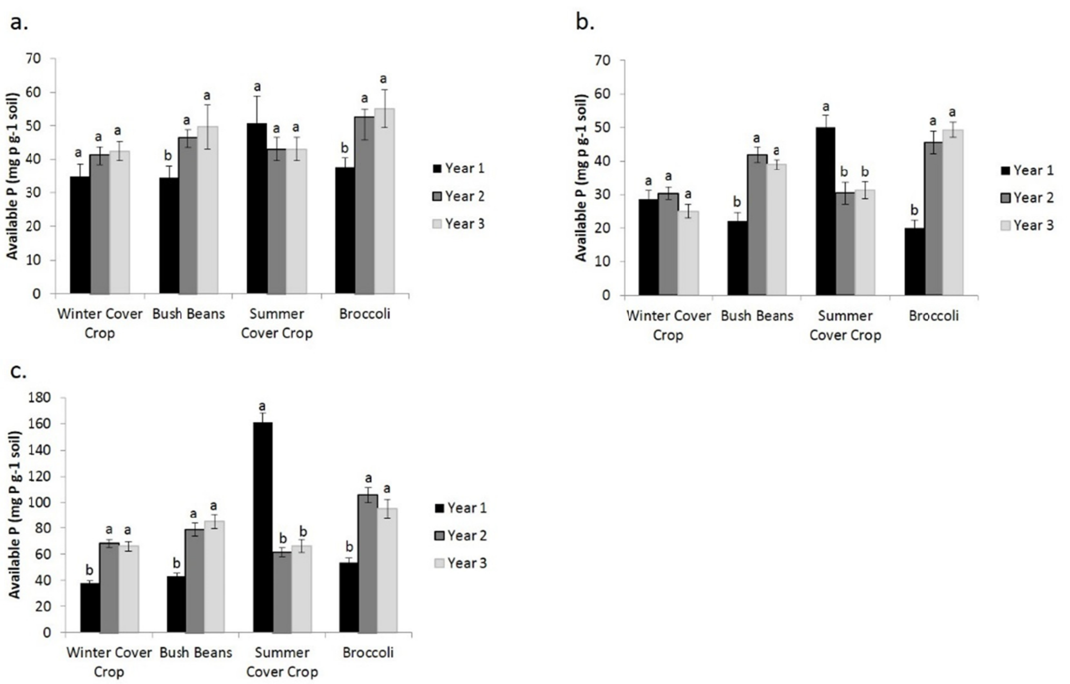

Figure 6. Comparison of soil available P over time for each crop in the vegetable rotation in the a. 0-year bahiagrass, b. 2-year bahiagrass, and c. 25-year bahiagrass treatments. Significant differences between years within each crop are indicated by lower case letters. Data from both tillage treatments were combined

4. Discussion

Growing bahiagrass prior to organic vegetable rotation significantly increased vegetable yields after the first year of the study. Yield increases were accompanied by increased soil N available for vegetable crop uptake and reduced available P. After only one year of vegetable rotation, the benefits of using bahiagrass for at least two years prior to converting to organic vegetable production was demonstrated by increased yields and increased soil organic N and P. Previous studies conducted in the southeastern US incorporating bahiagrass within a conventional rotation also resulted in increased yields (Dickson and Hewlett, 1989, Norden et al., 1980; Hagan et al., 2003; Katsvairo et al., 2007a). Two years of bahiagrass provided the most pronounced benefits of increased cotton and peanut yields and soil parameters (Katsvairo, et al., 2007b). Crop yields have also been found to be increased with even one year of bahiagrass (Hagan et al., 2003). This data shows that one year of bahiagrass may improve yields and soil parameters, but two years of bahiagrass provided more benefits.

Tillage treatment affected yields and biomass initially, but differences diminished after the first year of the study. Only in the 0-year bahiagrass treatment in Year 1 had a decrease in yield due to conservation tillage. The 2-year bahiagrass treatment was not affected by tillage. Other studies have documented that conservation tillage in organic production systems decreased yield, approximately 5-10 percent, compared to conventional tillage (Cooper et al., 2014). Tillage did not affect yield or soil available N and P during the three years of our vegetable rotation. Given that the advantage of conventional tillage on yield were short-lived, and that tillage did not impact measurements of soil quality, this vegetable rotation with cover crops did not show a disadvantage of one tillage treatment over the other. The weed pressure may have been the reason soil degradation did not seem to occur as with many other studies using conventional tillage.

The significantly higher bush bean yield in the 0-year bahiagrass treatment compared to the 2-year bahiagrass treatment in Year 1 may have been due to increased initial fertility from the previous land use of conventional soybean production. Repeated planting of a leguminous crop may be reflected by the high mineralizable N in Year 1. Initial fertility in the 0-year bahiagrass treatment likely caused the significant increased yield in Year 1. All treatments were fertilized similarly, and the majority of available nutrients were reduced to similar amounts after being in the vegetable rotation more than a year. Yields after the first year of vegetable crop rotation then reflected the bahiagrass treatment instead of initial fertility.

Broccoli yields in Year 1 were doubled compared to the following years, unlike bean yield which increased annually. Other organic systems have found a reduction in yield during the transition period into organic production (Buys, 1993; Warman, 1997). Although broccoli yield did not increase over time, yields in this study were comparable or higher than other broccoli yields reported in both conventional (Díaz-Pérez, 2009) and organic systems (Pasakdee et al., 2007; Ouda and Mahadeen, 2008). One major problem of organic production is weed control. Weed density may also have contributed to the declining broccoli yields in this study. Both crop rotations (Liebman and Dyck, 1993) and perennial grass (Franzluebbers, 2007) help to suppress weeds via mechanical soil disturbance, soil moisture and nutrient competition, and potential alleopathy (Liebman and Dyck, 1993). Although we did not directly measure weed density, visual observations suggest weed pressure increased annually during the study. This trend was reflected by the disconnect between yield and biomass by Year 3, whereas yields and biomass showed a positive relationship in Year 1 and Year 2. Plant biomass included both planted crop and weeds, thus comparing changes in biomass weights and yields may suggest differences due to weed density. Plant biomass weights, although affected by bahiagrass treatments, did not affect vegetable yields. Visual observations also suggest weed pressures increase seasonally.

Mineralizable soil C was not affected by the bahiagrass treatments. As expected, potential C mineralization decreased over time, indicating a loss in labile C in consecutive years in our crop rotation. Conversion of grasslands to agriculture reduces the amount of SOC (Guo & Gifford, 2002). Agriculture management allows for increased degradation of soil C due to tillage (Six et al., 1999; Paul et al., 2013), and removal of plant biomass that would add to soil C if left on site. Carbon mineralization had a net increase during the year for the first two years of the study but had an overall reduction in C mineralization after three years. However, after three years of vegetable rotation, C mineralization was similar for all treatments likely due to the large amount of organic matter added back into the soil from weeds.

Both mineralizable and available soil N and P, were positively affected by bahiagrass and cover crops. Although available N was not significantly affected by the bahiagrass treatments, more available N was also found after cover crops compared to the cash crops in Year 3. Other studies have found similar results of increased soil N availability due to cover crops (Wyland et al., 1996; Sanchez et al., 2001; Fortuna et al., 2003; Smith et al., 2008). Nitrogen fertilization requirement has been found to be reduced due to cover crops (Reeves et al., 1995) due to added N availability. Cover cropping (Jackson et al., 1993; Wyland et al., 1996; Constantin et al., 2010) and perennial grass (Woodward, 2002) also reduced the potential of nitrate leaching. Soil organic N has also been found to increase with perennial grass (Giddens et al., 1971). An increase in soil organic N due to bahiagrass also occurred in this study, shown by the increased potential of N mineralization. Phosphorus, although only significantly affected by years in vegetable rotation, showed a trend of decreasing availability with increasing years of bahiagrass. Phosphorus concentration in this soil was not considered limiting to plant growth, and the addition of poultry litter containing available P may contribute to increase available P over time. An increased potential mineralizable P with increased years of bahiagrass also indicated an increase in the soil P organic fraction, similar to the increased soil organic N. Both cover crops and bahiagrass help to efficiently use soil nutrients, reducing the potential of nutrient losses (Brandi-Dohrm et al., 1997; Logson et al., 2002). Our three-year organic vegetable study using both cover crops and bahiagrass contribute to this finding, showing an increase in the soil organic fractions and potential to recycle soil nutrients.

5. Conclusion

This study has shown the benefits of using bahiagrass with cover crops in an organic vegetable rotation including increased yields, increased available N due to cover crops, increased soil organic P, and a reduction in leachable available P . Soil C was mainly affected by number of years in vegetables, with reduced soil C mineralization with increasing years in vegetables. However, being in bahiagrass for two years prior to vegetable production did not affect soil quality after three years, possibly due to the weed biomass. Tillage impacted yields in the first year of the study but had no effect thereafter. Both bush bean and broccoli yields were increased with increasing years of bahiagrass with two or more years of bahiagrass providing higher yields. Yields were not affected by decreasing available P, indicating P was not limiting in this system. Two years or more of bahiagrass provided the most benefits and may provide a profitable, sustainable organic vegetable system.

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