Soil Analysis, Mapping, Project Setup and Water Quality Monitoring Plan for the C-139 Vegetable Demonstration Project

Deliverable 2.0

Submitted 05 February 2009

University of Florida/IFAS

Southwest Florida Research & Education Center

Immokalee, FL

Kelly Morgan

Soil Scientist and Project Leader

Gene McAvoy

Multi-County Extension Agent III

Sponsored by

South Florida Water Management District and

Florida Department of Agriculture and Consumer Services

Office of Agricultural Water Policy

John Folks

Project Manager, FDACS

Jose Gomez

Project Manager and Engineer Specialists 4, SFWMD

Table of Contents

List of Tables

List of Figures

Summary

This report describes the soils in the C-139 Basin with emphasis on the vegetable production areas and the five demonstration sites participating in the C-139 Basin Vegetable Demonstration Project. This report also presents the demonstration project design for the four sites participating in the phosphorus (P) nutrients Soil Test Best management practice (BMP) optimization project, and the water quality monitoring plan for the two sites per year which also include the pH adjustment as an alternative BMP for improved P use of existing soil P.

The soil on which crops are grown greatly influences how irrigation water, nutrients, and other agrichemicals should be managed to maximize production while minimizing resource use and effects on the environment. Soil chemical characteristics affect a soil's ability to retain P and thus may cause P to leach to surrounding water bodies. Soils are classified by soil orders and into categories by soil parent material and changes due to weathering of parent materials over time. These changes can affect both the soil physical (e.g. drainage, water holding capacity, nutrient exchange capacity) and chemical (e.g. pH, ion sorption nutrient availability) characteristics.

For purposes of this analysis, the C-139 Basin was divided into four areas with common crop uses and soils. Specific ratios of the different soil orders and soil series within each order are found in each of these areas. A description of soil orders and series, and their physical and chemical characteristics is presented in Appendix 1. The water movement through the soils during soil formation has resulted in the development of horizons characteristic of soil orders in those areas of the basin. These physical and chemical characteristics (expressed as diagnostic horizons) are likely to influence the crop (i.e. citrus, vegetable or pasture) use currently seen in the areas.

Soil Characteristics: The dominate soil orders in the vegetable production areas are Entisols and Spodosols. The dominate soil series in these two orders are Basinger and Immokalee sands, respectively. The Basinger soil series has a weak to no diagnostic horizon (i.e. a layer of dense leached materials that impedes water movement) to raise water during the wet rainy season (e.g. June-September) and hold little P except in the form of calcium precipitates with reduced chemical activity and thus not in soil solution until all other P in solution is removed providing

the potential for leaching over time. Immokalee series soils on the other hand have a well developed spodic horizon that can retain P allowing little P leaching.

Demonstration sites at four of the six are Immokalee sand and the other two sites have plots that are all Immokalee sand and some plots that are mixtures of Immokalee, Basinger, and Holopaw. Sites with multiple soil orders will be blocked such that all treatments are represented in a specific soil order or a mixture of soil orders and thus make up a statistical block allowing for statistical analysis. Treatments in all blocks of a site with a single soil order and blocks within a site with the same soil order can be compared directly. The third soil, Holopaw, is one of the two dominate Alfisols in the area. Therefore it can be concluded that these sites are representative of the soil conditions of other vegetable operations in the C-139 Basin as they are dominated by one of the dominate soil series of the area and have some sites with another dominate soil.

Review of the soil characteristics of the demonstration project farms indicates that soil pH is not similar to the typical values for Entisols and Spodosols. Soil calcium values for these farms are also very high (Table 1) and would explain the elevated pH values. Origin of the calcium in soils at the selected farms may be natural deposition during soil formation as evidence by the existence of shell fragments in the upper soil layers and repeated applications of agricultural lime and is most likely a combination of both.

Table 1. Soil pH level and Calcium concentrations at 5 farms used in the C-139 Soil Phosphorus Test Demonstration Project.

Farms	pH	Calcium Concentration (ppm)
1	7.5 -7.9	850-1050
2	6.8-7.7	765-984
3a	6.6-7.8	866-1029
3b	6.6-8.1	890-934
5	7.1-8.1	855-985

Experimental design Soil Test BMP Optimization: The experimental design of four (4) demonstration sites was expanded from the initial contract three year design of a randomized complete block (RCB) with two or three replications of two or three P rates, to a RCB with four replications of four P rates of 0%, 50%, 75% and 100% of current University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) recommended rates assuming low soil P levels (Table 2).

Table 2. Target P_2O_5 treatment levels of 0%, 50%, 75% and 100% of IFAS recommended P rate using soil test P index of low as recommendation.

	Target P_2O_5 rates using low soil test P recommendations				Current C-139 Demonstration P_2O_5 application range	
Crop	0%	50%	75%	100%	Half	Grower
	Pounds of P_2O_5/acre					
Tomato	0	60	90	120	50-84	100-168
Green pepper	0	60	90	120	50-60	100-120
Green beans	0	40	60	80	20-25	40-50

Experimental design Soil Test BMP Optimization with pH Adjustment: The experimental design for two sites (i.e. one site each of two growing seasons per year) that will also include plots with pH moderation treatments using sulfur (S). The experimental design for the sites will be a split complete block design with four P application rates (Table 2) of P as the sub treatments and three levels of S application with target soil pH of 7.5, 7.0 and 6.5 applied via banding in the root zone of mulched vegetable beds. Each combination of P rate and soil pH will be replicated four times per site. Sulfur was selected based on review of technical literature towards selecting a current and practical method for pH moderation. A water quality monitoring plan for S and P at the sulfur moderation plots will be conducted in the ditches surrounding the plots to evaluate the relative effects on P and S levels of the different P and S application rates.

1.0 Introduction

The objective of the C-139 Basin Vegetable Production Demonstration Project is to develop technical information to optimize phosphorus (P) nutrient application rates (Soil Test Best Management Practice) in the C-139 Basin. Specifically, to prevent unnecessary application of P, encourage mining of existing soil P instead of new application, and prevent losses of excess P in farm runoff and seepage without affecting the marketable yield and quality of the crops obtained by the growers using current practices.

Understanding the soil types of the C-139 Basin and of vegetable production areas within the Basin is essential, as soil properties can affect P release, availability, uptake, precipitation, and leaching. It is also necessary that the demonstration project sites have soil characteristics that are representative of the rest of the C-139 Basin vegetable areas. Because soil characteristics can be modified overtime by agricultural practices, the sample of demonstration sites also includes a new farming area.

In accordance with the scope of work this report includes:

- A map of the C-139 Basin indicating: the lands currently under vegetable production overlaid on a soil type distribution map based on digital soil surveys from the United States Department of Agriculture and the Natural Resource Conservation Service.

- An explanation of the C-139 Basin soil properties and characteristics, and how they may affect P availability, precipitation and leaching.

- A description of the experiment design including: anticipated crops and crop seasons (fall, winter and spring), site locations, project acreage, current fertilization practices, schematics of the experimental design, and planned project schedule.

- A detailed water quality monitoring plan for sulfur and phosphorus for the demonstration sites for pH adjustment demonstration. As required in the scope of work, the proposed water quality monitoring plan is event based taking place during and after storm, irrigation, and discharge events and covers ditches and canals representative of the demonstration fields and control sites. The data for the water quality monitoring is expected to be sufficient to determine P and S speciation and transport for the site. The analysis of speciation and transport will be included in the annual and final reports. Because of the innovative nature of this research it is expected that the water quality monitoring plan may be refined from year to year based on findings.

Plant available P is always present in the soil solution as phosphate anion ($H_2\ PO_4^-$), but the concentration is usually very low (often < 0.5 ppm). Unlike nitrogen, P does not undergo oxidation or reduction. Between pH 4 and 6, most P in the soil solution occurs as phosphate. However, barely soluble P precipitates are formed in the presence of aluminum, iron or calcium, and solubility depends strongly on pH (greater precipitation as pH increases above 7.0). High pH and the presence of $CaCO_3$ usually result in reduced amounts of P and micronutrient available for uptake.

Currently, S is applied to the entire soil surface to moderate soil pH. This practice has been neglected in the C-139 Basin in recent years because S applications have only a limited impact on long-term moderation of soil pH with high soil Ca (i.e. the soil pH returns to the near the original soil pH within 3 to 9 months). The growers have instead resorted to applications of P to make the element available for plant uptake.

A literature review (Appendix 2) was conducted to determine the most appropriate practices and materials available to moderate soil pH and improve soil P availability to crop plants. Sulfur application has been shown to improve soil P availability resulting in increased plant biomass and yield. Sulfur applications of 1000 kg ha^{-1} or more were found to reduce soil pH by 1 to 1.5 units. Supplementary activities, such as addition of carbon sources to the soil (e.g. compost) concurrent with sulfur application was found to significantly reduce S runoff to surface water bodies thus being an area to explore for counter balancing any effects.

The only other methods found in the literature to moderate soil pH was applications of aluminum sulfate and inoculation of the soil with Mycorrrhizae fungi. Applications of aluminum sulfate requires 6 to 8 times the volume of material to cause the same soil pH change compared with elemental S. resulting in increased costs to vegetable growers and more sulfate available for runoff to surface water. Mycorrhixae fungi enter into symbiotic relationships with plant roots by supplying soil nutrients (e.g. phosphorus) to the host plant and receiving photosynthates (e.g. sugars) in return, The symbiotic relationship requires months to complete (a period of time greater that the cropping season of most vegetable) and the use of soil fumigants to reduce soil growth of weeds and pathogens increases the time required to establish the fungi/host complex.

Thus application of elemental S was seen as the only viable alternative for testing as a soil pH moderation BMP to improve P availability and reduce legacy P, due to the potential cost limitations in using aluminum sulfate and relatively low probability of success using Mychorrhizae. However, the environmental impacts of any S leaving the field sites must be assessed to determine the potential consequences of an elemental S based pH moderation BMP.

2.0 Soils in the C-139 Basin

2.1 Soil Characteristics that Affect Phosphorus Movement

The movement of phosphorus (P) from agricultural fields to surface water bodies has become an environmental concern in Florida. Most soils nationwide have a moderate to high capacity to *adsorb* or hold soil P against leaching because they contain considerable quantities of silt and clay that provide a chemical mechanism to bind P. Florida soils are dominated by quartz sand and lack appreciable amounts of these silts and clays. However, in many cases the sand particles are coated with iron (Fe) and/or aluminum (Al) compounds that also have some capacity to adsorb P.

One way to judge if coated sand grains are present is to observe the soil color. Yellow, orange, or brown colored sand is more likely to be coated, while bright white sand is not. Therefore, soils containing coated sands have the ability to build up a soil P reserve following P fertilizer applications. The presence of this P reserve can be determined with soil testing, and P fertilization may be curtailed if a high soil test P is found. Conversely, uncoated sandy soils typically lacks the ability to hold soil P. Excessive P fertilization in this case may induce P leaching, so P fertilizer should not be used indiscriminately due to the likelihood that it may be lost to the environment.

Many soils in south Florida used for crop production are naturally high in soil pH level and P and Ca concentrations (>800 ppm). Fertilizer P added to soil with high pH levels and Ca concentrations precipitate quickly and become unavailable for uptake by crop plants. Soil test extractants can dissolve P from these precipitates, thus making the soil test appear to have more P available for crop uptake than the plant can access. Plant availability of P extracted by soil test extractants must be understood to determine adequate amount of P to be applied to produce acceptable crop yields.

The physical and chemical characteristics of soil series found in the C-139 Basin are described in Appendix 1 and are representative of the four soil orders present in south Florida The C-139 Basin was subdivided into four geographical regions based on location within the basin and the crops and/or native vegetation grown in the areas as shown in Figure 1. The general description for the four areas is:

1. The area near the northeast corner of the basin that is currently planted to sugarcane with vegetables used in rotation,

2. The area of pasture and wetlands occupying the western portion of the basin,

3. The vegetable growing regions in the center of the basin and the southeastern corner of the basin, and

4. The citrus production area along the southern boundary of the basin.

Separation of the basin into the four areas by crop or vegetation may not reflect an exact boundary, in that areas supporting the four categories of vegetation also contain relatively small areas of landscapes that do not fit into the general description for the area. These exceptions in landscape were slough and depressional areas within the sugarcane/vegetables, vegetables and citrus areas that are not normally planted to those commodities. Also, no attempt was made to eliminate areas that are currently used for drainage ditches or retention ponds, the assumption was that these areas were once filled with soil similar to the soil identified by the current soil survey.

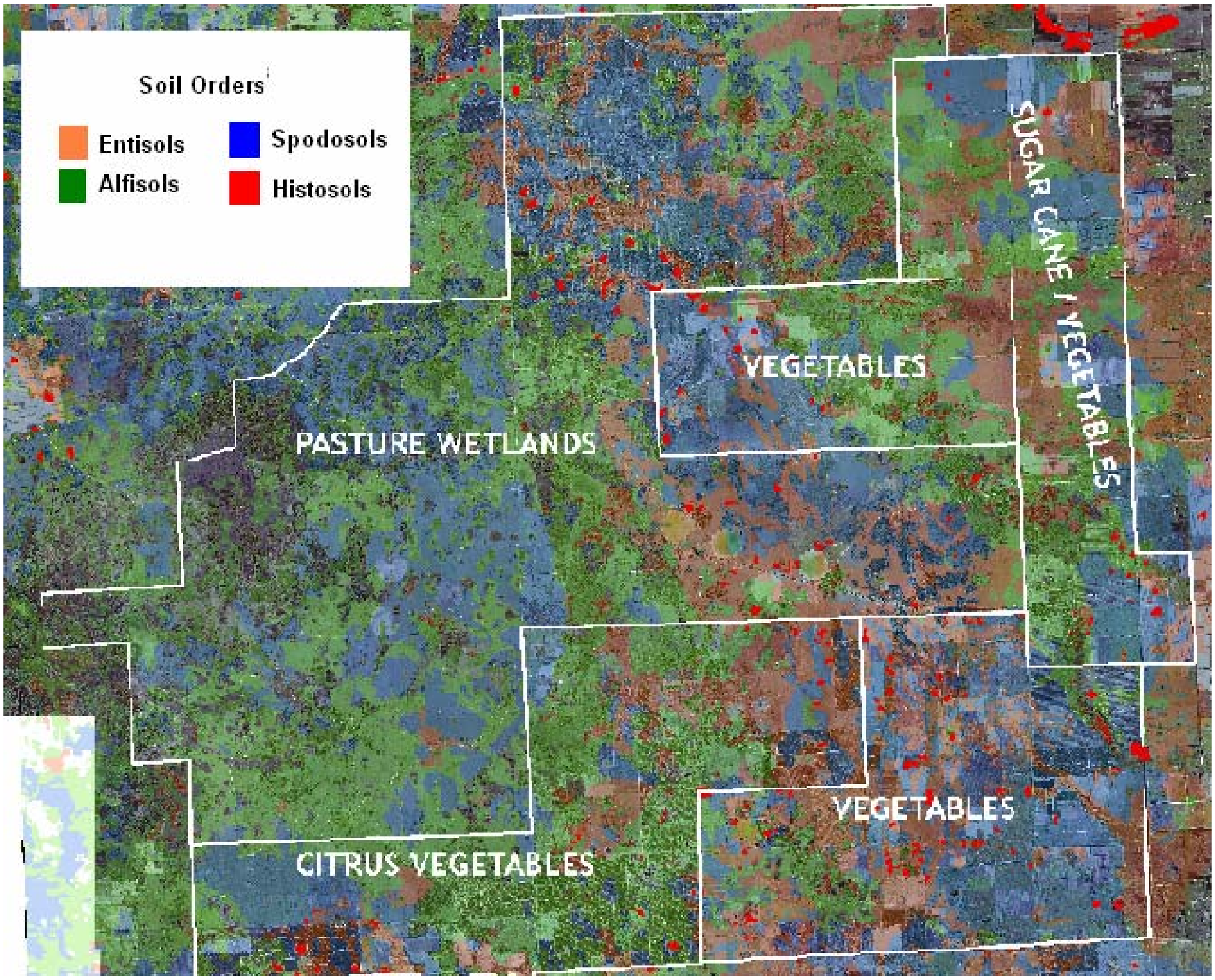


Figure 1 Division of the C-139 Basin into four predominate crop types. The division indicated on this figure is approximate. Soil series acreage by area in tables 3 and 4 were determined using aerial photographs in the USDA-NRCS Web Soil Survey.

Soil series with 1% or more of the land area in any of the four areas are listed in Table 3 by soil order (Entisols, Spodosols, Alfisols, and Histosols). The number of acres and proportion for each soil series varied among soil orders in each area of the C-139 Basin (Table 4). The soil series representative of the four soil orders present in the C-139 Basin are described in Appendix 1. The following soil series distribution was developed from the USDA-NRCS Web Soil Survey data base available on line at www.//websoilsurvey.nrcs.usda.gov/app/websoilsurvey.aspx.

- Sugarcane/Vegetables Area: The dominate soil orders in the sugarcane producing area were Alfisols and Spodosols occupying approximately one-third (37.6% and 32.4%, respectively) of the acreage each (Table 3). Entisols had a similar but smaller proportion of acreage (29.5%) compared with the Alfisols and Spodosols. Hollandale (16.3%), Boca (17.1%) and Immokalee (15.8%) were the dominate Entisols, Alfisols, and Spodosols, respectively.

- Pasture and Wetland Area: The pasture and wetlands area was dominated by Alfisols (36.8%). Spodosols were nearly equal in proportion of acreage with 30.4% of the pasture area. Basinger (Entisols) and Oldsmar (Spodosols) constituted similar land areas in the pasture and wetlands area with 10.2% and 11.8% of the total land area, respectively. The proportions of Boca, Chobee, Holopaw and Riviera soil series were nearly equal with the Alfisols order with 8.9%, 7.8%, 8.1% and 8.1% respectively.

- Vegetable Area: The vegetable production area had nearly equal proportions of Entisols and Spodosols with 32.7% and 44.2%, respectively. These are sandy mineral soils of low fertility, with the difference that Spodosols have a hardpan, or layer made of iron and aluminum cemented organic matter at about 1 meter below the soil surface. The proportion of Alfisols in the vegetable production area was approximately half that of Entisols and Spodosols at 18.8%. Alfisols are sandy mineral soils with higher natural fertility than both Entisols and Spodosols. Basinger was the dominate Entisols and Immokalee the dominate Spodosols with 24.3% and 23.2% of total acreage, respectively. The percentage of total acres with Boca series soil (Alfisols) in the pasture area was 7.3%. As indicated above the organic soils (Histisols) do not constitute a large area of any of the areas of the C-139 Basin. with a range of 0.4% to 1.6% of the total area. The vegetable production area has only 1.6% of the area in Okeelanta series.

- Citrus and Vegetable Area: The citrus and vegetable production area was dominated by Alfisols with 47.3% of the acreage. Entisols and Spodosols in the citrus production area were lower than Alfisols but nearly equal to each other with 23.7% and 22.4%, respectively. Holopaw was the dominate Alfisols (23.7%) with Basinger and Oldsmar series the dominate Entisols and Spodosols, respectively.

Table 3. Soil Distribution as acreage and proportion of total acreage of selected Entisols, Alfisols, Spodosols and Histisols series in the C-139 Basin by area within the basin.

Soil series	Sugarcane and vegetable area		Pasture and wetlands area		Vegetable areas		Citrus and vegetable area	
	Acres	%	Acres	%	Acres	%	Acres	%
				ENTISOLS				
Basinger	403.9	2.1	8586.4	10.2	8824.5	24.3	6068.1	21.8
Hallandale	3200.6	16.3	2460.1	2.9	1380.5	3.8	178.5	0.6
Jupiter	112.5	0.6	550.5	0.7	263.9	0.7	283.0	1.0
Margate	2075.5	10.6	1133.90	1.4	1390.0	3.8	46.8	0.2
Total	5792.5	29.5	12739.9	15.1	11.858.8	32.7	6576.4	23.7
				ALFISOLS				
Boca	3347.0	17.1	7456.9	8.9	2657.0	7.3	3090.6	11.1
Chobee	421.8	2.2	5642.5	7.8	294.1	0.8	1122.3	4.0
Holopaw	1697.9	8.7	6800.5	8.1	1141.1	3.1	6581.5	23.7
Malabar	114.2	0.6	1469.4	1.7	896.0	2.5	22.0	0.1
Pineda	1271.6	6.5	1953.4	2.3	1825.9	5.0	803.4	2.9
Riviera	522.2	2.7	6793.4	8.1	13.0	0.1	1529.9	5.5
Total	7374.5	37.6	31016.1	36.8	6827.0	18.8	13150.2	47.3
				SPODOSOLS				
Immokalee	3087.1	15.8	6955.7	8.3	8437.9	23.2	2188.1	7.9
Myakka	2073.8	10.6	3856.5	4.6	6507.8	17.9	932.9	3.4
Oldsmar	1162.2	5.9	9960.6	11.8	1036.3	2.9	3019.8	10.9
Wabasso	26.6	0.1	4874.2	5.8	63.8	0.2	73.2	0.3
Total	9349.7	32.4	25647.0	30.4	16045.7	44.2	6214.0	22.4
				HISTISOLS				
Okeelanta	89.5	0.5	335.7	0.4	572.8	1.6	186.2	0.7
Total	89.5	0.5	335.7	0.4	572.8	1.6	186.2	0.7
All orders	19606.2	100.0	69729.8	82.8	35304.3	97.3	26126.7	94.0

Source: U.S. Department of Agriculture, Natural Resources Conservation Service Web Soil Survey (www.//websoilsurvey.nrcs.usda.gov/app/websoilsurvey.aspx).

Table 4. Dominate soil series with greatest percentage of acreage by area within the C-139 basin.

Soil order	Northern sugarcane and citrus area	Central: pastures and wetlands area	Southeastern vegetable area	Southwestern citrus area
Entisols	Hollandale (16.3%)	Basinger (10.2%)	Basinger (24.3%)	Basinger (21.8%)
Alfisols	Boca (17.1)	Boca (8.9%) and Holopaw (8.1%)	Boca (7.3%)	Holopaw (23.7%)
Spodosols	Immokalee (15.8%)	Oldsmar (11.8%)	Immokalee (23.2%)	Oldsmar (10.9%)

2.2 Soils in the Demonstration Project Sites

Soil pH, Particle size distribution, organic matter content, cation exchange capacity in the surface 6 inch depth and depth to diagnostic horizon was determined for five replicate soil samples at all 5 sites in the project. Soil pH varied slightly with location but was in the range of upper 6 to low 8 across most samples (Table 5). Similarly, percentage sand and organic matter were in a very narrow range and averaged 97.3 and 1.7, respectively. The cation exchange capacity ranged from 2.1 to 4.5 and was highest at Farm 1 and lowest at Farm 5 (the new farm). The depth of the diagnostic horizon (mostly spodic) was 26 to 34 inches. All of these values are similar to the values for Entisols and Spodosols listed in Table 2 with the exception of soil pH (Table 5). Soil calcium values for these farms are very high (Table 5) and would explain the elevated pH values.

Table 5. Average soil physical and chemical analysis results for five soil samples collected from the five farms participation in the C-139 project.

Farms	pH	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	Cation Exchange Capacity (meq/100g)	Calcium Concentration (ppm)	Depth to Diagnostic Horizon (in)
1	7.5 -7.9	97-98	1	<1	1.5-2	2.2-4.5	850-1050	28-34
2	6.8-7.7	96-98	1	<1	1.5-2.5	2.5-3.8	765-984	26-30
3a	6.6-7.8	97-98	<1	<1	1.0-1.5	2.3-3.4	866-1029	28-32
3b	6.6-8.1	96-97	<1	<1	1.5-2.0	2.5-3.1	890-934	29-34
5	7.1-8.1	98	<1	<1	1.5-2.0	2.1-2.6	855-985	30-34

3.0 Demonstration Project Experimental Design

The experimental design and crops used in the first three years of the demonstration project were revised to accommodate the addition of one or two P rate(s) at each experimental site. The incorporation of S into the soil at two rates to produce three target soil pH values of 7.5, 7.0 and 6.5 was done to reduce soil pH and attempt to make the soil P more available to the crop plants. The moderation of soil pH will be done at Farms 1 (fall season) and 2 (spring season). The S trial will be split among Farms 1 and 2 because the plots at Farm 1 are only used to grow tomatoes in the fall of each season. Sulfur will be added to split plots at Farm 2 in the spring of each year so that the soil can be observed in the fall season to determine if one application per year will affect crops grown in both fall and spring seasons. The experimental design for the soil pH moderation study will be a split plot design with the main effect being the P rate and each plot of a given P rate divided into three subplots, one with each target soil pH. An additional change from the previous demonstration project was that plots were added to the number of blocks used in the first three year demonstration project to accommodate the one or two added replications for a total of four P replications of each treatment per site. This improvement in the design required all farms to devote greater amounts of land to the project at additional risk and expense to the grower voluntarily participating in this project. Consequently, Farm 3 had to be reduced from two sites (Farms 3a and 3b) to one site (farm 3). Farm 4 stopped operations and was replaced with another farm (Farm 5) to maintain a minimum of four participating growers. Soils of the demonstration project were reviewed and are documented using soil survey maps overlying photographs in Figures 4, 7, 10, 12, and 15 for Farms 1, 2, 3a, 3b, and 5, respectively.

The soil pH adjustment via incorporation of S into the soil at four phosphorus application rates and three target soil pH levels is conducted to reduce soil pH to make the soil P more available to the crop plants. The objective being that growers would obtain similar marketable yields and crop quality (e.g., fruit size) to that obtained at their in-house developed rates with no phosphorus applied or reduced rates if P precipitates levels in the soil are substantial but not available to the plant.

3.1 Farm 1

Experimental design:

> The experimental design for Farm 1 in the first three year demonstration project was a randomized complete block with three replications of three P rates (zero, half and full of the grower's customary application rate based on field experience; Figure 2). Each plot was 6 rows wide and 500 to 700 feet long.

The experimental design for Farm 1during the second three year demonstration project will be a split plot complete block with four replications of four P rates (see Table 2) at the main plot, and three split plots with S rate to establish the target soil pH levels (4.0 Supplementary Soil and Water Quality Monitoring for Soil Test BMP Optimization with pH Adjustment Alternative, Figure 3). Each subplot is 6 rows by 175 to 225 feet long. Plots receiving the zero, half and full of the grower's application rate in the first demonstration will receive respectively the 0%, 50% and 100% of the UF/IFAS recommendation assuming low soil test P levels. The assumptions on phosphorus application rates for the demonstration projects were revised to ensure that all demonstration sites used comparable application rates. The application rates used during the initial three-year project could differ because they were based on the individual landowners.

Plots were added to replications 1, 2 and 4 that will receive the 75% P rates. One complete replication (Rep. 3) was added with each of the four rates. Added plots received full grower rates prior to the second demonstration project.

Crop:

The crop at this farm will be the same as the first 3 year demonstration project, one crop of tomatoes grown in the fall season of each year.

Soils:

The soils in the experimental area are Rep. 1 = Immokalee and Holopaw, Rep. 2 = Holopaw, Basinger and Immokalee, Rep.3 = Basinger and Immokalee and Rep. 4 = Holopaw (Fig. 4).

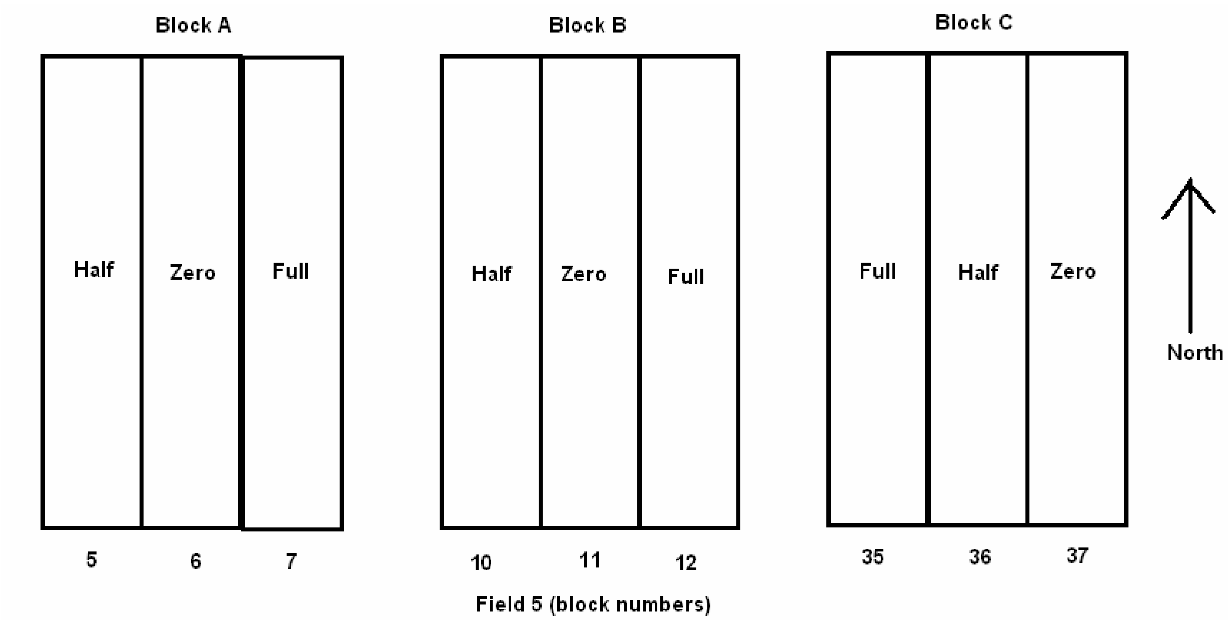


Fig. 2. Randomized complete block design for demonstration project at Farm 1 (n-1 = 8). Each plot is 6 rows wide and 500 to 700 feet long.

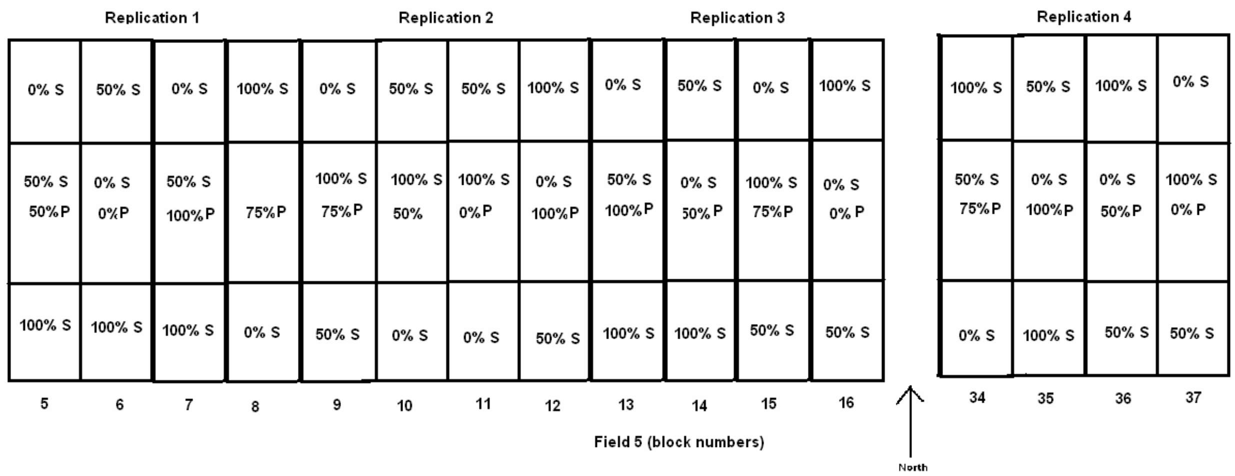
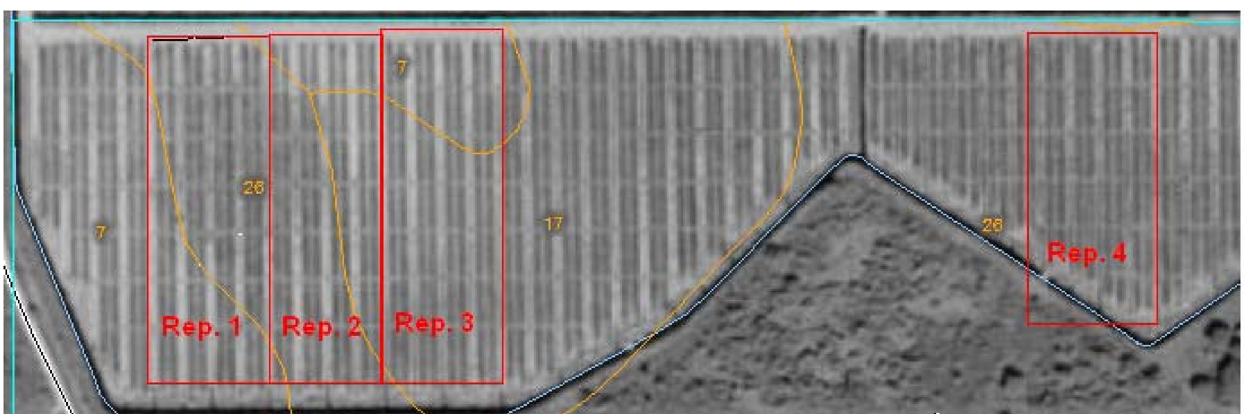


Fig. 3. Split plot complete block design for demonstration project at Farm 1 (n-1=40). Main plot is P rate and split plot is S rate.



Hendry County, Florida (FL051)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
7	Immokalee sand	9.9	19.7%
17	Basinger sand	13.5	27.1%
26	Holopaw sand, limestone substratum	26.5	53.0%
29	Oldsmar sand, limestone substratum	0.1	0.1%
Totals for Area of Interest		**50.0**	**100.0%**

Fig. 4. Soil map of experimental site at Farm 1. Soil series in the experimental area are Immokalee, Basinger, Holopaw and Oldsmar.

3.2 Farm 2

Experimental design:

The experimental design for Farm 2 in the first three year demonstration project was a randomized complete block with three replications of all three P rates (0%, 50% and 100%l) based on the rate used by the grower for that site based on site-specific experience growing crops (Figure 5). Each plot was 14 rows wide and 900 feet long.

The experimental design for Farm 2 during the second three year demonstration project will be a randomized complete block in the fall planting with four replications of four P rates (see Table 2). Split plots at this farm will receive S application in the spring growing season of each year with target pH levels of 7.5, 7.0 and 6.5 (see 4.0 Supplementary Soil and Water Quality Monitoring for Soil Test BMP Optimization with pH Adjustment Alternative). In the fall of each year, the plots will receive the same P rates, except the differential S applications will not be made. Thus the experimental design will be a randomized complete block. Subsamples collected from plots previously receiving S applications will be analyzed to determine residual effect of S applications on soil pH and P availability. The design was accomplished by adding one plot to Block A (75% P), taking one plot from Block C and adding it to Block B (75% P), adding two new plots to Block C (50% P and 75% P) and four blocks (one for each P rate) to make Block D (Fig. 6). A split plot complete block with four replications of four P rates (0, 50%, 75% and 100% of recommended rate by crop) as the main plot and three split plots with S rate (target pHs of 7.5, 7.0 and 6.5) in the spring planting will be used in the spring planting (Figure 6). Each subplot is 4 rows by 900 feet long.

Crops:

The crops at this farm will be the same as the first 3 year demonstration project, a rotation of tomatoes and peppers with green beans.

Soils:

The soils in all plots of this experimental area are Immokalee series (Fig. 7).

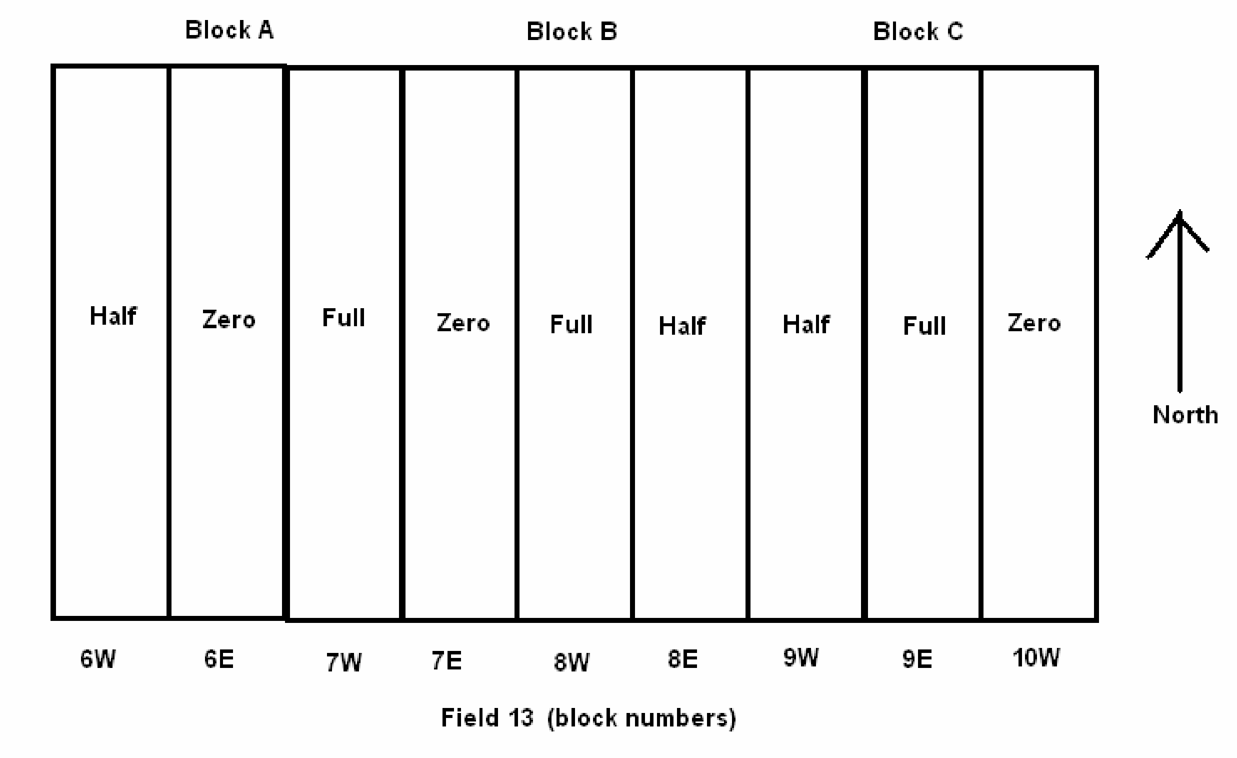


Fig. 5. Randomized complete block design for demonstration project site at Farm 2 (n-1 = 8).

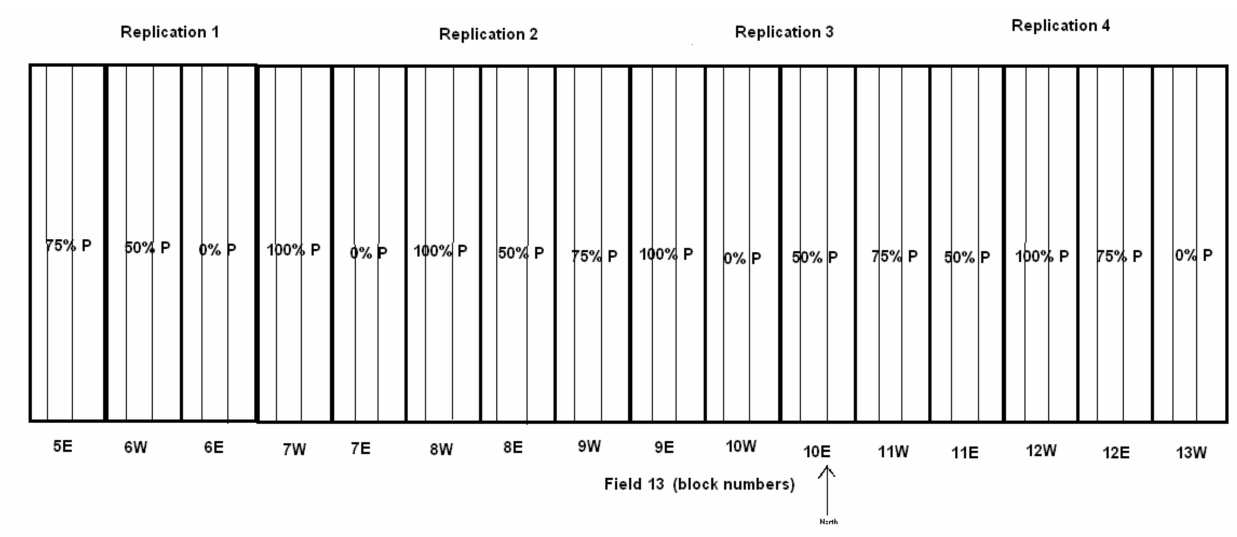
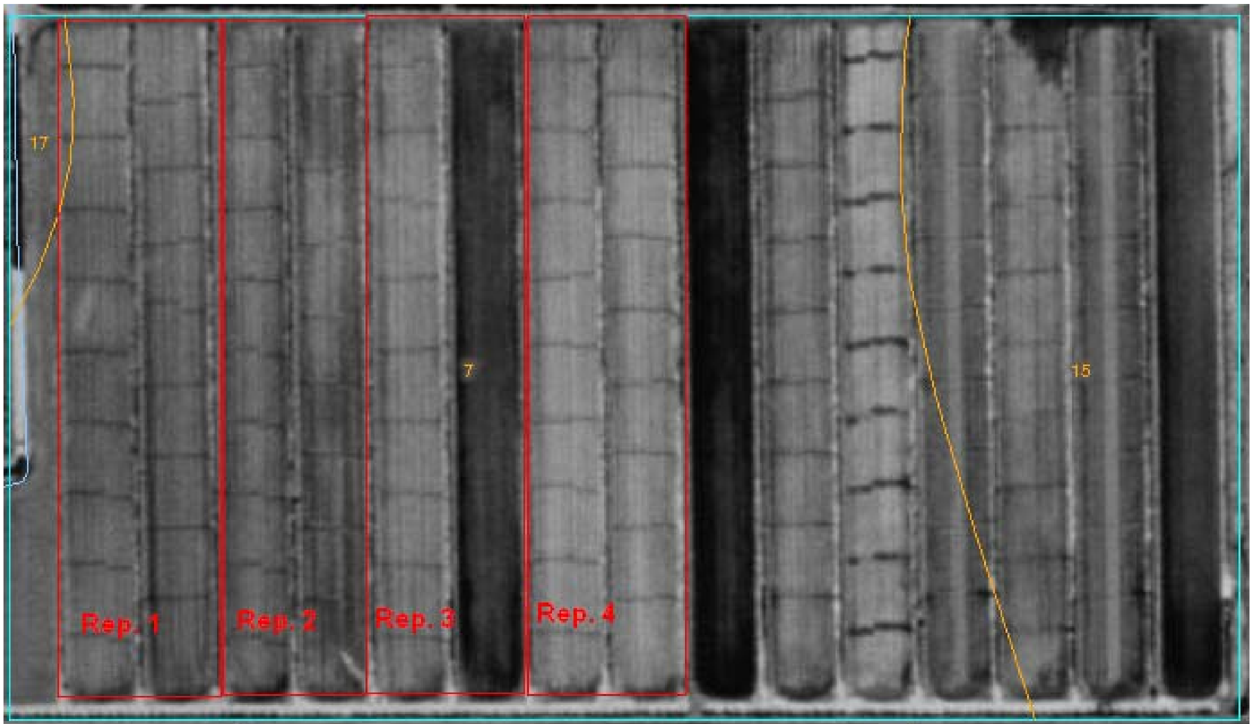


Fig.6. Split plot complete block design for demonstration project site at Farm 2 (n-1 = 46)



Hendry County, Florida (FL051)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
7	Immokalee sand	29.5	74.3%
15	Myakka sand	9.5	24.0%
17	Basinger sand	0.7	1.7%
Totals for Area of Interest		**39.7**	**100.0%**

Fig.7. Soil survey map of experimental site at Farm 2. Soil series in the experimental site is Immokalee sand.

3.3 Farm 3

Experimental design:

The experimental design for Farm 3a in the first three year demonstration project was a randomized complete block with three replications of two P rates (0% and 100% of the growers current P rate based on experience; Figure 8).

The experimental design for Farm 3a during the second three year demonstration project will be a randomized complete block with four replications of four P rates (see Table 2; Fig. 9). The design was accomplished by combining Blocks A and B into Rep. 1.

Crops:

The crops at this farm will be the same as the first 3 year demonstration project, a rotation of tomatoes and green beans.

Soils:

The soils in all plots of this experimental area are Immokalee series (Fig. 10).

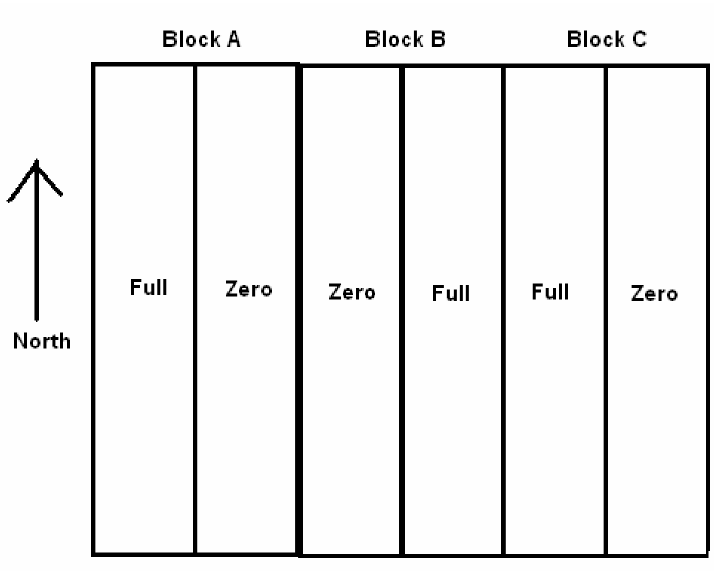


Fig. 8. Experimental design of Farm 3a. The design was changed from three plots (blocks A, B and C) in year 1 (n-1 = 2) to six plots in year 2 (n-1 = 5).

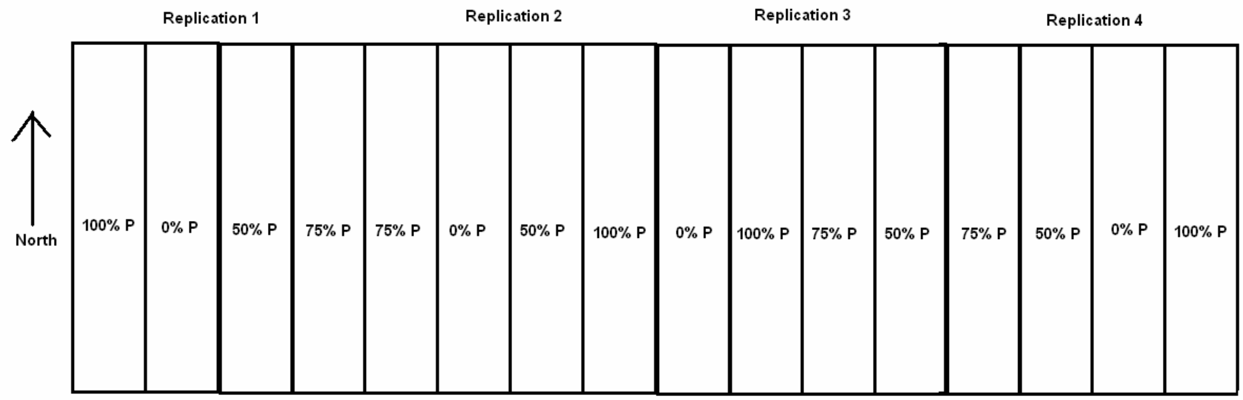
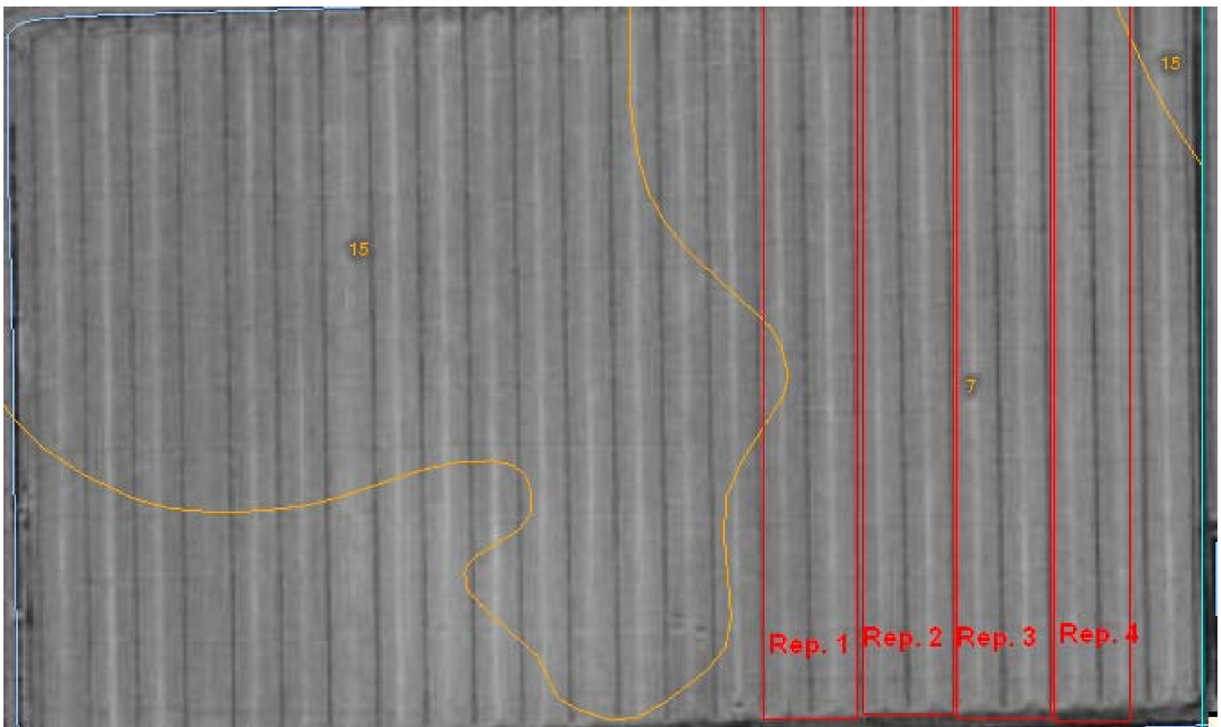


Fig. 9. Randomized complete block design for demonstration project site at Farm 3a (n-1 = 15)



Hendry County, Florida (FL051)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
7	Immokalee sand	44.6	57.4%
15	Myakka sand	33.1	42.6%
Totals for Area of Interest		**77.8**	**100.0%**

Fig. 10. Soil survey map of experimental site at Farm 3a. Soil series in the experimental site is Immokalee sand.

3.4 Farm 5

Experimental design:

This farm was added to the project for the second three year demonstration project to bring the total to 4 participants after the lost of Farm 3B and 4. Farm 4 only participated in one crop in the first year project and did not grow subsequent crops on that land.

The experimental design for the second three year demonstration project will be a randomized complete block with four replications of four P rates (see Table 2; Fig. 11).

Crops:

The crops at this farm will be tomatoes and peppers followed by green beans.

Soils:

The soils in all plots of this experimental area are Immokalee series (Fig. 12).

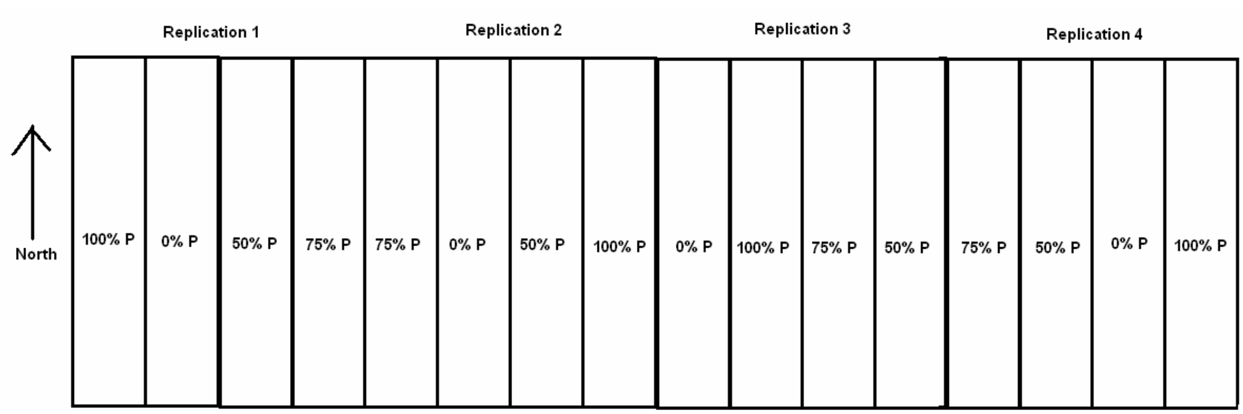
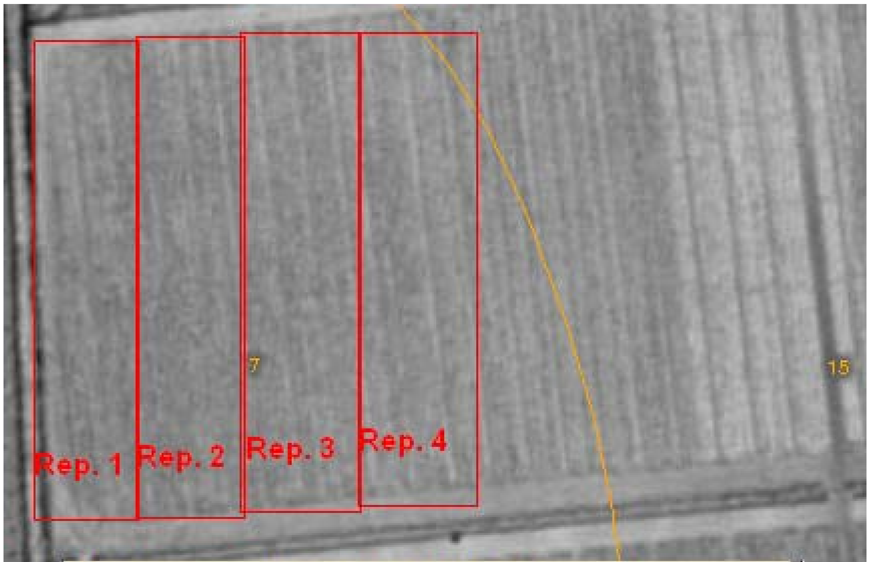


Fig. 11. Randomized complete block design for demonstration project site at Farm 5 (n-1 = 15).



Hendry County, Florida (FL051)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
7	Immokalee sand	17.1	52.6%
15	Myakka sand	15.4	47.4%
Totals for Area of Interest		**32.5**	**100.0%**

Fig. 12. Soil survey map of experimental site at Farm 5. Soil series in the experimental site is Immokalee sand.

4.0 Supplementary Soil and Water Quality Monitoring for Soil Test BMP Optimization with pH Adjustment Alternative

4.1 Sulfur application

Currently, S is broadcasted evenly over the entire soil surface and incorporated by disking to change soil pH. The application of S only in the fertilizer bands will reduce the amount of S required to lower the relatively small soil volume where the fertilizer P comes in contact with the soil. Additionally, because the soil treated with S is completely covered by plastic mulch the potential for S runoff to surface water is reduced. Soil pH will be moderated at one farm of the four farms used in each season (fall and spring). . Blocks will be established by application of sulfur (S^0) in “bottom” or “cold mix” bands prior to bed formation to establish randomized blocks of 3 target pH levels (7.5, 7.0 and 6.5). Amounts of S required to reduce soil pH will be site specific based on pH and Ca concentration results of soil tests performed prior to fertilizer applications using recommendations in the Vegetable Production Handbook for Florida (Olson and Simonne, Eds.; 2008). Application of S^0 in this manner will reduce the amount of S required compared with a blanket application to a large area and should reduce the potential for particulate S entering the field ditch water. Vegetable are planted in rows on plastic covered raised beds that are typically five feet apart. The bands of bottom fertilizer applied to each bed are approximately 30 cm wide, thus only 20% of the land area will receive an S^0 application and thus only 20% of the amount of S will be required compared with the amount of S required if we were to attempt to change the pH of the entire land area. We can reduce the amount of land that S is applied to because precipitation of the fertilizer P will only occur in the soil that P is applied to, therefore, the soil pH only needs to be moderated in that relatively small volume. Another advantage of applying S to the planted row is the beds will be covered with plastic mulch, limiting their exposure to rainfall and research on P movement with seepage irrigation indicates that movement within these mulched beds is very limited (Sato et al., 2009).

4.2 Sample collection, handling, processing and analysis

Soil and ditch water samples will be collected at 30 day intervals and will be analyzed for total P and S. These samples will provide data on movement of P and S in the soil solution through the beds and into surrounding surface waters (Fig. 13). Samples of both materials will be collected from all plots of all replications of all treatments at farms participating in the soil pH moderation study. Soil and ditch water samples began with the fall 2008 crop and will continue with subsequent crops at 30 day intervals during subsequent fallow periods that will include the rainy season. Ditch water samples are, and will continue to be, collected from all ditches surrounding the individual plots. Only sites using seepage irrigation (i.e. maintenance of water table at specific depth below the soil surface with no distinct water additions to the soil surface) will be in the soil pH moderation project and thus irrigation scheduling will not be a factor for sample collection scheduling. Additional ditch water samples will be collected within 72 hours of a 1.25 cm rainfall event. Rainfall will be monitored using the Florida Automated Weather Network station located at the SWFREC in Immokalee. These rainfall data will be confirmed using on-site weather stations. The rainfall amount of 1.25 cm is used because the soil in a raised bed contains

15 to 20 cm of soil. At field capacity (~0.1 cm water cm^{-1} soil) the soil in the raised bed would be 1.5 to 1.0 cm, thus a 1.25 cm rain would be the minimum rainfall required to completely displace the water held in the raised bed and leach S from the beds. Procedures used to consistently collect representative surface water and soil samples were taken from Florida Department of Environmental Protection Standard Operating Procedures 001/01 FS2100 (FS2100) and FS3000 (FS3000), respectively. Sample collections were performed so that samples are neither contaminated nor altered from improper handling and analysis using procedures found in Chapter 62-160.210, F.A.C. (Chapter 62-160.210) and Chapter 62-160.320, F.A.C (Chapter 62-160.320), respectively.

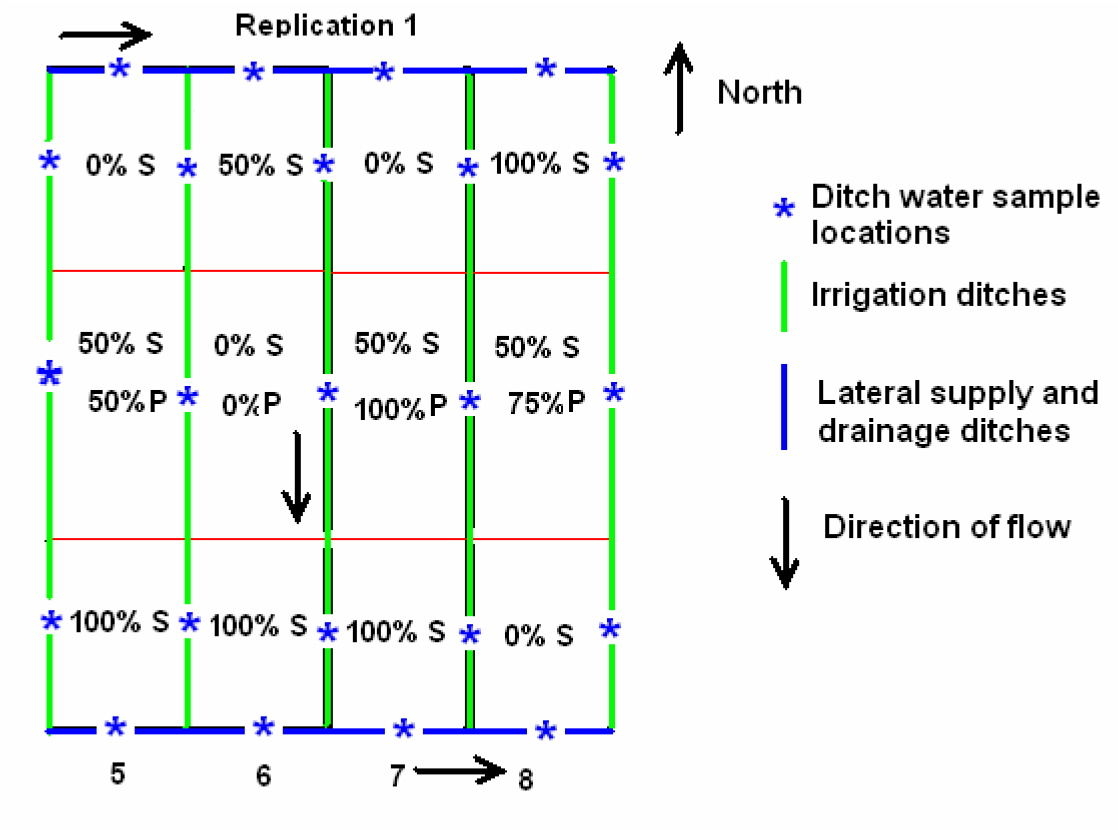


Figure. 13. Diagram of surface water sample locations (*) in shallow irrigation ditches (green) and deep lateral supply and drainage ditches (blue).

Soil samples will be collected using procedures outlined in FS 3000 to ensure that the collected samples are neither altered nor contaminated by sampling and handling techniques. Precautions in section 2 of FS 3000 will be followed to ensure a representative sample (e.g. representative location in the planted row, area of healthy plant growth, location not previously sampled, etc.). Sample augers will be cleaned free of soil on the inside by passing a clean chemwipe through the auger between samples as instructed in FS 1000. All samples will be composited samples for each plot. Samples within each plot from each selected soil depth will be placed into the sample container to avoid contamination (section 4, FS 3000). Samples will be mixed at the lab after dried and screened.

Soil samples will be taken using procedures in FS 3100. Samples are classified as surface soil, therefore

1) Any vegetation will be removed prior to sampling.

2) Sample augers will be 3 cm diameter core samplers constructed of 316 stainless steel (Table 1000-2, FS 1000).

3) Samples will be collected and placed into 1000ml polypropylene bottles and placed on a cooler with ice until returned to the laboratory.

4) Samples will be placed in a cold room (4C) until the samples are dried and screened.

5) Specific to our sampling of soil in plastic mulch covered planting rows, a hole will be placed in the plastic prior to sampling and the hole will be sealed afterward with a length of duct tape.

Dried soils will be extracted using five common soil extractants (Mehlich 1, Mehlich 3, Olsen, ammonium bicarbonate-DTPA (AB-DTPA) and Bray).

Water sample will be collected from each ditch adjacent to the plots in the pH moderation experiment. Disturbing sediments in the area of sample collection following FS 2100 section 2.3. Water samples will be collected prior to collection of sediment samples at the bottom of each ditch bordering the plots (FS 2100 section 2.4). Shallow ditch water was assumed not to be stratified and therefore homogeneous (FS 2100 section 2.5). Samples are collected from the downstream end of the plots first and proceeding upstream (FS 2100 section 2.7). Sampling equipment and containers have conformed to FS 2100 Section 3 and follow materials detailed in Tables 1-3 of FS 1000. Manual grab samples will be taken in accordance with conditions in section 1 of FS2110. Samples will be taken within the top 12 inches of the ditch water. Care will be taken to avoid skimming the surface of the water during collection. The 20 ml polypropylene vile used for sample storage will be used in collecting each water sample and is known as a direct grab sample. This procedure reduces sample handling and potential loss of analytes or contamination of the sample from other sources (e.g. additional sampling equipment, environment, etc.). The following sampling procedures will be followed for all water sample collections:

1) An unpreserved sample vile will be submerged, opening first, into the water (Sections 1.1.1.1 and 1.1.1.2, FS 2110).

2) The vile will be inverted so that the opening is pointing up stream and close to vertical as possible without extending above the water surface (section 1.1.1.3, FS 2110).

3) Once filled, the sample vile will be pulled above the surface as quickly as possible and a small amount poured out for the addition of preservatives and sample expansion (sections 1.1.1.4-1.1.1.5, FS 2110).

4) Sample preservation will be by addition of sulfuric acid to lower pH below 2.0.. The sample vile will be inverted several times to ensure sufficient mixing (sections 1.1.1.6-1.1.1.8, FS 2110).

Anaytical Methods. Soil extracts and water samples will be analyzed for P and S using colorimetery and atomic absorption/flame spectrophotometer methods, respectively. Soil samples will be analyzed for total P (USEPA method 365.4) and water samples will analyzed for Ortho P and total P using USEPA methods 365.1 and 365.4, respectively. Since water flow from the raised bed to the ditches can not be determined unless the growing system (i.e. soil profile, raised bed and crop plant) is contained within a lysimeter, a complete mass balance of P and S can not be produced. Therefore, P and S concentrations in soil and water samples collected during this project will be used as indicators of nutrient movement from the application site (i.e. raised bed) to the surface water surrounding the field.

5.0 References

Olsen, S.M. and Simonne, E.H. 2008. Vegetable Production handbook for Florida. University of Florida, Gainesville.

Sato, S., K.T. Morgan, M. Ozores-Hampton and E.H. Simonne. 2009. Phosphorus and Potassium Spatial Distribution and P Transformation in a Sandy Soil Cropped with Tomatoes Under Seepage Irrigation. Soil Sci. Soc. Am. J. in press.

Appendix 1: Soil Classification

A1.1 Soil Science Concepts

A soil order is the most basic category of soil classification. Twelve soil orders exist in the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) Soil Taxonomy classification scheme (http://ortho.ftw.nrcs.usda.gov/osd/dat/). The soil order gives a general understanding of some physical and chemical characteristics of a soil. Orders are classified based on the parent material that formed the soil and any diagnostic horizons or layers that have formed due to weathering of the parent materials. In Florida these diagnostic horizons are formed by the eluding or leaching of materials from an upper layer of soil to a lower layer. This movement of materials is due primarily to the action of water on the parent materials over time and/or organic materials. Four *soil orders* are predominate in Florida agricultural production areas and are described below.

Entisols are sandy mineral soils low in organic matter, natural fertility, and water-holding capacity. These soils have weak or no diagnostic subsurface layers (Table 6). Entisols are designated as “young” soils and maintain much of the characteristics of the sandy marine deposit parent materials with little or no alteration over time.

Alfisols are sandy mineral soils low in organic matter in the surface layer but higher in relative natural fertility compared with Entisols. These soils contain a subsurface layer of loamy material (a mixture of mostly clay and sand with little silt) that has a relatively high water-holding capacity (Table 1). The loamy layer can cause these soils to be poorly drained, so artificial drainage is needed for agricultural production.

Spodosols are sandy mineral soils and are low in organic matter but generally higher in organic matter than Entisols and are thus higher in natural fertility in the surface layer. These soils contain an acidic subsurface hardpan composed of aluminum and iron “cemented” together with organic matter (Table 1). The hardpan imparts poor drainage to most south Florida Spodosols, thus they cannot support healthy agricultural production without an artificial drainage system.

Histisols are organic soils, thus are very high in organic matter to the underlying limestone and are high in natural fertility compared to other soils due to mineralization (Table 6). These soils have little to no diagnostic horizons or layers and are differentiated by location and depth to limestone.

The general characteristics of these soil series can differ in landscape position, slope, natural drainage, and existence and type of subsurface restrictive layer (Table 6). Essentially all soil material on which Florida crops are grown originated from marine sediments that were deposited as a result of the cyclical rise and fall of sea level through geologic time. Exceptions to this soil origin are the Histisols and limestone based soils of Dade County, The Entisols, other than the four listed in Table 6, occur on high ridges and upland plains at an elevation greater than 100 ft above mean sea level (MSL) in the Central Ridge production area. Alfisols, Spodosols, and the Entisols of south Florida occur on broad, low flat areas or in sloughs at elevations from near MSL to 100 ft elevation (Table 6). Some of the Alfisols and Spodosols can occur in depressional areas, even though they are normally located a little higher on the landscape (Table 6).

The south Florida *landscape positions* called *flatwoods, sloughs,* and *depressions* can look very similar, and can differ by as little as 6 inches in depth to the wet season water table. The following are traditional definitions of these landscape positions as used to describe Florida soils. **Flatwoods** occupy the highest positions on the landscape and are rarely under water. **Sloughs** occupy transitional areas between flatwoods and depressions, and usually have overland sheet flow of slowly moving water during the wet season. **Depressions** remain under ponded water for 6 to 12 months during the year. Most agricultural production in south Florida occurs on flatwoods soils.

Entisols are moderately well drained due to their sandy texture, relatively high elevation (Table 6). On the other hand, flatwoods Alfisols and Spodosols are poorly to very poorly drained in their natural state because although the surface texture is sandy, the sub-surface *argillic* (clay) or *spodic* (organic hardpan) layer restricts downward water flow (Table 6). These layers can be as shallow as 12 inches or as deep as 80 inches below the soil surface. The depth to the restrictive layer sometimes differentiates one soil series from another. An additional factor that contributes to poor drainage is a minimal horizontal gradient (slope). Most south Florida Alfisols and Spodosols exist on a flat landscape with relatively low elevation, so little driving force exists for surface water flow unless it is artificially provided by a network of furrows, ditches, canals, and drainage pumps. Histisols are developed as a result of accumulation and decomposition of organic matter over long periods of time. These organic soils are formed in sloughs and depressions where water logging of the accumulated organic matter does not allow for rapid decomposition.

Table 6. Typical characteristics of Entisols, Alfisols, and Spodosols in south Florida.

Soil series	Parent material	Landscape position	Slope (%)	Natural drainage	Spodic layer depth (inches)	Argillic layer depth (inches)	Can find in a landscape depression?	Can have limestone substratum?
ENTISOLS								
Basinger	Sandy marine sediment	Slough	<2	Moderately drained	---	---	Yes	No
Hallandale	Sandy marine sediment	Slough	<2	Moderately drained	---	---	Yes	No
Jupiter	Sandy marine sediment	Slough	<2	Moderately drained	---	---	Yes	No
Margate	Sandy marine sediment	Fatwoods	<2	Moderately drained	---	---	Yes	No
ALFISOLS								
Boca	Sandy and loamy marine sediment over limestone	Flatwoods	<2	Poorly drained	---	28-33	Yes	Yes
Chobee	Sandy and loamy marine sediment	Flatwoods	<2	Poorly drained	---	13-80	Yes	Yes
Holopaw	Sandy and loamy marine sediment	Slough	<2	Poorly drained	---	48-65	Yes	Yes
Malabar	Sandy and loamy marine sediment	Slough	<2	Poorly drained	---	45-80	Yes	Yes
Pineda	Sandy and loamy marine sediment	Slough	<2	Poorly drained	---	38-52	Yes	Yes
Riviera	Sandy and loamy marine sediment	Slough	<2	Poorly drained	---	23-54	Yes	Yes

				SPODOSOLS				
Immokalee	Sandy marine sediment	Flatwoods	<2	Poorly drained	36-55	---	No	No
Myakka	Sandy marine sediment	Flatwoods	<2	Poorly drained	26-60	---	Yes	No
Oldsmar	Sandy and loamy marine sediment	Flatwoods	<2	Poorly drained	38-50	50-80	Yes	Yes
Wabasso	Sandy and loamy marine sediment	Flatwoods	<2	Poorly drained	25-34	34-58	No	Yes
				HISTISOLS				
Gator	Decomposing organic matter	Slough	<2	Poorly drained	---	---	Yes	Yes
Okeelanta	Decomposing organic matter	Slough	<2	Poorly drained	---	---	Yes	Yes

A1.2 Soil Physical and Chemical Characteristics

Soil properties that influence water management include soil texture, hydraulic conductivity, water-holding capacity, and natural drainage, while nutrient management is influenced by these factors plus organic matter content, soil pH, cation exchange capacity, and coatings on sand grains. The following soil physical and chemical characteristics data were compiled from the USDA-NRCS Soil Survey of Hendry County and Web Soil Survey (www.//websoilsurvey.nrcs.usda.gov/app/websoilsurvey.aspx).

Soil texture is the relative proportion of sand, silt, and clay in a mineral soil. Texture influences how much water a soil can hold against drainage by gravity and how quickly water will drain away if it has an outlet. Florida mineral soils contain 94% or more sand in the root zone, with most of the series having 97% or more sand (Table 7). These high sand concentrations make irrigation water management extremely difficult because sands are dominated by large pores that have little capacity to hold water through capillarity. Therefore, if too much water is applied to the soil, the excess will be lost below the root zone and can induce nutrient leaching. Organic soils have little sand, silt or clay (Table 7).

Soil organic matter includes anything that was once alive, from freshly deposited plant residues to highly decomposed humus. In their native state, typical Florida soils may contain as much as 5% organic matter under grass vegetation, and somewhat less under pine and palmetto cover. Cultivated soils usually contain less organic matter than native soils due to decreased plant diversity and the use of herbicides or plastic mulches that reduce weed growth and are typically less than 3 percent organic matter (Table 7). Under well drained conditions, soil organic matter is rapidly lost as carbon dioxide by oxidation in Florida's warm and humid climate, and it is not replaced in large quantities by crop production because relatively low area is covered by plant materials at any one time. In a sandy soil, organic matter is an extremely valuable component because it provides both water and nutrient-holding capacity, and its decomposition provides recycled nutrients to plants. In general, the more chronically wet Histisol soils are, the higher its organic matter content tends to be due to poor conditions for microbial decomposition of the organic matter (Table 7).

Soil water-holding capacity is provided by the smaller pores that exist between and within the smallest fraction of soil and organic matter particles. Therefore, water-holding capacity is directly related to the amount of silt, clay and organic matter present. Since most Florida mineral soils contain only minimal amounts of these components, their water-holding capacities are rarely greater than 1 inch per foot of soil depth, and are often less than 0.75 inches per foot (Table 7). However, organic soils are relatively high in water holding capacity due to the high organic matter content of these soils.

Soil pH affects the availability of plant macronutrients nutrients including phosphorus, calcium, magnesium, and the micronutrients. Most soils used for crop production are acidic in their native state, so they usually require liming prior to planting and may require additional liming over time and thus have rather broad range of pH (Table 7). The optimum soil pH range for crops is 6.0 to 6.5. The pH of Florida soils can change rapidly as a result of chemical reactions caused by lime or fertilizer applications. An exception to this tenet is a *calcareous* soil. Some of the Alfisols can be calcareous due to a substratum of natural calcium carbonate rock or shell that dominates their chemistry. The pH of a calcareous soil remains relatively constant around 8.3, soils with less amounts of carbonate will have pH in the 7.0 to 8.2 range.

Table 7. Typical root zone† soil physical and chemical properties for common soil series found in south Florida soils.

Soil series	Physical Properties							Chemical Properties	
	Soil texture ‡			Organic matter	Hydraulic conductivity	Water-holding capacity		pH	Cation exchange capacity
	Sand	Silt	Clay						
	--------------%--------------				inches/hr	inches/foot	inches/root zone depth		meq/100 g
ENTISOLS									
Basinger	98.5	0.5	1.0	0.5-1.0	8-17	0.4-0.8	0.6-1.2	3.6-7.3	2-4
Hallandale	97.5	0.5	1.0	0.2-0.55	10-15	0.4-1.0	0.4-1.0	4.5-6.7	1-2
Jupiter	98.5	0.5	2.0	0.1-0.3	10-15	0.2-0.7	0.2-0.8	5.8-7.5	2-3
Margate	97.5	0.25	1.25	0.1-0.4	8-15	0.2-1.7	0.1-3.1	4.5-6.0	2-4
ALFISOLS									
Boca	94.0	3.0	3.0	1.0-2.5	3-20	0.4-0.9	0.6-1.4	5.1-8.4	6-10
Chobee	93.5	2.5	1.0	2.5-3.5	1-3	0.9-1.8	0.9-3.0	5.3-7.3	10-16
Holopaw	94.0	3.5	2.5	1.0-2.5	1-10	0.7-1.2	1.1-1.8	5.1-7.3	3-7
Malabar	98.0	0.5	1.0	0.2-0.5	6-10	0.2-1.0	0.3-0.8	5.5-6.8	0.1-1
Pineda	96.0	2.5	1.5	0.5-2.0	2-26	0.3-0.6	0.5-0.9	5.6-7.3	2-6
Riviera	96.5	2.0	1.5	0.5-2.0	3-18	0.6-1.0	0.9-1.5	4.5-6.5	2-6
SPODOSOLS									
Immokalee	98.5	1.0	0.5	1.0-2.0	6-20	0.4-0.8	0.6-1.2	3.6-6.0	2-6
Myakka	98.5	1.0	0.5	1.0-2.0	5-17	0.4-0.8	0.6-1.2	3.6-6.5	2-6
Oldsmar	98.0	1.5	0.5	1.0-2.0	5-28	0.3-0.6	0.5-0.9	3.6-7.3	2-6
Wabasso	97.5	1.5	1.0	1.0-2.0	2-35	0.3-0.6	0.5-0.9	4.5-7.0	2-6
HISTISOLS									
Gator	0.0	28.5	0.5	61-78	7-10	4.0-7.8	5.4-10.8	5.8-	5-8

							7.2	
Okeelanta	0.0	25.0	0.0	71-78	6-12	5.2-10.4	5.4-10.8	5.7-7.4	4-9

† Top 18 inches of soil for flatwoods Entisols, Alfisols, and Spodosols.
‡ Particle diameters – sand: 2mm to 0.05 mm; silt: 0.05 to 0.002 mm; clay: <0.002 mm.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service Soil Survey of Hendry county and Web Soil Survey (www.//websoilsurvey.nrcs.usda.gov/app/websoilsurvey.aspx).

The argillic and spodic layers of some Alfisols (Holopaw, Malabar and Pineda) and Spodosols (Immokalee, and Oldsmar), respectively, are relatively deep (Table 8). Whereas, other Alfisols (Boca, Chobee and Riviera) and Spodosols (Myakka and Wabasso) have relatively shallow argillic or spodic layers, respectively (Table 8). The chemical and physical properties of argillic and spodic layers differ substantially from the sandy surface layers (Table 8). Compared with sandy surface soil, material from an argillic layer is higher in clay, while spodic layer material is higher in organic matter. Argillic layers can be either acidic or alkaline in pH, while spodic layers are always highly acidic. In addition, water-holding and cation exchange capacities are higher in argillic or spodic layers compared with the surface layers (Table 8). The chemical properties of these restrictive layers influence the depth of the root zone, water holding characteristics near the surface and soil nutrient retention properties. Entisols and Histisols do not have these diagnostic horizons.

Table 8. Physical and chemical properties of the subsurface diagnostic layers of typical Alfisols and Spodosols found in south Florida flatwoods.

Soil Series	**Layer**	**Physical Properties**						**Chemical Properties**	
		Soil texture‡			**Organic matter**	**Hydraulic conductivity**	**Water-holding capacity**	**pH**	**Cation exchange capacity**
		Sand	**Silt**	**Clay**					
		-------------%--------------				inches/hr	inches/foot		meq/100 g
				ALFISOLS					
Boca	Argillic	81.0	4.0	15.0	0.3-1.2	0.3-1.0	1.2-1.8	5.1-8.4	16-24
Chobee	Argillic	65.0	13.4	21.2	0.2-0.5	0.1-0.3	1.4-2.6	5.4-7.8	10-20
Holopaw	Argillic	80.0	7.0	13.0	0.2-0.4	0.1-0.4	1.8-2.4	5.1-8.4	11-22

Malabar	Argillic	87.5	10.2	2.0	0.2-0.5	0.1-0.3	1.4-2.1	5.6-8.1	10-20
Pineda	Argillic	77.0	3.5	19.5	0.1-0.3	0.1-0.2	1.2-1.8	5.1-8.4	4-18
Riviera	Argillic	77.0	4.5	18.5	0.2-0.3	0.1-0.2	1.4-1.8	6.1-8.4	9-24
					SPODOSOLS				
Immokalee	Spodic	95.0	2.5	2.5	2.5-3.8	0.1-14	1.2-3.0	3.3-4.4	14-25
Myakka	Spodic	90.5	5.0	4.5	2.8-4.5	0.2-11	1.2-2.4	4.0-4.7	13-18
Oldsmar	Spodic	92.0	3.5	4.5	1.8-3.0	0.1-15	1.2-1.8	4.7-5.3	7-15
Wabasso	Spodic	93.0	2.0	5.0	1.8-2.1	1.0-12	1.2-1.8	4.7-5.2	5-12

‡ Particle diameters--sand: 2mm to 0.05 mm; silt: 0.05 to 0.002 mm; clay: <0.002 mm.
Source: U.S. Department of Agriculture, Natural Resources Conservation Service Soil Survey of Hendry county and Web Soil Survey (www.//websoilsurvey.nrcs.usda.gov/app/websoilsurvey.aspx).

Entisols, Alfisols and Spodosols used for crop production in the Florida flatwoods must be leveled with a slight slope to perimeter ditches provide artificial drainage. Precise shaping of a field directs drainage water to its designated outlet, and bedding allows excessive rainfall to drain quickly by means of surface flow to avoid ponding of water after rainfall events. The topsoil layer of native mineral soils is usually no more than 6 to 8 inches thick. Below this layer is the first subsoil layer, which is usually white or light gray sand that is extremely low in fertility and water-holding capacity. Occasionally, land leveling removes all of the topsoil from a higher part of the field and transports it to a lower part, leaving the light-colored sandy subsoil as the new surface. Crop growth and productivity in these “scraped” areas is usually poor. If drip or other low volume irrigation is used, land leveling may not be needed as long as drainage system is effective in removing surface water.

A1.3 Soil Series Descriptions

The following descriptions of soil series found in south Florida were extracted from the USDA-NRCS website. The descriptions below are of specific soils sampled in south Florida and are representative of those soils in the C-139 Basin. The descriptions are by soil diagnostic horizon and are listed as A, E, B, C, R or O. The A diagnostic horizon is the “plow layer” and is the surface most layer of soil, typically disturbed by mixing of the soil over time and contains the highest levels of organic matter due to plant growth at the surface. The E horizons are eluivated soils that differ from the soil parent material due to leaching of organic matter and smaller soil fractions (slit and clay) over time. The B horizons are layers of soil where soil materials have accumulated over time. Bw horizons are layers of accumulations of clay but not at a high enough level to be called an argillic horizon that can be found in some Entisols. Bt horizons are soil layers in Alfisols and some Spodosols where sufficient slit and clay have accumulated great enough (>2%) to be called argillic horizons. Bh horizons are the spodic layers with an accumulation of organic matter, Al and Fe over time found in all Spodosols. The C horizons are soil layers that remain typical of the parent material from which the soil was formed. The R horizon is a layer of rock underlying the soil near the soil surface. In Florida this rock material is typically limestone. The O horizon is only found in Histisols in Florida and is accumulated organic materials near the surface. Photographs of selected soil series have been provided to illustrate these diagnostic horizons.

A1.3.1 Entisols

A1.3.1.1 Basinger Series

The Basinger series consists of very deep, poorly drained and very poorly drained, rapidly permeable soils in sloughs, depressions, low flats, and poorly defined drainageways. They formed in sandy marine sediments. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Siliceous, hyperthermic Spodic Psammaquents

Ag--0 to 2 inches; very dark gray rubbed, fine sand; weak fine granular structure; very friable; many fine roots; many uncoated light gray, sand grains; strongly acid; clear smooth boundary.

Eg--2 to 18 inches; light gray fine sand; single grained; loose; few fine and medium roots; common medium distinct very dark grayish brown, streaks along root channels; very strongly acid; clear wavy boundary.

Bh/Eg--18 to 36 inches; brown (Bh) and light brownish gray, (E) fine sand; common medium distinct dark reddish brown, weakly cemented bodies; common medium distinct very dark grayish brown, streaks along root channels; single grained; loose; few fine and medium roots; many uncoated sand grains in Bh portion; few fine faint yellowish brown masses of iron accumulation; strongly acid; gradual wavy boundary.

Cg--36 to 80 inches; light brownish gray fine sand; single grained; loose; many uncoated sand grains; strongly acid.

Drainage and permeability: Poorly and very poorly drained; rapid permeability.

Use and vegetation: Most areas of Basinger soil that are cleared are used for rangeland. With water control, they are used for winter truck crops and tame pasture. The natural vegetation consists of waxmyrtle, St. Johnswort, maidencane, pineland threeawn, cypress, slash pine, longleaf pine, pond pine, and other water tolerant plants.

A1.3.1.2 Hallandale Series

The Hallandale series consists of shallow, poorly and very poorly drained, rapidly permeable soils formed in thin deposits of marine sandy materials over limestone. They occur on broad low flats, sloughs, shallow depressions, and adjacent tidal areas in Peninsular Florida. They are saturated during the summer rainy season and after periods of heavy rainfall in other seasons. Slopes are less than 2 percent.

Taxonomic class: Siliceous, hyperthermic Lithic Psammaquents

A--0 to 4 inches; black fine sand; weak fine granular structure; loose; many medium and fine roots; strongly acid; clear smooth boundary.

E--4 to 10 inches; light brownish gray fine sand; few faint very dark gray mottles and streaks along root channels; single grained; loose; few fine roots; cyclic thickness is 2 to 8 inches; medium acid; gradual wavy boundary.

Bw1--10 to 14 inches; brown fine sand; few faint very dark grayish brown mottles; single grained; loose; many sand grains uncoated; some thinly or partly coated, few are well coated; cyclic thickness is 0 to 20 inches; medium acid; gradual wavy boundary.

Bw2--14 to 16 inches; yellowish brown fine sand, and very pale brown decomposed limestone fragments; common medium distinct grayish brown and yellowish brown mottles; single grained; loose; slight increase in clay content; common uncoated sand grains; discontinuous and cyclic thickness is 0 to 8 inches; neutral; abrupt irregular boundary.

2R--16 inches; hard, fractured limestone that can be excavated with power equipment.

Drainage and permeability: Poorly to very poorly drained; slow to ponded runoff; rapid permeability. In depressional areas the soil is covered by water up to 6 to 9 months each year. In other undrained areas the water table is within 12 inches of the surface for 4 to 5 months during most years, and within a depth of 12 to 20 inches most of the rest of the year. In drained areas, the water table fluctuates with the water level in canals and ditches through the solution holes in the limestone. It is below the soil most of the time in drained areas. Slough areas are covered with shallow slow moving water for about 7 days to one month. Tidal areas are flooded with tide water almost daily.

Use and vegetation: In their native state, most of these soils are used for range land and tame pasture. Native vegetation consists of pineland threeawn, paspalum spp., bluejoint panicum, blue maidencane, bluestem, scattered cypress, saw palmettos, and slash pine. In tidal areas the vegetation includes seashore saltgrass, needlegrass rush, Jamaica sawgrass, smooth cordgrass and saltwort.

A1.3.1.3Jupiter Series

The Jupiter series consists of shallow, poorly and very poorly drained, rapidly permeable soils formed in a thin bed of sandy marine sediments deposited over limestone. They are on broad low flats, low hammocks, and in poorly defined drainageways. Slopes are 2 percent or less.

Taxonomic class: Sandy, siliceous, hyperthermic Lithic Endoaquolls

Ap--0 to 9 inches; black fine sand; weak fine granular structure; very friable; many fine and medium roots; many uncoated sand grains; slightly acid; clear wavy boundary.

A--9 to 11 inches; black fine sand; weak fine granular structure; very friable; few medium and fine roots; many fine and medium distinct dark grayish brown mottles and streaks, few coarse distinct light brownish gray mottles; neutral; clear wavy boundary.

C--11 to 14 inches; light gray fine sand; single grained; loose; few fine roots; few fine distinct black mottles or streaks in thin root mat at contact with limestone; mildly alkaline; abrupt irregular boundary.

2R--14 to 16 inches; hard fractured limestone bedrock containing solution holes filled with marl and brownish fine sand.

Drainage and permeability: Jupiter soils are poorly and very poorly drained. Permeability is rapid. Runoff is slow. In undrained areas the soil is covered by shallow water for about 7 days to 1 month during most years. The water table is at depths of less than 18 inches for periods of 2 to 4 months. In drained areas the water table fluctuates with the water level of the drainage canals and ditches through the porous limestone and is in the limestone most of the time.

Use and vegetation: Most areas are used for range or wildlife. Some areas are used for tame pasture. Natural vegetation on the low hammocks consists of cabbage palm, laurel oak, water oak, scattered south Florida slash pine, red mulberry, and redbay with an understory of marlberry, waxmyrtle, wild coffee, greenbriars, ferns, longleaf uniola, Eastern gamagrass, chalky bluestem, maidencane, and switchgrass. The wetter area vegetation is dominated by cabbage palm, pondcypress, red maple, dahoon holly, water oak, and strangler fig with an understory of pickerelweed, arrowhead, ferns, swamp dogwood, lizards tail, maidencane, and switchgrass.

A1.3.1.4 Margate Series

The Margate series consists of poorly drained, rapidly permeable soils that formed in sandy marine sediments of variable thickness over fractured limestone. The water table is near the surface during wet periods. Slope is less than 2 percent.

Taxonomic class: Siliceous, hyperthermic Mollic Psammaquents

Ap--0 to 8 inches; very dark gray fine sand; single grained; loose; many medium and fine roots; very strongly acid; clear, smooth boundary.

E--8 to 16 inches; light brownish gray fine sand; few streaks of very dark gray in root channels; single grained; loose; few fine roots; medium acid; gradual wavy boundary.

Bw1--16 to 26 inches; brown fine sand; few streaks of black in root channels; single grained; loose; few medium and fine roots; few uncoated sand grains, some are partly coated; slightly acid; gradual wavy boundary.

Bw2--26 to 28 inches; brown fine sand; common medium distinct black mottles; single grained; loose; few medium and fine roots; slight increase in clay content; many sand grains partly coated; common clean sand grains; neutral; abrupt irregular boundary.

C--28 to 32 inches; brown gravelly fine sand; single grained; loose; about 50 percent very pale brown fragments of limestone; moderately alkaline; abrupt irregular boundary.

2R--32 inches; hard fractured limestone that can be excavated with power equipment.

Drainage and permeability: Poorly drained; very slow runoff; rapid permeability. In undrained areas, the water table is within l0 inches of the soil surface for 2 to 4 months or shallow water covers the soil for l to 4 months during most years. In drained areas, the water table fluctuates with the water level in the canals and ditches through the solution holes in the limestone.

Use and vegetation: Some areas with adequate water control are used for improved pasture grasses, vegetables, sugarcane and citrus. In their native state, these soils are used for rangeland

and as a wildlife habitat. Native vegetation consists of waxmyrtle, pineland threeawn, St. Johnswort, and scattered cypress.

A1.3.2 Alfisols

A1.3.2.1 Boca Series

The Boca series consists of moderately deep, poorly drained and very poorly drained, moderately permeable soils in low broad flats, poorly defined drainageways and depressions of the flatwoods and adjacent tidal flats. They formed in sandy and loamy marine sediments deposited over limestone bedrock. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 1 percent.

Taxonomic class: Loamy, siliceous, superactive, hyperthermic Arenic Endoaqualfs

Ap--0 to 7 inches; dark gray fine sand; single grained; loose; many fine and medium roots; moderately acid; clear wavy boundary.

E--7 to 13 inches; light gray fine sand; many medium distinct very dark gray mottles; single grained; loose; moderately acid; clear wavy boundary.

EB--13 to 25 inches; very pale brown fine sand; single grained; loose; few fine distinct brownish yellow and common fine distinct yellowish brown masses of iron accumulation; neutral; abrupt smooth boundary.

Btg--25 to 32 inches; grayish brown sandy clay loam; weak medium subangular blocky structure; friable; common fine and medium distinct yellowish brown masses of iron accumulation; moderately alkaline; abrupt irregular boundary.

2C--32 to 34 inches; decomposed white to yellowish brown rock, marl, sandy clay loam and sand mixed with limestone rock fragments; massive in place; friable; moderately alkaline; abrupt irregular boundary.

2R--34 inches; limestone bedrock. This layer has two solution holes approximately 15 inches in diameter and extending from 40 to 82 inches below the surface. The solution holes contain sandy clay loam.

Drainage and permeability: Poorly drained and very poorly drained; moderate permeability.

Use and vegetation: Most areas of Boca soils are used for rangeland. With adequate water control, some areas are used for truck crops, citrus, and pasture. Native vegetation consists of gallberry, sawpalmetto, cabbage palmettos, slash pine, and an understory of pineland.

A1.3.2.2 Chobee Series

The Chobee series consists of very deep, very poorly drained, slowly to very slowly permeable soils in depressions, flats, and occasionally on river flood plains in the lower Coastal Plain. They formed in thick beds of loamy marine sediments. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Fine-loamy, siliceous, superactive, hyperthermic Typic Argiaquolls

Ap--0 to 5 inches; black loamy fine sand; weak fine subangular blocky structure; friable; many fine and medium roots; neutral; gradual wavy boundary.

Btg1--5 to 17 inches; black sandy loam; moderate medium subangular blocky structure; slightly sticky and slightly plastic; common fine and medium roots; few faint clay films on sand grains; neutral; clear wavy boundary.

Btg2--17 to 28 inches; very dark gray sandy clay loam; moderate medium subangular blocky structure; slightly sticky and slightly plastic; few fine roots; common faint clay films on ped faces; few fine prominent yellowish brown and strong brown masses of iron accumulation in the matrix and along root channels; slightly acid; gradual wavy boundary.

Btg3--28 to 35 inches; dark grayish brown sandy loam; weak medium subangular blocky structure; slightly sticky and plastic; few fine roots; common faint clay films on ped faces and sand grains; common fine prominent yellowish brown masses of iron accumulation; slightly acid; clear wavy boundary.

Btg4--35 to 46 inches; gray sandy loam; medium fine subangular blocky structure; slightly sticky and slightly plastic; few fine prominent yellowish brown masses of iron accumulation; common medium distinct dark gray areas of iron depletions; slightly acid; gradual smooth boundary.

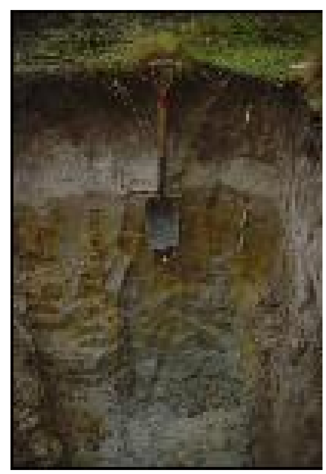
BCg--46 to 54 inches; gray loamy fine sand; weak fine subangular blocky structure; slightly sticky; slightly acid; gradual wavy boundary.

Cg--54 to 80 inches; greenish gray loamy fine sand; massive; slightly sticky; moderately alkaline.

Drainage and permeability: Very poorly drained; slow to very slow permeability.

Use and vegetation: The drained areas are used principally for citrus, pasture, and range. Most of the soils remain in their natural state and have vegetation consisting of pickerelweed, lilies, sawgrass, and scattered swamp maples in treeless areas. Some areas have a growth of ash, gum, maple, and cypress.

A1.3.2.3 Holopaw Series



The Holopaw series consists of deep and very deep, poorly and very poorly drained soils formed in sandy marine sediments. These soils are rapidly permeable in the A and E horizons and moderately or moderately slowly permeable in the B horizon. These soils are on low lying flats, in poorly defined drainages or depressional areas. Slopes range from 0 to 2 percent.

Taxonomic class: Loamy, siliceous, active, hyperthermic Grossarenic Endoaqualfs

A1--0 to 2 inches; very dark gray sand; weak fine granular structure; very friable; many fine and medium roots; color is mixture of light gray sand grains and black organic matter; slightly acid; gradual smooth boundary.

A2--2 to 7 inches; dark gray sand; weak fine granular structure; very friable; many fine roots; slightly acid; gradual smooth boundary.

Eg1--7 to 18 inches; grayish brown sand; common medium distinct yellowish brown mottles and many fine and medium faint gray to light gray streaks; single grained; loose; common fine roots; slightly acid; gradual smooth boundary.

Eg2--18 to 35 inches; coarsely mottled gray and grayish brown sand; few fine faint very pale brown mottles and few medium distinct black streaks along root channels; single grained; loose; few fine roots; slightly acid; gradual smooth boundary.

Eg3--35 to 45 inches; gray sand; single grained; loose; few fine roots; neutral; abrupt wavy boundary.

Btg--45 to 58 inches; gray sandy loam; common fine faint light gray and common medium distinct dark yellowish brown mottles; weak medium subangular blocky structure; friable; few fine roots; clay bridging between sand grains; mildly alkaline; gradual wavy boundary.

BCg--58 to 62 inches; gray sandy loam; few medium distinct dark yellowish brown mottles; massive; friable; common pockets and streaks of loamy sand and sandy clay loam; mildly alkaline; gradual wavy boundary.

Cg--62 to 71 inches; gray loamy sand; massive; friable; common pockets and lenses of sand; mildly alkaline.

Drainage and permeability: Holopaw soils are poorly and very poorly drained. Runoff is slow. Permeability is moderately slow. A water table is within 12 inches of the soil surface for 2 to 6 months during most years. Depressional areas are ponded for more than 6 months during most years

Use and vegetation: Large areas of Holopaw soils are used for range. With adequate water control, these soils are used for citrus, truck crops, and tame pasture. Native vegetation is scattered slash and pond pine, cabbage and sawpalmettos, scattered cypress, myrtle, sand cordgrass, and pineland threeawn.

A1.3.2.4 Malabar Series

The Malabar series consists of very deep, poorly to very poorly drained soils in sloughs, shallow depressions, and along flood plains. They formed in sandy and loamy marine sediments. Near the type location, the mean annual temperature is about 73 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Loamy, siliceous, active, hyperthermic Grossarenic Endoaqualfs

A--0 to 5 inches; dark grayish brown sand; weak fine granular structure; very friable; many fine and few medium roots; slightly acid; gradual smooth boundary.

E1--5 to 11 inches; light brownish gray sand; single grained; loose; few fine and medium roots; common medium distinct yellowish brown masses of iron accumulation and strong brown pore linings along some root channels; brownish colors are iron coatings on sand grains; slightly acid; gradual wavy boundary.

E2--11 to 14 inches; pale brown sand; single grained; loose; few fine roots; common medium faint yellowish brown masses of iron accumulation and light brownish gray iron depletions; moderately acid; clear wavy boundary.

Bw1--14 to 18 inches; yellow sand; weak fine granular structure; very friable; few fine roots; many uncoated sand grains; iron coatings on sand grains; common coarse distinct yellow and strong brown masses of iron accumulation and common coarse distinct light brownish gray iron depletions; moderately acid; clear wavy boundary.

Bw2--18 to 24 inches; strong brown sand; weak medium granular structure; very friable; iron coatings on sand grains; common coarse faint yellowish brown masses of iron accumulation and common medium and coarse distinct light gray iron depletions; moderately acid; clear wavy boundary.

Bw3--24 to 35 inches; pale brown sand; single grained; loose; iron coatings on sand grains; common coarse faint yellowish brown masses of iron accumulation and common medium and coarse faint light gray iron depletions; moderately acid; clear wavy boundary.

E'--35 to 45 inches; about 50 percent olive gray and about 50 percent dark grayish brown sand; single grained; loose; sand grains uncoated; many medium and coarse faint light gray iron depletions; slightly acid; abrupt wavy boundary.

Btg--45 to 54 inches; gray sandy loam; weak coarse subangular blocky structure; very friable; sand grains coated and bridged with clay; few medium distinct dark yellowish brown pore linings along ped faces and some root channels; neutral; gradual wavy boundary.

BCg--54 to 61 inches; gray sandy loam; common coarse pockets of sand and sandy clay loam; massive; friable; few medium distinct dark yellowish brown pore linings along ped faces and some root channels; neutral; clear wavy boundary.

Cg--61 to 65 inches; grayish brown sand; single grained; loose; few coarse pockets of gray sandy clay loam; neutral.

Drainage and permeability: poorly and very poorly drained; rapid permeability in the A, E, Bw and Cg, horizons, and slow to very slow permeability in the Btg horizon.

Use and vegetation: Large areas of the Malabar soils are used extensively for range. Some areas are used for citrus crops, truck crops, and improved pasture with adequate water control. Native vegetation consists of scattered slash pine, cypress wax myrtle, cabbage palm, pineland threeawn, and maidencane. In depressions, the vegetation is dominantly St. Johnswort or maidencane.

A1.3.2.5 Pineda Series

The Pineda series consists of deep and very deep, poorly and very poorly drained, very slowly permeable soils in depressions, low hammocks, poorly defined drainageways, broad low flats, and flood plains. They formed in thick beds of sandy and loamy marine sediments on the lower Coastal Plain. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Loamy, siliceous, active, hyperthermic Arenic Glossaqualfs

A--0 to 1 inch; black fine sand; single grained; loose; many fine and medium roots, few coarse roots; moderately acid; clear smooth boundary.

E--1 to 5 inches; very pale brown fine sand; single grained; loose; many fine and medium roots; moderately acid; clear wavy boundary.

Bw1--5 to 13 inches; brownish yellow fine sand; single grained; loose; strongly acid; clear wavy boundary.

Bw2--13 to 24 inches; reddish yellow fine sand; single grained; loose; moderately acid; clear wavy boundary.

E'--24 to 36 inches; light gray fine sand; single grained; loose; few fine distinct brownish yellow masses; moderately acid; abrupt irregular boundary.

B/E--36 to 54 inches; light brownish gray fine sandy loam (Btg) with 20 percent light gray vertical tongues or intrusions of fine sand (E) 3 to 10 inches in length and 0.5 inch to 2 inches in width; weak fine subangular blocky structure; slightly sticky and slightly plastic; sandy intrusions are single grained and loose; neutral; abrupt irregular boundary.

Cg--54 to 80 inches; light gray fine sand; single grained; loose; slightly acid.

Drainage and permeability: Poorly or very poorly drained; very slow permeability.

Use and vegetation: Areas of Pineda soils that are drained are used for citrus, truck crops, and tame pasture. In their undrained state, these soils are used for range. Natural vegetation consists of slash pine, cypress, myrtle, cabbage palm, blue maidencane, chalky bluestem, bluepoint panicum, sedges, pineland threeawn, and sand cordgrass.

A1.3.2.6 Riviera Series

The Riviera series consists of very deep, poorly drained, very slowly permeable soils on broad, low flats and in depressions in the Lower Coastal Plain. They formed in stratified sandy and loamy marine sediments on the Lower Coastal Plain. Near the type location, the mean annual temperature is about 75 degrees F., and the mean annual precipitation is about 62 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Loamy, siliceous, active, hyperthermic Arenic Glossaqualfs

A--0 to 6 inches; dark grayish brown sand; weak fine crumb structure; very friable; moderately acid; gradual smooth boundary.

E--6 to 28 inches; very pale brown sand; single grained; loose; moderately acid; abrupt irregular boundary.

Bt/E--28 to 36 inches; grayish brown sandy clay loam (Bt); common coarse distinct very pale brown tongues of sand (E); weak coarse subangular blocky structure; slightly sticky; sand grains coated and bridged with clay; common coarse faint olive brown masses of iron accumulation; slightly alkaline; clear wavy boundary.

Btg--36 to 42 inches; grayish brown sandy clay loam; weak coarse subangular blocky structure; slightly sticky; sand grains coated and bridged with clay; common coarse faint olive brown masses if iron accumulation; slightly alkaline; abrupt smooth boundary.

2C--42 to 62 inches; gray sand and shell fragments; single grained; loose; moderately alkaline.

Drainage and permeability: Poorly and very poorly drained; very slow permeability.

Use and vegetation: When drained, Riviera soils are used for citrus, winter truck crops, and improved pasture. Native vegetation consists of slash pine, cabbage, and sawpalmetto, scattered cypress, maidencane, and pineland.

A1.3.3 Spodosols

A1.3.3.1 Immokalee series

The Immokalee series consists of deep and very deep, poorly drained and very poorly drained soils that formed in sandy marine sediments. They occur on flatwoods and in depressions of Peninsular Florida. Slopes are dominantly 0 to 2 percent but range to 5 percent.

Taxonomic class: Sandy, siliceous, hyperthermic Arenic Alaquods

A--0 to 6 inches; very dark gray fine sand; mixture of organic matter and light gray sand grains has a salt-and-pepper appearance when dry; weak fine crumb structure; very friable; many fine and medium roots; very strongly acid; clear smooth boundary.

E1--6 to 12 inches; gray fine sand, many coarse faint gray and few coarse faint dark gray mottles; single grained; loose; common fine and medium roots; very strongly acid; gradual wavy boundary.

E2--12 to 35 inches; white fine sand; single grained; loose; few fine, medium, and coarse roots; few fine very dark gray streaks in root channels; very strongly acid; wavy boundary.

Bh1--35 to 43 inches; black fine sand; lower 2 inches grades to dark reddish brown; weak fine granular structure; friable common fine and medium roots; very strongly acid; clear wavy boundary.

Bh2--43 to 54 inches; dark reddish brown fine sand; single grained; loose; few fine and medium roots; common fine and medium dark reddish brown; few fine distinct gray sand lenses and pockets; very strongly acid; gradual wavy boundary.

BC--54 to 72 inches; dark brown fine sand, few fine faint dark brown, pale brown, and light gray mottles; single grained; loose; strongly acid.

Drainage and permeability: Immokalee soils are poorly drained or very poorly drained. Runoff is slow or ponded. Permeability is rapid or very rapid in the A and E horizons and moderate or moderately rapid in the Bh horizon. The water table is at depths of 6 to 18 inches for 1 to 4 months during most years. It is between depths of 18 inches to 36 inches for 2 to 10 months during most years. It is below 60 inches during the dry periods of most years. Depressional areas are covered with standing water for periods of 6 to 9 months or more in most years.

Use and vegetation: Principal vegetation is longleaf and slash pines and undergrowth of sawpalmetto, gallberry, waxmyrtle, and pineland threeawn. In depressions, water tolerant plants such as cypress, loblollybay gorodonia, red maple, sweetbay, maidencane, blue maidencane, chalky bluestem, sand cordgrass, and bluejoint panicum are more common. Most areas are used for range and forest. Large areas with adequate water management are used for citrus, tame pasture, and truck crops.

A1.3.3.2 Myakka Series

The Myakka series consists of deep and very deep, poorly to very poorly drained soils formed in sandy marine deposits. These soils are on flatwoods, high tidal areas, flood plains, depressions, and gently sloping to sloping barrier islands. They have rapid permeability in the A horizon and moderate or moderately rapid permeability in the Bh horizon. Slopes range from 0 to 8 percent.

Taxonomic class: Sandy, siliceous, hyperthermic Aeric Alaquods

A--0 to 6 inches; black crushed, sand; weak fine granular structure; very friable; matted with many fine and medium roots; strongly acid; clear smooth boundary.

E--6 to 20 inches; white sand; common fine faint vertical dark grayish brown, dark gray, and gray streaks along root channels; single grained; loose; common fine and medium roots; strongly acid; abrupt wavy boundary.

Bh1--20 to 24 inches; black sand; weak coarse subangular blocky structure; many fine and medium roots; sand grained coated with organic matter except for common fine pockets of uncoated sand grains; very strongly acid; clear wavy boundary.

Bh2--24 to 32 inches; dark reddish brown sand; common coarse faint vertical tongues of very dark brown, weak coarse subangular blocky structure; many fine and medium roots; sand grains coated with organic matter; very strongly acid; clear smooth boundary.

Bh3--32 to 36 inches; dark reddish brown sand; weak fine granular structure; very friable; few fine roots; sand grains coated with organic matter; strongly acid; clear wavy boundary.

C/B--36 to 56 inches; dark brown sand (C); weak fine granular structure; very friable; few fine roots; common medium distinct dark reddish brown, Bh bodies; strongly acid; clear wavy boundary.

C--56 to 85 inches; dark grayish brown sand; single grained; loose; few fine roots; strongly acid.

Drainage and permeability: Myakka soils are poorly to very poorly drained. They have slow internal drainage and slow to ponded runoff. Permeability is rapid in the A and E horizons and moderate or moderately rapid in the Bh horizon. The water table is at depths of less than 18 inches for 1 to 4 months duration in most years and recedes to depths of more than 40 inches during very dry seasons. Depressional areas are covered with standing water for periods of 6 to 9 months or more in most years.

Use and vegetation: Most areas are used for commercial forest production or native range. Large areas with adequate water control measures are used for citrus, improved pasture, and truck crops. Native vegetation includes longleaf and slash pines with an undergrowth of sawpalmetto, running oak, inkberry, waxmyrtle, huckleberry, chalky bluestem, pineland threeawn, and scattered fetterbush.

A1.3.3.3 Oldsmar Series

The Oldsmar series consists of very deep, poorly drained and very poorly drained soils in flats and depressions of Peninsular Florida. They formed in sandy marine sediments overlying loamy materials. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Sandy, siliceous, hyperthermic Alfic Arenic Alaquods

A--0 to 6 inches; very dark gray sand; weak fine granular structure; very friable; many fine roots, common medium roots; very strongly acid; clear smooth boundary.

E1--6 to 32 inches; light gray sand; single grained; loose; common medium roots; strongly acid; clear wavy boundary.

E2--32 to 38 inches; grayish brown sand; single grained; loose; common medium distinct very dark grayish brown organic bodies; very strongly acid; clear wavy boundary.

Bh1--38 to 40 inches; black sand; single grained; loose; sand grains are well coated with organic matter; very strongly acid; clear wavy boundary.

Bh2--40 to 50 inches; dark reddish brown sand; single grained; loose; very strongly acid; clear wavy boundary.

Btg1--50 to 70 inches; dark grayish brown sandy clay loam; massive in place, parts to weak fine subangular blocky structure; friable; sand grains are coated and bridged with clay; slightly acid; clear wavy boundary.

Btg2--70 to 80 inches; olive gray sandy clay loam; massive in place, parts to weak fine subangular blocky structure; friable; sand grains are coated and bridged with clay; common medium distinct grayish brown areas of iron depletions; slightly alkaline.

Drainage and permeability: Poorly drained on flatwoods and very poorly drained in depressions. Rapidly permeable in the A and E horizons, moderately rapid to moderately slow in the Bh horizon, and slow to very slow permeability in the Bt horizon.

Use and vegetation: Most areas of Oldsmar soils remain in native vegetation. Areas with water control are used for citrus, truck crops, and tame pasture. Native vegetation consists of cabbage palmetto, sawpalmetto, live oak, slash pine, with an undergrowth of laurel, wax myrtle, and pineland threeawn. In depressions the trees are cypress, blackgum, pond pine, loblolly bay, red maple, and sweetbay. Other plants included maidencane, blue maidencane, chalky bluestem, sand cordgrass, and bluejoint panicum.

A1.3.3.4 Wabasso Series

The Wabasso series consists of deep or very deep, very poorly and poorly drained, very slowly and slowly permeable soils on flatwoods, flood plains, and depressions in Peninsula Florida. They formed in sandy and loamy marine sediments. Near the type location, the mean annual temperature is about 72 degrees F., and the mean annual precipitation is about 55 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Sandy over loamy, siliceous, active, hyperthermic Alfic Alaquods

A--0 to 4 inches; very dark gray fine sand; mixture of organic matter and light gray sand grains has a salt-and-pepper appearance; weak fine crumb structure; very friable; many fine and medium roots; very strongly acid; clear smooth boundary.

E--4 to 16 inches; gray fine sand; single grained; loose; common fine and medium roots; strongly acid; abrupt wavy boundary.

Bh--16 to 28 inches; dark reddish brown fine sand; massive; friable; common fine and medium roots; reddish brown areas having less organic matter than the matrix and gray organic matter depletions lining pores along old root channels; strongly acid; gradual smooth boundary.

E'--28 to 32 inches; very pale brown fine sand, single grained; loose; common fine and medium roots; few fine faint yellow areas having more organic matter than the matrix; few medium faint light brownish gray organic matter depletions lining pores along old root channels; neutral; clear wavy boundary.

Bt1--32 to 36 inches; gray fine sandy loam, weak coarse subangular blocky structure; few fine and medium roots; few faint clay films in root channels; sand grains coated with clay; few small nodules of ironstone; many medium distinct brownish yellow masses of iron accumulation; neutral; gradual wavy boundary.

Bt2--36 to 48 inches; yellowish brown fine sandy loam; weak medium subangular blocky structure; few fine and medium roots; sand grains bridged and coated with clay; common streaks of white calcium carbonate in root channels; many coarse distinct gray pockets and areas of redoximorphic depletions; slightly alkaline; gradual wavy boundary.

Cg1--48 to 60 inches; light gray loamy fine sand; massive; very friable; few fine and medium roots; common strong brown nodules of ironstone; many medium and coarse brownish yellow masses of iron accumulation; slightly alkaline; gradual wavy boundary.

Cg2--60 to 75 inches; gray fine sand; single grained; loose; common medium and coarse light olive brown masses of iron accumulation; slightly alkaline.

Drainage and permeability: Poorly and very poorly drained; rapidly permeable in the A and E horizons and slowly to very slowly permeable in the Bh and Bt horizons.

Use and vegetation: Most areas of Wabasso soils are in natural vegetation and are used for native range. Areas with adequate water control measures are used for citrus, truck crops, and tame pasture. The natural vegetation consists of longleaf pine, slash pine, cabbage palm, live oak, with an understory of sawpalmetto, laurel oak, waxmyrtle, chalky bluestem, and pineland threeawn.

A1.3.4 Histisols

A1.3.4.1 Gator Series

The Gator series consists of very poorly drained organic soils that formed in moderately thick beds of hydrophytic plant remains overlying beds of loamy and sandy marine sediments. They are in depressions and on flood plains. Slopes are less than 1 percent.

Taxonomic class: Loamy, siliceous, euic, hyperthermic Terric Haplosaprists

Oa--0 to 34 inches; black muck; about 10 percent fiber, less than 5 percent rubbed; moderate medium granular structure; friable many fine roots; slightly acid in 0.01M calcium chloride; gradual wavy boundary.

Cg1--34 to 46 inches; very dark gray sandy clay loam; massive; slightly sticky and plastic; slightly acid; gradual wavy boundary.

Cg2--46 to 52 inches; dark grayish brown stratified loamy fine sand, fine sandy loam and fine sand; massive; nonsticky, nonplastic, slightly acid; gradual wavy boundary.

Cg3--52 to 58 inches; light gray fine sand; single grained; loose; slightly acid.

Drainage and permeability: Gator soils are very poorly drained. They are saturated with water that is always at or above the surface except during extended droughts. Flood plains are flooded for a very long duration. Permeability is rapid in the Oa and moderate in the loamy parts of the Cg horizon.

Use and vegetation: Almost all areas are in marsh or swamp wetlands used for wildlife and water storage. Native vegetation is mostly cordgrass or Jamaica sawgrass, maidencane, Coastal Plain willow, redosier dogwood, or swamp vegetation including baldcypress, sweetgum, red maple, and American hornbeam.

A1.3.4.2 Okeelanta Series

The Okeelanta series consists of very deep, very poorly drained, rapidly permeable soils in large fresh water marshes and small depressional areas. They formed in decomposed hydrophytic non-woody organic material overlying sand. Near the type location, the mean annual temperatures is about 74 degrees F., and the mean annual precipitation is about 59 inches. Slopes range from 0 to 2 percent.

Taxonomic class: Sandy or sandy-skeletal, siliceous, euic, hyperthermic Terric Haplosaprists

Oap--0 to 8 inches, black rubbed and unrubbed sapric material muck; about 5 percent fiber unrubbed; weak fine and medium granular structure; very friable; many fine roots and pores; estimated mineral content 10 percent; slightly alkaline; clear smooth boundary.

0a--8 to 31 inches, dark reddish brown rubbed and unrubbed sapric material muck; about 30 percent fiber unrubbed, about 10 percent rubbed; massive; friable; many fine roots and pores; sodium pyrophosphate extract very dark grayish brown; estimated mineral content 10 percent; slightly alkaline; clear smooth boundary.

C1--31 to 55 inches, very dark gray fine sand; single grained; loose; slightly alkaline; clear wavy boundary.

C2--55 to 65 inches, light gray fine sand; single grained; loose; many fine fragments of shell; calcareous, moderately alkaline.

Drainage and permeability: Very poorly drained; rapid permeability.

Use and vegetation: Many areas of Okeelanta soils are cleared and are used for truck crops, sod, sugarcane, and improved pasture grasses. Some areas are not developed and are used for water storage and as a wildlife habitat. Native vegetation consists of sawgrass, lilies, sedges, and other water tolerant plants. Willow, southern bayberry, and melaleuca are common tree species.

Appendix 2. Literiture review on soil pH moderation methods

Large numbers of papers and books are devoted to the increasing of soil pH by liming, but surprisingly few technical sources were found on the practices that reduce soil pH and the near-field environmental impact of these practices. This is due to the fact that a relatively greater soil area for crop production is naturally acidic (pH < 7) compared with the area of crop land that is alkaline (pH >7) (Van Breemen et al., 1983; Adams, 1984). In alkaline silt soil, elemental sulfur (S^0), which is biologically oxidized (via soil bacteria respiration) to H_2SO_4 under aerobic conditions (Wainwright, 1978), is often applied to reduce soil pH and dissolve insoluble nutrients. Many studies in calcareous soils (similar to soils in the C-139 basin) have report an improvement in P and micronutrient availability after the soil application of S^0 (Sen Gupta and Cornfield, 1964; Hilal and Abd-Elfattah, 1987) and increased crop yields (Abo-Rady et al., 1988; Modaihsh et al., 1989; Rashid et al., 2007), the response is often dependent on the amount of $CaCO_3$ present in the soil.

Slaton et al. (2001) found that water soluble elemental sulfur had the greatest affect on soil pH. Soil pH was reduced from 8.1 to 6.7 by application of 1000 kg S ha^{-1}. Li and Caldwell (1966) determined the effects of particle size, rate of application, soil pH, temperature, and amount of organic matter on the oxidation of elemental S in soil. In general the amount of S oxidized increased with decrease in particle size (greatest oxidation with particle size < 100 mesh). It was determined that oxidation reached a peak at 60 days of incubation time. Oxidation rate was greatest at soil temperature > 23C. Cifuentes and Lindemann (1993) found that increased organic matter improved conditions for biological oxidation of S by soil bacteria, presumably due to increased soil carbon to support bacterial growth.

Although S cycling in watersheds potentially is controlled by several processes (Rochelle and Church, 1987), sulfate adsorption-desorption is probably of greatest importance in most terrestrial systems. Sulfate adsorption is influenced by several factors including soil content of Fe- and Al-oxides, organic matter and clay. Nodvin et al. (1986) determined that sulfate adsorption was linked to pH with adsorption increasing with a decrease in pH for mineral soils in New Hampshire having an initial pH greater than 4.0. Rochelle et al. (1987) identified an apparent relationship between S retention and soil order, with sites dominated by Spodosols being associated with low net retention and sites dominated by Alfisols retaining more incoming S. These soil orders are prominent in the C-139 basin and will control the amount of P and S moving out of the filed soils to surface waters. Spodic layers of Sodosols have greater amounts of Fe- and Al-oxides compared with Alfisols, however, the argillic horizons of the Alfisols have much higher clay contents. Sorption of P and S by these oxides and clays determine the amount retained by the soils and not subject of leaching. As noted above, lowering of soil pH in the crop root zone by targeted applications of S^0 in this soil layer would allow for greater P availability from Ca precipitates for crop uptake, but could potentially also increase the sorption of these materials by the spodic and argillic horizons.

Other methods of lowering soil pH are the incorporation of soil applied aluminum sulfate and inoculation of soil with Mycorhyzal fungi. As noted above the oxidation of elemental S to sulfate is responsible for lowering soil pH. Therefore soluble Al is responsible for soil acidification with aluminum sulfate since the S is already in the sulfate form. Islam et al. (2004) found that 6 to 8 times the quantity of aluminum sulfate was required to change a soil by one pH unit compared with elemental S. The amount of material needed to adequately change the soil pH would likely be cost prohibitive. The inoculation of soil with Mycorrhizae fungi can increase yields of certain crop plants (Eccher and Noe, 2002; Eccher, Noe and Villa, 2002). Mychorrhyzal fungi grow into the tissue of plant roots and inter into a symbiotic relationship. Excess soil nutrients are provided to the crop plant and carbohydrates from photosynthesis are passed along to the fungi. These fungi are more efficient at uptake of nutrients than are most plant roots because proliferation of the fungal hyphae provides greater surface area for nutrient uptake from the soil than the limited root system of some crops. Long-term perennial crops such as citrus and blueberry have shown the greatest benefit of Mycorrhizae in improved yields. It was concluded that in short-term crops (120 days or less) planted into chemically sterilized soils (as vegetables in south Florida are) the time required to inoculate the soil, establish adequate soil populations of fungi and establishment of a symbiotic relationship with the short term crops would minimize the impact of these fungi to improve nutrient uptake and positively affect growth and yield.

References

Abo-Rady, M.D.K., O. Duheash, M. Khalil, and A.M. Turjoman. 1988. Effect of elemental sulfur on some properties of calcareous soils and growth of date palm seedlings. Arid Soil Res. Rehabil. 2:121-130.

Adams, F. 1984. Soil acidity and liming. Second edition. American Society of Agronomy, Inc. Madison WI.

Cifuentes, F.R. and W.C. Lindemann. 1993. Organic matter stimulation of elemental sulfur oxidation in calcareous soils. Soil Sci. Soc. Am. J. 57: 727-731.

Eccher T. and N. Noe. 2002. The influence of Ericoid Endomycorrhizae and mineral nutrition on the growth of micropropagated plants of vaccinium corymbosum L. Acta Hort. 715:411-416.

Eccher, T., N. Noe and C. Villa. 2002. Interaction Between mycorrhizae inoculated in vitro on rooting and early growth of micropropagated plants. Acta Hort. 574:379-385.

Hilial, M.H., and A. Adb-Elfattah. 1987. Effect of CaCO3 and clay content of alkaline soils on their response to added sulphur. Sulphur Agric. 11:15-19.

Islam, M.A., P.J. Milham, P.M Dowling, B.C. Jacobs and D.L. Garden. 2004. Improved procedures for sdjusting soil pH for pot experiments. Comm.. Soil Sci. and Plant Anal. 35: 25-37.

Li, P, and A.C. Caldwell. 1966. Oxidation of elemental sulfur in soil. Soil Sci. Soc. Am. J. 30: 370-372.

Modaihsh, A.S., W.A. Al-Mustafa and A.I. Metwally. 1989. Effect of elemental sulphur on chemical changes and nutrient availability in calcareous soils. Plant Soil 116:95-101.

Nodvin, S.C., C.T. Driscoll and G.E. Likens. 1986. Simple partitioning of anions and dissolved organic carbon in a forest soil. Soil Sci. 142:29-35.

Rochelle, B.P., M.R. Church. 1987. Regional patterns of sulfur retention in watersheds of the eastern U.S. Water, Air, and Soil Pollution 36:61-73.

Rochelle, B.P., M.R. Church and M.B. David. 1987. Sulfur retention at intensively-studied watersheds in the US and Canada. Water, Air and Soil Pollut. 33:73.

Sen Gupta, M.B. and A.H. Cornfield. 1964. Effect of four acidifying materials added to a calcareous soil on the availability of phosphorus to ryegrass. Plant Soil 126:9-14.

Slaton, N.A., R.J. Norman and J.T. Gilmour. 2001. Oxidation rates of commercial elemental sulfur products applied to an alkaline silt loam form Arkansas. Soil Sci. Soc. Am. J. 65: 239-243.

Van Breemen, N., J. Mulder and C.T. Driscoll. 1983. Acidification and alkalinization of soils. Plant Soil 75:283-308.

Wainwright, M. 1978. Microbial sulphur oxidation in soil. Soil Sci. Prog. (Oxford) 65:459-475.