AGRONOMIC AND ENVIRONMENTAL IMPACTS OF LAND APPLICATION OF BIOSOLIDS TO BAHIAGRASS PASTURES IN FLORIDA

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ABSTRACT – Biosolids have clear agronomic benefits, but concerns over nutrient accumulation in soils and subsequent impacts on water quality can limit land application in Florida. The ***objectives*** of this proposal are (1) to select, evaluate, and thoroughly characterize biosolids materials that represent the most common sources applied to Florida pastures, (2) to establish a field trial designed to evaluate the agronomic benefits of biosolids application on forage production, and (3) to obtain and install equipment to monitor potential impacts of biosolids application on water quality. Our ***principal hypothesis*** is that most biosolids applied to pastures convey significant agronomic benefits and that they behave as "slow release" nutrient sources with minimal negative environmental impact. A field trial was established to evaluate the agronomic and environmental impacts of various biosolids sources applied to bahiagrass (*Paspalum notatum* Flugge) pastures at the Range Cattle REC in Ona. Biosolids applied to, and soil samples obtained from, the amended sites were thoroughly characterized. Surface water quality and greenhouse gas emissions were also monitored. The ***broader impact*** of this proposal is that limited (or no) field data are available on nutrient fate, particularly N and P dynamics, in soils amended with different biosolids materials. Pastures represent the major cropping system where biosolids are recycled in Florida, yet limited information is available to document and support agronomically and environmentally-sound biosolids recycling programs in forage systems. Most studies of the implications of land application of biosolids were conducted under greenhouse and laboratory conditions, and extrapolation to field conditions is problematic. Thus, it is essential to investigate the effectiveness and sustainability of biosolids applications under field conditions, particularly with respect to N and P dynamics in the soil-plant-water interface.

PROJECT GOALS AND OBJECTIVES

The project addresses **FCA Priorities # 9 "Land Application of Biosolids on Pastures"** and **# 1 "Fertilization (Alternative Fertilizer Sources).** The objectives are (1) to select, evaluate, and thoroughly characterize biosolids materials that represent the most common sources applied to Florida pastures, (2) to establish a field trial designed to evaluate the agronomic benefits of biosolids application on forage production, and (3) to obtain and install equipment to monitor potential impacts of biosolids application on water quality.

CURRENT PROJECT STATUS

Objective 1. *To select, evaluate, and thoroughly characterize biosolids materials that represent the most common sources applied to Florida pastures*

Rationale: Research on the co-application of biochar (fine-grained carbon-rich residue produced through the pyrolysis of biomass) with organic residuals is contemporary and despite preliminary evidence that biochar may lead to more efficient use of nutrients present in biosolids, the mechanisms explaining the interaction between biochar and nutrients has not been fully investigated. Because its chemical and physical characteristics, biochar can act as a strong sorbent that is potentially useful to control the liability of inorganic and organic contaminants in soil and water. For example, research suggests that biochar can retain significant amounts of plant nutrients, particularly N and, to a lesser extent, P (Ippolito et al., 2016). In addition, biochar has a great potential to be used in combination with biosolids to improve nutrient use efficiency and reduce nutrient losses. Knowles et al. (2011) evaluated application of biosolids (at rates equivalent to 600 and 1200 kg total N ha^{-1}) and concluded that biochar reduced nitrate leaching with no negative impact on ryegrass biomass production. Cumulative nitrate leaching for the treatments receiving biosolids at the 600 kg N ha^{-1} level + biochar was similar to control treatments (no biosolids, no bichar). Steiner et al. (2010) observed N loss reduction by as much as 52% when biochar was used (at a rate of 20% w/w) during poultry litter composting. Increases in soil water status and C accumulation in response to co-application of biochar and manure were also observed. In addition, biochar can also resulted in positive agronomic benefits; however, studies in this area are still sparse.

Soils under perennial pastures in FL generally exhibit poor soil fertility conditions (e.g., acidic pH and low levels of organic matter) and limited nutrient holding capacity making them ideal candidates for organic residuals application. Application of biosolids amended with biochar may provide multiple benefits including better nutrient utilization, which may translate into greater forage production and nutritive value, while minimizing nutrient losses. In addition, addition of carbon rich materials such as biosolids and biochar are expected to improve soil biological and physical properties resulting in improved overall soil quality conditions.

Biosolids and biochar materials were gathered from a variety of sources in Florida. Class B biosolids sources were collected from various wastewater treatment plants (Plant City, Bradenton, and St. Petersburg) representing different treatment processes and contrasting chemical characteristics. Class A biosolids was obtained from a local dealer representative. A total of six waste and by-products materials were selected and thoroughly characterized in the laboratory using routine analysis (Table 1).

Nutrient concentrations in the biosolids varied considerably depending on the source but were typical of most biosolids land applied to pastures in Florida. For most biosolids materials, N to P ratio ranged from 3.3 to 3.6, which is similar to the typical bahiagrass requirements when soil and tissue test low in P. The only exception were the biosolids materials from both Bradenton facilities, which exhibited much greater P concentration relative to N (N:P ratio of ~ 1.3). As most biosolids, materials evaluated in this study exhibited relatively low concentrations of K concentrations (0.03 to 0.1% of K, wet-basis concentrations).

Heavy metal concentrations in biosolids and biochar materials were considerably smaller than the limits established by U.S. EPA part 503 rule. Thus, no risk associated with heavy metal contamination is expected to occur in response to land application of these materials when applied at agronomic rates.

Table 1. Chemical characterization of biosolids and biochar materials.

	Biosolids					**Biochar**		
Chemical properties†	Heat-dried Class A biosolids	Cake - Class B biosolids (Plant City)	Cake - Class B biosolids (St Petersburg)	Cake-Class B biosolids (Bradenton plant facility A)	Cake-Class B biosolids (Bradenton plant facility B)	Wood biochar (Dunnellon)	Pine biochar (Wakerfield)	Grass biochar (Wakerfield)
Moisture (%)	8.7	83.3	83.1	83.7	84.97	3.6	3.9	4.0
pH‡	7.7	8.1	8.6	7.9	8.2	9.9	9.2	7.1
EC (mS/cm) ‡	4.5	0.8	2.8	1.2	1.1	3.5	0.3	6.2
Total N (%)	6.1	1.4	1.3	0.8	0.9	1.0	0.2	1.8
Total P (%)	1.7	0.4	0.4	0.6	0.7	0.2	0.0	0.3
Total K (%)	0.1	0.04	0.03	0.04	0.03	0.2	0.1	2.2
S (%)	1.5	0.3	0.3	0.14	0.16	0.1	0.01	0.1
Zn (%)	0.08	0.02	0.02	0.03	0.03	0.3	0.003	0.01
Mn (%)	0.01	0.001	0.002	0.002	0.003	0.03	0.03	0.02
Fe (%)	0.9	0.3	0.3	0.97	1.1	0.2	0.1	0.3
Cu (%)	0.03	0.01	0.01	0.01	0.01	0.004	0.001	0.001
Ca (%)	2.1	0.6	0.7	0.3	0.4	2.0	0.7	0.9
Mg (%)	0.4	0.1	0.1	0.08	0.09	0.5	0.2	0.3
Na (%)	0.3	0.03	0.03	0.04	0.04	0.2	0.02	0.08
Al (%)	0.49	0.04	0.06	0.07	0.08	0.5	0.02	0.01
Cd (ppm)	1.1	0.29	0.12	0.001	0.001		0.001	0.001
Cr (ppm)	60.8	4.3	5.2	9.3	10.0		41.0	11.6
Pb (ppm)	26.2	25.4	7.1	3.5	4.0		1.	1.2
Co (ppm)	2.1	0.3	0.3	0.8	0.8		1.8	8.1
Ni (ppm)	39.1	3.9	5.3	3.0	3.2		8.3	6.1

† Values are expressed on wet-basis concentrations. Each value represents the average of three replicated samples. ‡pH and EC were determined using a 1:4 solid:water ratio

Objective 2. *To establish a field trial designed to evaluate the agronomic benefits of biosolids application on forage production,*

Experimental setup

A field experimental area was established at the UF/IFAS Range Cattle REC on an established bahiagrass pastures. The specific location was chosen to represent a typical low-fertility soil condition that most cow-calf operations experience in Central-South Florida. The criteria for selection included lack of fertilization during the past 10 yr, good bahiagrass stand (little or no weeds present), and adequate soil pH conditions. The experimental area (~ 20 acres) was fenced and a total of 40 experimental plots (as shown in Fig. 1) were marked in February, 2016. Plot size was 20 by 30 ft with 10-ft alleys between plots. Soil was a Pomona fine sand (sandy, siliceous, hyperthermic Ultic Alaquods).

★ 1-1 T6-Rep1	★ 1-2 T5-Rep1	★ 1-3 T1-Rep1	★ 1-4 T9-Rep1	★ 1-5 T10-Rep1
1-6 T2-Rep1	1-7 T3-Rep1	1-8 T7-Rep1	1-9 T8-Rep1	1-10 T4-Rep1
★ 2-1 T6-Rep2	★ 2-2 T10-Rep2	★ 2-3 T9-Rep2	★ 2-4 T1-Rep2	★ 2-5 T5-Rep2
2-6 T3-Rep2	2-7 T2-Rep2	2-8 T4-Rep2	2-9 T8-Rep2	2-10 T7-Rep2
★ 3-1 T5-Rep3	★ 3-2 T1-Rep3	★ 3-3 T6-Rep3	★ 3-4 T10-Rep3	★ 3-5 T9-Rep3
3-6 T7-Rep3	3-7 T8-Rep3	3-8 T2-Rep3	3-9 T3-Rep3	3-10 T4-Rep3
★ 4-1 T1-Rep4	★ 4-2 T6-Rep4	★ 4-3 T5-Rep4	★ 4-4 T9-Rep4	★ 4-5 T10-Rep4
4-6 T3-Rep4	4-7 T7-Rep4	4-8 T4-Rep4	4-9 T8-Rep4	4-10 T2-Rep4

Treatment ID	Biosolids/Fertilizer	Biochar
1	Control	no
2	Control	yes
3	Class A pellets	no
4	Class A pellets	yes
5	Class B_Bradenton	no
6	Class B_Bradenton	yes
7	Class B_St Pete	no
8	Class B_St Pete	yes
9	N+P inorg. Fertilizer	no
10	N+P inorg. Fertilizer	yes

Fig. 1. Schematic representation of experimental layout

Three biosolids materials were selected for the field study: class AA heat-dried pellets, class B St. Pete cake, and class B Bradenton 1 cake. The wood biochar material produced and market in Dunnellon, FL was selected for the field trial. Biosolids materials were surface applied to the experimental area and compared to nutrition provided with mineral fertilizers. Land application of the residuals occurred in the summer (August 25 through 29, 2016). Although the application period was not ideal, the delay occurred because of the high water table levels experienced during the 2016 growing season. In addition, since no background data on water quality or gas emissions were available for this specific site, we deemed it appropriate to intensify our pre-treatment water and gas collection by sampling more frequently during the summer months. This approach also contributed to the delay in biosolids/fertilizer application. In subsequent years, biosolids application will occur in the spring (between March and April of each year).

Biosolids sources were applied either alone or in combination with biochar to supply an estimated rate of 160 lb plant available N/A/yr. The rate corresponds to UF/IFAS high N option for established bahiagrass, and is the most common application rate used by commercial cow-calf operations in Florida. The availability of the N in the biosolids was estimated using Florida - DEP factor of 1.5; therefore, the N rate supplied by biosolids will be 240 lb total N/A (160 lb plant available N/A * 1.5 = 240 lb total N/A). The biosolids application rate was based on the total concentration of N in the material and total biosolids solids content. Biochar was also applied in late August, 2106 at 20 Mg ha^{-1} rate, which corresponds to an application rate of ~ 1% (wt. basis). Biochar application rate was chosen was based on previous research conducted elsewhere (Ippolito et al., 2016). Control treatments included plots receiving inorganic commercial fertilizer (ammonium nitrate + triple superphosphate alone and in combinations with biochar) and pastures receiving no biosolids, fertilizer, or biochar.

Initial soil characterization

Five soil cores 3 inches in diameter) were collected (to a depth of 36 inches) from each plot in March 2016 using a hydraulic probe. After collection, each soil core was sectioned into 5 depth intervals (0 to 4, 4 to 8, 8 to 16, 16 to 24, and 24 to 36 inches). A total of 600 soil samples (40 plots * 3 cores * 5 depths = 600) were sieved and air-dried for chemical characterization. The remaining samples (40 plots * 2 cores * 5 depths = 400) were used for bulk density determination.

Initial soil characterization included soil bulk density, pH, electrical conductivity (EC), total C and N concentrations, Mehlich-3 extractable P, K, Ca, and Mg, extractable NO_3-N and NH_4-N, and water extractable P concentrations. For each soil depth, the P saturation ratio (PSR) was calculated according to equation 1. The PSR is related to soil P retention capacity.

$$PSR = \text{Mehlich-3-P} / (\text{Mehlich-3-Al} + \text{Mehlich-3-Fe}) * 100 \qquad \text{[eq. 1]}$$

Where P, Fe, and Al concentrations are expressed in moles/kg.

Table 2. Initial unamended soil characterization.

						Mehlich-3 extractable							
Depth	Bulk density	pH	EC	Total C	Total N	P	K	Ca	Mg	Fe	Al	Water extractable P	PSI
Inches	g/cm^3		mS/cm	%		mg/kg (or ppm)							
0-4	1.00	5.0	18.1	1.6	0.1	190.1	37.0	110.5	481.0	241.1	1528.2	3.9	0.1
4-8	1.34	5.6	18.1	1.1	0.06	46.7	12.0	35.0	376.0	163.4	1783.5	0.1	0.0
8 to16	1.35	5.8	18.2	0.8	0.06	85.6	7.8	116.1	2.5	133.1	2479.5	1.0	0.0
16 to 24	1.71	5.9	18.2	0.4	0.01	153.3	0.1	40.6	0.2	135.1	1831.5	*BDL*‡	0.1
24-36	1.75	6.1	18.1	0.4	0.01	130.5	0.1	20.0	0.1	121.1	1700.8	*BDL*	0.1

†Each value represents the average across 40 experimental units. ‡BLD = below the detection limit of 0.01 mg P L^{-1}.

Initial soil chemical characterization indicated soil pH was slightly below the recommended value of 5.5 for established bahiagrass (Table 2). Despite the medium soil P concentrations observed at the 0 to 4" depth, ~ only 2% of Mehlich-3 P was water-extractable. Similarly, PSR were below the threshold of 0.1 proposed by Nair et al. (2004), which suggest minimal risk of P to become an environmental concern. The relatively low P liability is due to the presence of Al and Fe. Total C and N were typical of most coarse-textured soils in Florida.

Preliminary forage data (dry matter yield and nutritive value) was determined in May 2016. Forage samples were dried at 60°C for 48 hr for dry matter yield determination. Oven-dried samples will be ground to pass through a 1-mm mesh screen and analyzed for total N, P, and trace elements concentrations Crude protein concentration was calculated by multiplying N concentration by 6.25. Fiber analysis (neutral detergent fiber, acid detergent fiber, and lignin) were run in an Ankom fiber analyzer (Ankom Technology, 2013).

Relatively high herbage mass recorded at the beginning of the study associated with low crude protein concentrations are consistent with the site history (i.e., lack of liming and fertilization, and long regrowth interval) (Table 3). Tissue P concentrations were above the critical limit of 0.15%, which suggest that soil P reserves are likely sufficient to meet bahiagrass demand for P.

Table 3. Pre-treatment bahiagrass tissue characterization

Parameter	Concentration
Herbage mass (lb/A)	5,229
Crude Protein concentration (%)	5.6
Tissue P concentration (%)	0.2
Neutral Detergent Fiber (NDF) (%)	77
Acid Detergent Fiber (ADL) (%)	32
Lignin (%)	20

Objective 3. *To obtain and install equipment to monitor potential impacts of biosolids application on water and gas quality.*

Water quality was monitored in the control plots (Fig. 1, treatment # 1) and the treatments receiving the inorganic N and P fertilizer (Fig. 1, treatments 5 and 6) and Bradenton biosolids (Fig. 1, treatments 9 and 10). A total of 24 plots [1 biosolids material + 1 commercial fertilizer with or without biochar + 1 control (no N or P and biochar alone) * 4 replicates = 20 plots] were fully instrumented to obtain leachate and surface runoff samples. Drain gauge lysimeters, soil moisture sensors, pressure transducer, and static gas chambers were installed in the experimental plots in March, 2016 (Fig. 2).

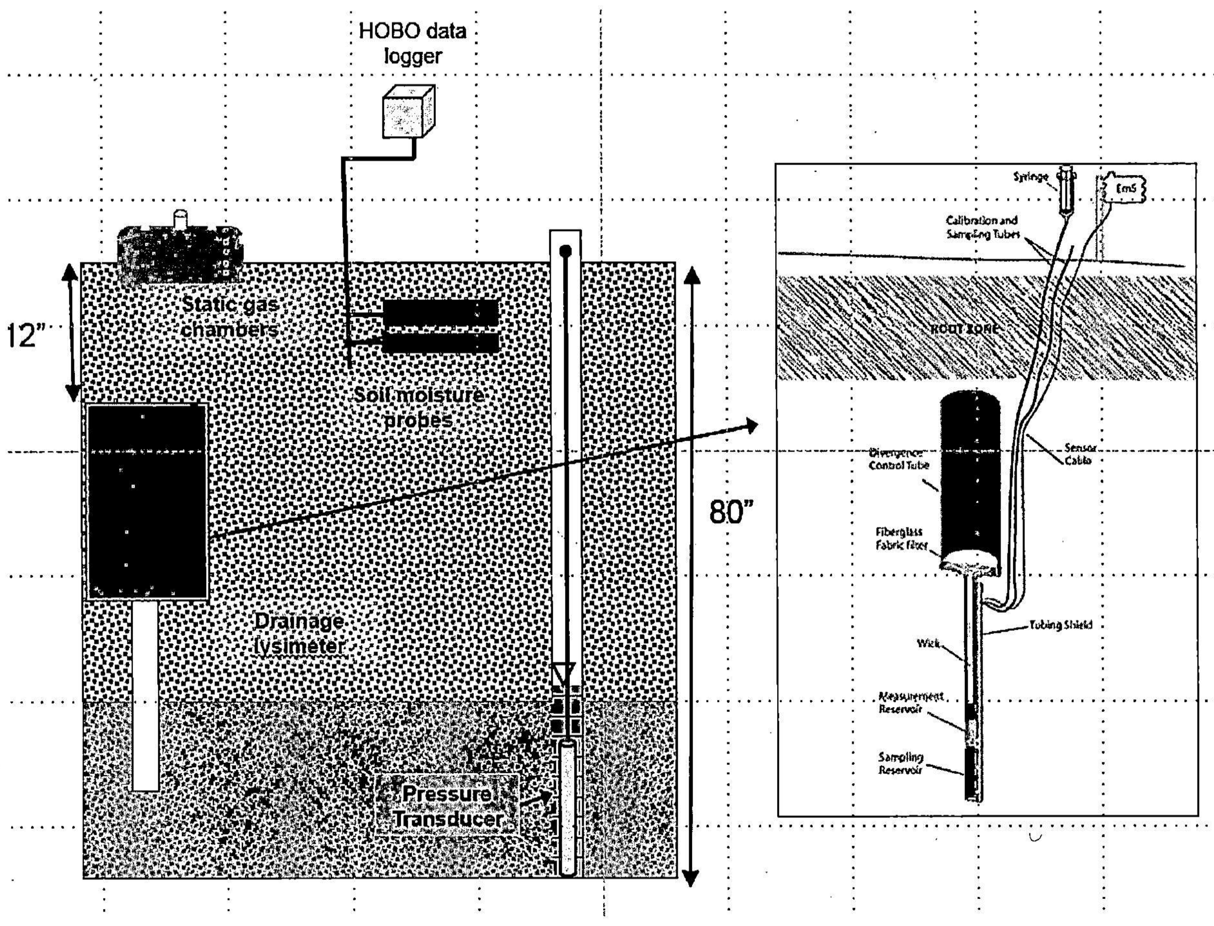


Fig. 2. Schematic representation of water and gas quality monitoring equipment

Preliminary water and gas quality samples have been collected and analyzed since May, 2016. Gas collection occurred on 7/11/2016, 7/21/2016, 7/28/2016, 8/4/2016, 8/11/2016, and

8/18/2016 for a total of 6 sampling events. Similarly, water samples were collected on 5/18/2016, 6/8/2016, 6/20/2016, 7/5/2016, 7/19/2016, 8/4/2016, 8/17/2016 for a total of 7 collection events.

Leachate volume collected at each water sampling event has been recorded (Table 4). Data indicated that spatial variability associated with leachate volumes decreased over time. Leachate samples are currently being analyzed in the laboratory for soluble reactive P, and NO_3-N and NH_4-N concentrations (data not presented).

Gas samples have also been collected and analyzed for methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) concentrations (Table 5). As expected, considerably seasonal variability was associated with preliminary greenhouse gas data recorded so far. Because temperature and soil moisture affect microbial processes controlling GHG emissions, we expect that this trend will likely continue as we progress in the growing season.

Table 4. Leachate volume as affected by sampling date.

Plot ID	Sampling Dates						
	1st sampling event (05/18/2016)	2nd sampling event (06/8/2016)	3rd sampling event (06/20/2016)	4th sampling event (07/05/2016)	5th sampling event (07/19/2016)	6th sampling event (08/4/2016)	7th sampling event (08/17/2016)
	Total Leachate Volume (mL)						
1-1	2400	2000	8900	8000	8000	8100	9000
1-2	4680	7400	8900	8000	7900	8100	9000
1-3	7000	5180	8650	7900	7800	8000	8700
1-4	1000	8000	8700	7800	8100	8000	9100
1-5	7200	3250	9100	8000	8000	8300	9200
2-1	1700	5200	9000	7450	7700	8000	9150
2-2	2500	6100	11000	7700	8000	8000	9100
2-3	6120	5700	9000	8000	8100	8300	9100
2-4	6780	8720	9000	8350	8200	8100	9300
2-5	6025	4500	8750	8200	8100	7500	9200
3-1	5500	9500	9000	8450	8150	8200	9300
3-2	4425	8500	9000	7800	8300	8150	9000
3-3	5450	9000	9000	7500	8050	8000	9300
3-4	6900	8900	9000	8050	8500	8300	9100
3-5	1450	7300	8600	8350	8400	8400	9200
4-1	6050	8000	8800	7800	8200	8100	8900
4-2	6820	8500	9000	7900	8000	8200	9000
4-3	8100	8750	8600	8000	8000	8100	9000
4-4	5220	8000	8100	8250	8000	8200	9200
4-5	10200	8500	8850	8000	8050	8250	9000

Table 5. Greenhouse gas fluxes for selected sampling dates. Each value represent the average of 5 static chambers.

	Sampling dates			
Block	7/11/2016	7/28/2016	8/4/2016	8/11/2016
	CH_4 Flux (μg CH_4 m^{-2} min^{-1})			
1	-0.19	3.11	9.88	39.91
2	1.22	4.32	12.11	51.41
3	1.24	9.81	32.85	101.23
4	1.97	3.51	8.22	40.27
5	1.33	3.11	24.79	35.37
	Sampling dates			
Block	7/11/2016	7/28/2016	8/4/2016	8/11/2016
	CO_2 Flux (mg CO_2 m^{-2} min^{-1})			
1	15.15	13.19	16.53	11.53
2	17.28	13.9	16.2	12.8
3	9.07	16.8	16.2	13.2
4	14.11	14.5	16.5	14.7
5	12.70	11.0	12.1	9.1
	Sampling dates			
Block	7/11/2016	7/28/2016	8/4/2016	8/11/2016
	N_2O Flux (μg N_2O m^{-2} min^{-1})			
1	0.42	0.48	0.8	0.61
2	2.79	0.52	0.64	0.63
3	2.45	0.68	0.71	0.72
4	2.64	0.55	0.67	0.54
5	2.68	0.57	0.51	0.36

Groundwater level and weather data have been continuously monitored in the experimental site. Because of the relatively high amount of precipitation that occurred during the beginning of the 2016 growing season, water table levels recorded during this period approached the soil surface (Fig. 3). Soil saturated conditions resulted in a delay in the application of biosolids and biochar amendments.

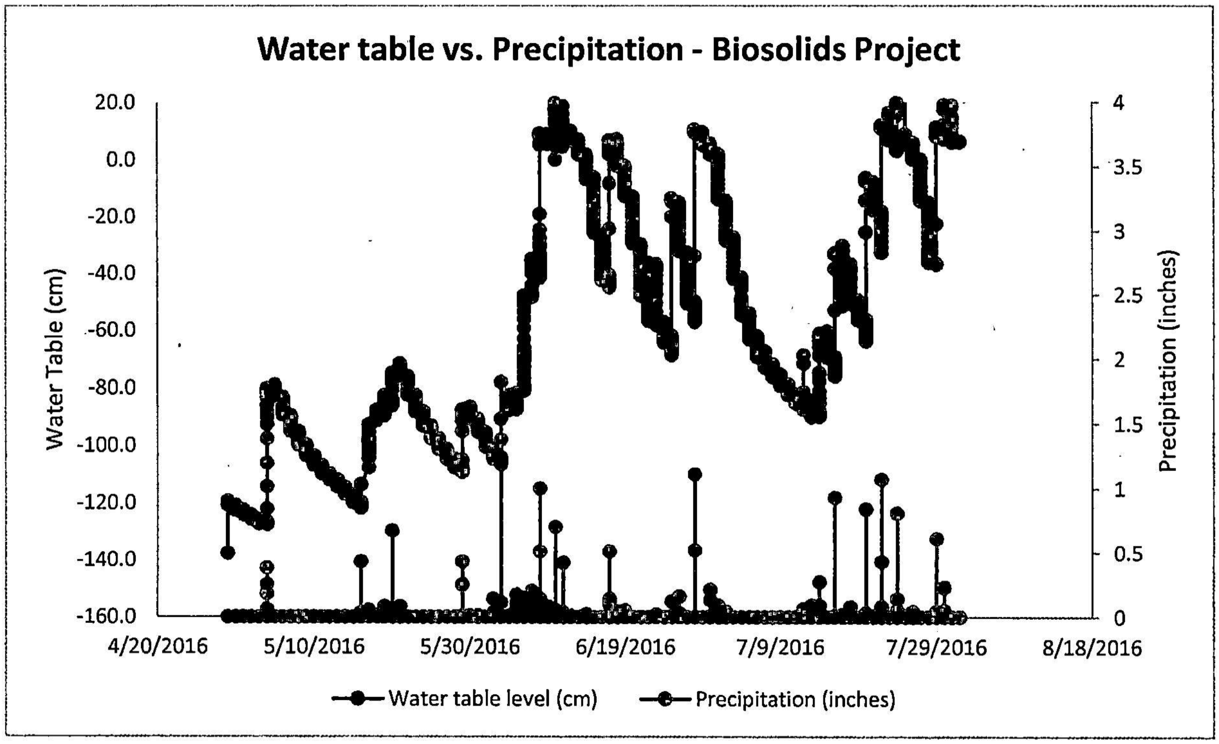
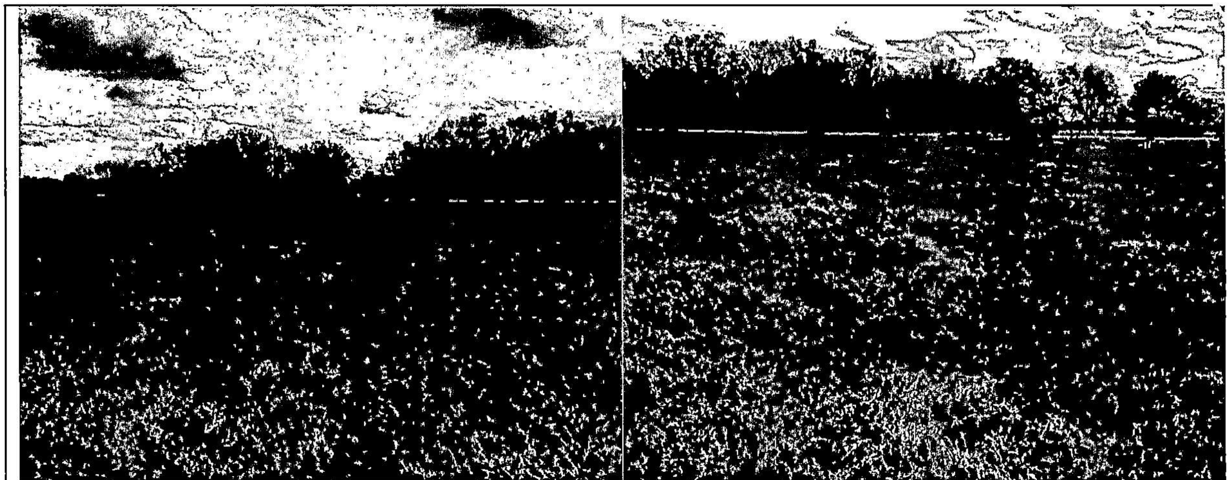
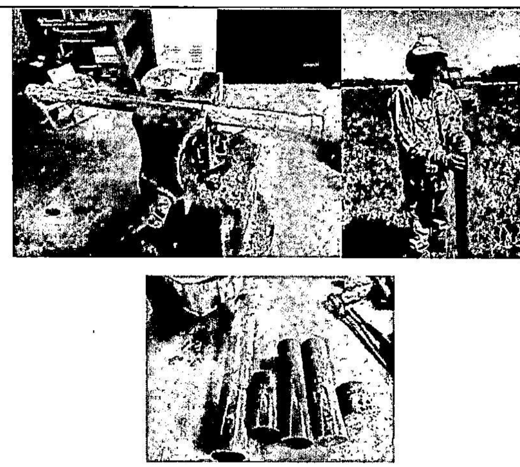
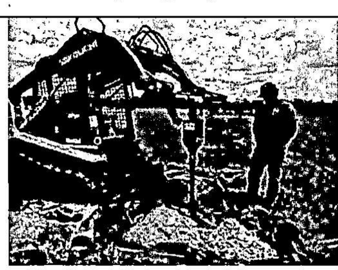
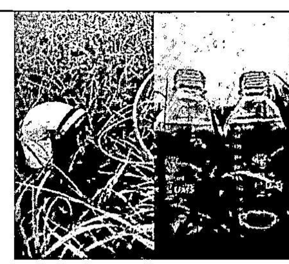


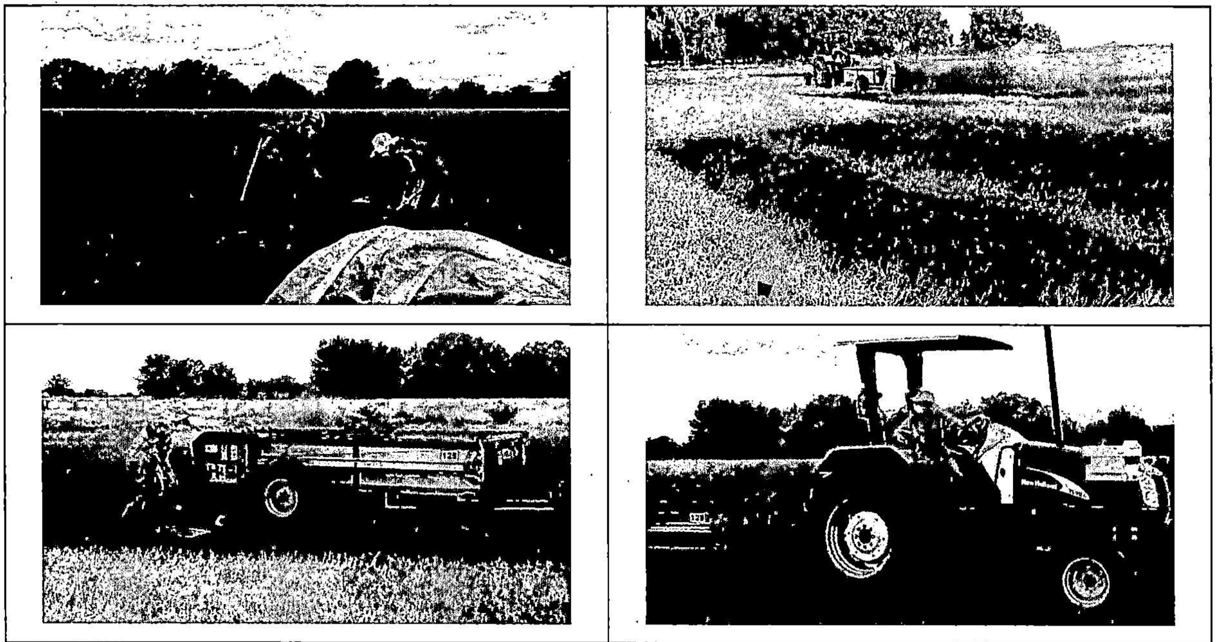
Fig. 3. Recorded precipitation and water table level during the 2016 experimental period.

FUTURE DIRECTIONS

During the first phase of this project, significant efforts and investment have been placed on two main priorities: 1. documenting soil, forage, water, and gas baseline data, and 2. instrumenting the experimental area. In addition to the equipment purchased through this grant, additional water quality monitoring equipment (rainfall simulator, pore water sampling devices, water pump, generator, etc) were acquired from other FDACS projects to support this field trial. We hope that funds will continue to be available through the Florida Cattlemen's Beef Enhancement program to support our current efforts that address research priorities # 9 "Land Application of Biosolids on Pastures" and # 1 "Fertilization (Alternative Fertilizer Sources).

Appendix 1 - Photos

	
Experimental Area	
	
Drain gauge lysimeter	**Initial soil core sampling**
	
Lysimeter instalation	**Water sampling**



Land application of biosolids and biochar to the experimental area

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