## Research Articles

# Assessing the Efficacy of Dredged Materials from Lake Panasoffkee, Florida: Implication to Environment and Agriculture

## Part 1: Soil and Environmental Quality Aspect

**Part 1: Soil and Environmental Quality Aspect** <DOI: http://dx.doi.org/10.1065/espr2004.08.212.1>
**Part 2: Pasture Establishment and Forage Quality** <DOI: http://dx.doi.org/10.1065/espr2004.08.212.2>

**Preamble.** This series of two papers discusses disposal alternatives of lake-dredged materials and the efficacy and beneficial use of dredged materials from Lake Panasoffkee, Florida in the environment and agriculture. **Part 1** presents the results on the effect of applied lake-dredged materials on soil physico-chemical properties and soil quality at the disposal site. **Part 2** discusses the effect of lake-dredged materials on beef cattle pasture establishment, crude protein and nutrient uptake of bahiagrass in south Florida, U.S.A.

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**Abstract**

**Background, Aims and Scope.** Dredged materials because of its variable but unique physical and chemical properties are often viewed by society and regulators as pollutants, but many have used these materials in coastal nourishment, land or wetland creation, construction materials, and for soil improvement as a soil amendment. Environmental impact assessment is an important pre-requisite to many dredging initiatives. The ability to reuse lake-dredge materials (LDM) for agricultural purposes is important because it reduces the need for offshore disposal and provides an alternative to disposal of the materials in landfills. Additional research on disposal options of dredged materials are much needed to supply information on criteria testing and evaluation of the physical and chemical impacts of dredged materials at a disposal site, as well as information on many other aspects of dredging and dredged material disposal. While preliminary efforts are underway to provide information to establish criteria for land disposal, testing procedures for possible land disposal of contaminated sediments are still in their developing stage. The objective of this study (Part 1) was to quantify the effect of applied LDM from Lake Panasoffkee (LP), Florida on soil physico-chemical properties (soil quality) at the disposal site. This series of two papers aims at providing assessment of the efficacy of lake-dredged materials from LP especially its implication to environment (soil quality, Part 1) and agriculture (forage quality and pasture establishment, Part 2).

**Methods.** The experimental treatments that were evaluated consisted of different ratios of natural soil (NS) to LDM: LDM0 (100% NS:0% LDM); LDM25 (75% NS:25% LDM); LDM50 (50% NS:50% LDM); LDM75 (25% NS:75% LDM); and LDM100 (0% NS:100% LDM). Field layout was based on the principle of a completely randomized block design with four replications. The Mehlich 1 method (0.05 N HCl in 0.025 N $H_2SO_4$) was used for chemical extraction of soil. Soil P and other exchangeable cations (Ca, Mg, K, Al, and Fe) were analyzed using an Inductively Coupled Plasma (ICP) Spectroscopy. The effects of dredged materials addition on soil quality and compaction were analyzed statistically following the PROC ANOVA procedures.

**Results and Discussion.** Sediments that were dredged from LP have high $CaCO_3$ content (82%) and when these materials were incorporated into existing topsoil they would have the same favorable effects as liming the field. Thus, sediments with high $CaCO_3$ may improve the physical and chemical conditions of subtropical sandy pastures. The heavy and trace metal contents of LDM were below the probable effect levels (PEL) and threshold effect levels (TEL). Average values for Pb, Zn, As, Cu, Hg, Se, Cd, and Ni of 5.2 ± 1.3, 7.0 ± 0.6, 4.4 ± 0.1, 8.7 ± 1.2, 0.01 ± 0.02, 0.02 ± 0.02, 2.5 ± 0.1, and 14.6 ± 6.4 mg $kg^{-1}$, respectively, were below the TEL and the PEL. TEL represents the concentrations of sediment-associated contaminants that are considered to cause significant hazards to aquatic organisms, while, PEL represents the lower limit of the range of the contaminant concentrations that are usually or always associated with adverse biological effects. As such, the agricultural or livestock industry could utilize these LDM to produce forages. LDM should be regarded as a beneficial resource, as a part of the ecological system. Addition of LDM had significant ($p \leq 0.001$) effects on soil physico-chemical properties and soil quality. Compared with the control plots, the soils in plots amended with LDM exhibited: (1) lower degree of soil compaction; (2) an increase in soil pH, Ca, and Mg; (3) decrease in the levels of soil Mn, Cu, Fe, Zn, and Si; and (4) no significant change in the level of Na in the soil. Results have shown the favorable influence that LDM had on soil compaction. The treatment x year interaction effect was not significant, but the average soil compaction varied widely ($p \leq 0.001$) with LDM application. In 2002 and 2003, soil compaction of plots was lowered significantly as a result of LDM additions. The least compacted soils in 2002 and 2003 were observed from plots with LDM75 with mean soil compaction of $300 \times 10^3$ and $350 \times 10^3$ Pa, respectively.

**Conclusion.** Beneficial uses of dredged materials from LP, Florida are both economical and environmental. Often these materials can be obtained at little or no cost to the farmers or landowners in south Florida. Environmentally, dredging of sediments that are rich in $CaCO_3$ should restore the 19.4-sq km LP by removing natural sediments from the lake bottom to improve the fishery, water quality, and navigation of the lake. The bottom sediment materials from lakes, river, and navigational channels usually are composed of upland soil enriched with nutrients and organic matter. These materials should be regarded as a beneficial resource to be used productively and not to be discarded as spoil materials.

**Recommendation and Outlook.** Land application of LDM from LP may not only provide substantial benefits that will enhance the environment, community, and society in south Florida, but also in other parts of the world especially those areas having tropical and subtropical climate with forage-based beef cattle pastures. The heavy and trace metal contents of LDM from LP were below the PEL and TEL. As such, the agricultural or livestock industry could utilize these LDM to produce forages (Part 2 of this study). LDM should be regarded as a beneficial resource, as a part of the ecological system. Further studies are still needed to determine whether the environmental and ecological implications of LDM application are satisfied over the longer term.

**Keywords:** Agriculture; bahiagrass; beef cattle; dredged materials; forage-based pasture; probable effect levels (PEL); threshold effect levels (TEL)

## 1 Background, Aim and Scope

The 19.4-km$^2$ Lake Panasoffkee (28.798°N; 82.103°W), located in Sumter County, Florida has enjoyed excellent water quality due to substantial groundwater flow from the Florida's aquifer, but at the same time has lost 324 ha of desirable fisheries habitats due to dissolved calcium carbonates carried by sub-surface groundwater, which settles on the bottom and fills in fish spawning areas (Allen 2000). The Southwest Florida Water Management District (SWFWMD) in cooperation with Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, Sumter County, and the LP Restoration Council have implemented a plan to restore the lake.

The LP Restoration Project has six planned phases to remove natural sediments from the lake bottom to improve fishery and navigation in the lake. Options were explored in the beneficial usage of sediments. One option was to use the sediment as a soil enhancement for agricultural use (see Part 2). Forage production offers an alternative to waste management since nutrients in the waste are recycled into crops such as bahiagrass (BG) that are not directly consumed by humans. Bahiagrass is a good general-use pasture grass that can tolerate a wide range of soil conditions and close grazing, and withstands low fertilizer input (Burson and Watson 1995, Kidder 1999). It has the ability to produce moderate yields on soils of very low fertility and easier to manage than other improved pasture grasses (Chambliss 1999).

Environmental impact assessment is an important pre-requisite to many dredging initiatives (Sigua et al. 2003, Patel et al. 2001, Sigua et al. 2000). Disposal and environmental quality of dredged sediments from navigational channels have been judged as beneficial by combinations of physical, chemical, and biological analyses for over 30 years. However, many people in the scientific community find this approach objectionable since the data does not provide sufficient environmental protection information because several site-specific geochemical and biological factors are typically excluded from the decision-making process (Wenning and Woltering 2001). Current dredged material disposal alternatives have several limitations (Fitzgerald and Pederson 2001). Options for dealing with dredged materials include leaving them alone, capping them with clean sediments, placing them in confined facilities, disposing of them at upland sites, treating them chemically, or using them for wetlands creation or other beneficial uses (Adams and Pederson 2001, Krause and McDonnel 2000, Gambrel et al. 1978).

The bottom sediment materials from lakes, river, and navigational channels usually are composed of upland soil enriched with nutrients and organic matter. These materials should be regarded as a beneficial resource to be used productively and not to be discarded as spoil materials (Patel et al. 2001, Sigua et al. 2000). While preliminary efforts are underway to provide information to establish criteria for land disposal, testing procedures for possible land disposal of contaminated sediments are still in their developing stages.

The sediment removal project in LP is being assessed to determine whether the operation satisfies environmental objectives or expectations. Additional research on disposal options of dredged materials are much needed to supply information on criteria testing and evaluation of the physical and chemical impacts of dredged materials at the disposal site. There is still much to be learned from this project. The goal of this study was to explore the beneficial and ecological use of LDM in improving the physico-chemical properties of existing sandy soils and for sustaining forage productivity in subtropical beef cattle pastures with calcium carbonate- and organic-enriched dredged materials. The LDM, if found to be beneficial, could be removed from the spoil containment areas, trucked to other locations and incorporated into existing pasture fields. The objective of this study was to quantify the effect of applied LDM on soil physicochemical properties at the disposal site.

## 2 Methods

### 2.1 Study site

The study site is located in Sumter County (Coleman Landing, 28.798°N, 82.103°W), Florida (**Fig. 1**). Most of the soils at Sumter County formed in sandy marine or eolian deposits and have a water table depth of 102 to 203 cm for more than 6 months during most years. These soils are hyperthermic, uncoated typic quartzipsamments (USDA 1988). Some selected physical and chemical properties of soils in the study site are shown in **Table 1**. The climate of Sumter County is characterized by long, warm, and relatively humid summers and mild dry winters. The average total annual precipitation (1988–2001) in the area was about 1,191 mm with approximately half (56%) this amount occurring during the mid-June through mid-August period (**Fig. 2**). The lowest average temperature of 15°C occurs during January. The highest average temperature in the mid- to upper-25°C range occurs regularly from June through September (see Fig. 2).

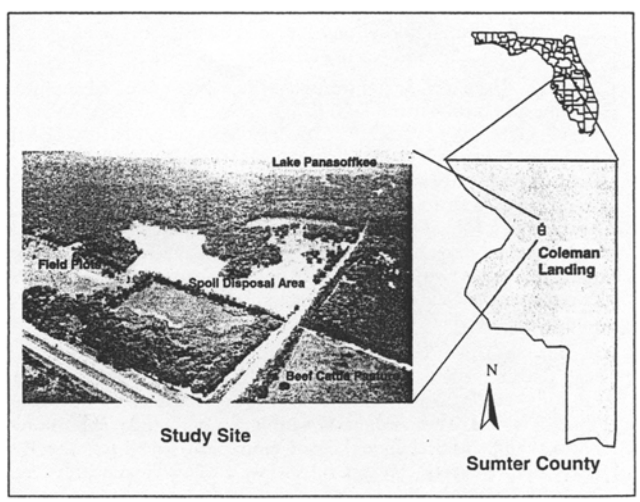


**Fig. 1:** Location of the study site and aerial view of the dredging site at Lake Panasoffkee, Sumter County, FL

**Table 1:** Selected physico-chemical properties of soils from the Coleman Landing site and dredged soil materials from Lake Panasoffkee

| Parameter | Unit | Natural Soil | Lake-Dredged Soil Materials | Analytical Method |
|---|---|---|---|---|
| Sand | % | 87.5 ± 0.0 | | |
| Silt | % | 1.2 ± 1.8 | | |
| Clay | % | 1.2 ± 1.8 | | |
| pH | | 5.9 ± 0.01 | 7.8 ± 0.2 | EPA150.1 |
| Soil Organic Carbon | % | 2.5 ± 1.2 | 12.7 | EPA9060 |
| Soil Organic Matter | % | 4.5 ± 2.2 | | EPA6020 |
| Potassium | mg $kg^{-1}$ | 33.9 ± 11.6 | 4.3 ± 1.8 | EPA6010 |
| Total Phosphorus | mg $kg^{-1}$ | 20.6 ± 38.9 | 1.6 ± 1.2 | EPA351.2 |
| Total Nitrogen | mg $kg^{-1}$ | 2.9 ± 1.5 | 6.9 ± 0.3 | EPA351.1 |
| Ammonium-N | mg $kg^{-1}$ | 0.3 ± 0.3 | | EPA351.1 |
| Nitrate-N | mg $kg^{-1}$ | 2.6 ± 2.0 | 0.2 ± 0.05 | EPA351.1 |
| Nitrite-N | mg $kg^{-1}$ | | 0.3 ± 0.05 | EPA351.1 |
| Magnesium | mg $kg^{-1}$ | 66.2 ± 29.2 | | ASTM C25-95 |
| Zinc | mg $kg^{-1}$ | 0.4 ± 0.3 | 7.0 ± 0.06 | EPA6020 |
| Manganese | mg $kg^{-1}$ | 1.3 ± 0.7 | | EPA6020 |
| Copper | mg $kg^{-1}$ | 0.2 ± 0.4 | 8.7 ± 1.2 | EPA6020 |
| Iron | mg $kg^{-1}$ | 4.9 ± 10.0 | 710.0 ± 1.3 | EPA6020 |
| Aluminum | mg $kg^{-1}$ | 83.4 ± 170.1 | | EPA7471 |
| Sodium | mg $kg^{-1}$ | 25.1 ± 18.7 | | EPA6020 |
| Ca (as $CaCO_3$) | % | | 82.8 | ASTM C25-95 |
| Mg (as $MgCO_3$) | % | | 0.9 | ASTM C25-95 |

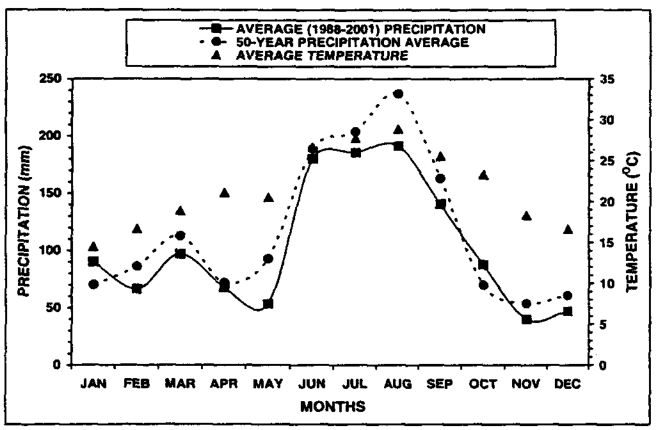


**Fig. 2:** Monthly average rainfall and temperature in Sumter-Hernando County, FL (1988–2001)

### 2.2 Field site preparation and experimental design

This field study was adjacent to the Coleman Landing spoil disposal site in Sumter County, FL (see Fig. 1). Each plot (961 $m^2$) was excavated to a depth of about 28 cm, and existing NS and organic materials were completely removed. Excavated NS materials were placed at the south end of the test plots. Existing vegetation from each plot was totally removed prior to backfilling each plot with different ratios of NS and LDM: (100% NS + 0% LDM); (75% NS + 25% LDM); (50% NS + 50% LDM); (25% NS + 75% LDM); and (0% NS + 100% LDM). These ratios of NS to LDM represent the treatment combinations of LDM0; LDM25; LDM50; LDM75; and LDM100, respectively. Natural soils that were excavated were backfilled to each plot along with LDM that were hauled from the adjacent settling pond (see Fig. 1) on December 15, 2001. The total amount of LDM and NS that was placed back on each test plot was in accordance with the different ratios of LDM and NS that were described above. After mixing the NS and LDM, each of the test plots was disked to a uniform depth of 28 cm. Plots were disked in an alternate direction until LDM and NS were uniformly mixed. Each plot was seeded with BG at a rate of 6 kg $plot^{-1}$, followed by dragging a section of chain link fence across each test plot to ensure that BG seeds were in good contact with the NS and LDM. Field layout was based on the principle of a completely randomized block design with four replications.

### 2.3 Chemical analysis of LDM

Prior to LDM applications in the field, a private laboratory (Flowers Chemical Laboratories, Inc.) in Leesburg, FL performed the physical and chemical analyses of LDM that were used in the study. Results and methods of analyses are given in Table 1. Chemical analyses of LDM are important for its safe and effective use on soils used to grow forages.

### 2.4 Soil sampling and soil analyses

Three sub-samples of soils (0–20 cm depth) were taken from each plot using a 15-cm steel bucket-type hand auger on December 16, 2003. Soil samples were air-dried and passed through a 2-mm mesh sieve prior to soil chemical extractions. The Mehlich 1 method (0.05 N HCl in 0.025 N $H_2SO_4$) was used for chemical extraction of soil (Mehlich 1953). Soil chemical analyses were conducted at the University of Florida-Institute of Food and Agricultural Sciences Soil Testing Laboratory, Gainesville, FL. Soil P and other exchangeable cations (K, Ca, Mg, Al, Fe, Zn, Mn, Cu, Si, and Na) were analyzed using an Inductively Coupled Plasma (ICP) Spectroscopy. Soil organic matter content was analyzed following the method of Walkley and Black (Walkley and Black 1934). Soil pH was determined by using 1:2 soils to water ratio (Thomas 1996).

### 2.5 Soil compaction test

Measurement of soil compaction (0–20 cm depth) was taken on December 16, 2002 and on December 18, 2003 using the Dickey-John Penetrometer[1] (Dickey-John Corp, Auburn, IL). The penetrometer is designed to mimic a plant root, which consists of a 30-degree circular stainless steel cone with a driving shaft and pressure gauge. This penetrometer comes with two cones, one with a base diameter of 2.03 cm for soft soils and 1.28 cm for hard soils. The driving shaft is graduated every 7.62 cm (3 inches) to allow determination of depth of compaction. The pressure gauge indicates pressure in pounds per square inch.

### 2.6 Statistical analysis

The effects of dredged materials addition on soil physico-chemical properties/quality and on soil compaction were analyzed statistically following the PROC ANOVA procedures (SAS 2000). Where the F-test indicated a significant ($p \leq 0.05$) effect, means were separated, following the method of LSD test, using appropriate mean squares (SAS 2000).

## 3 Results

### 3.1 Chemical properties of LDM

The LP dredged sediments had high Ca (as $CaCO_3$) content of 828 ± 2.1 g $kg^{-1}$ and an average pH of 7.8 ± 0.2 (see Table 1). The Mg content of the dredged sediment was about 9.0 ± 3.0 g $kg^{-1}$, while OC level was about 127.0 ± 1.5 g $kg^{-1}$. The TP, TKN, and K contents of the dredged materials were relatively low with mean concentrations of 1.6 ± 1.2, 6.9 ± 0.3, and 4.3 ± 1.8 mg $kg^{-1}$, respectively (**Table 2**). Average values for Pb, Zn, As, Cu, Hg, Se, Cd, and Ni of 5.2 ± 1.3, 7.0 ± 0.6, 4.4 ± 0.1, 8.7 ± 1.2, 0.01 ± 0.02, 0.02 ± 0.02, 2.5 ± 0.1, and 14.6 ± 6.4 mg $kg^{-1}$, respectively, were below the threshold effect levels (TEL) and the probable effect levels (PEL) published by the Florida Department of Protection (McDonald 1994). TEL represents the concentrations of sediment-associated contaminants that are considered to cause significant hazards to aquatic organisms, while, PEL represents the lower limit of the range of the contaminant concentrations that are usually or always associated with adverse biological effects.

### 3.2 Soil compaction

Results have shown the favorable influence that LDM had on soil compaction (**Fig. 3**). The treatment x year interaction effect was not significant, but the average soil compaction varied widely ($p \leq 0.001$) with LDM application. In 2002 and 2003, soil compaction of plots was lowered significantly as a result of LDM additions (see Fig. 3). The least compacted soils in 2002 and 2003 were observed from plots with LDM75 with mean soil compaction of 300 x $10^3$ and 350 x $10^3$ Pa, respectively. The most compacted soils in 2002 and 2003 were from the control plots with mean soil compaction of 1800 x $10^3$ and 1600 x $10^3$ Pa, respectively. The degree of soil compaction in the control plots were com-

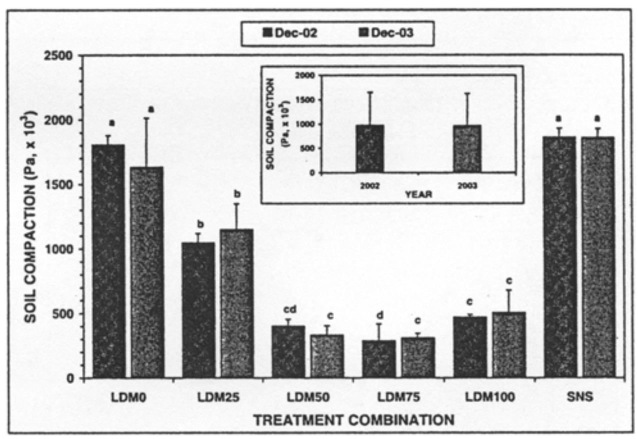


**Fig. 3:** Degree of soil compaction in 2002 and 2003 for soils with varying levels of dredged materials. Soil compactions from plots with or without LDM are significantly different ($p \leq 0.05$) in 2002 and in 2003 when superscripts located at top of bars are different

[1] Mention of trademark, propriety product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

**Table 2:** Trace and heavy metals analyses of dredged materials from Lake Panasoffkee

| Parameter | Unit | Mean | Threshold Effect Levels (TEL)[a] | Probable Effect Levels (PEL)[b] |
|---|---|---|---|---|
| Iron | mg $kg^{-1}$ | 710.0 ± 1.3 | | |
| Silicon | mg $kg^{-1}$ | 490.0 ± 1.2 | | |
| Copper | mg $kg^{-1}$ | 8.7 ± 1.2 | 18.7 | 108 |
| Zinc | mg $kg^{-1}$ | 7.0 ± 0.6 | 124 | 271 |
| Cadmium | mg $kg^{-1}$ | 2.5 ± 0.1 | 0.7 | 4.2 |
| Lead | mg $kg^{-1}$ | 5.2 ± 1.3 | 30.2 | 112 |
| Nickel | mg $kg^{-1}$ | 14.6 ± 6.4 | 15.9 | 42.8 |
| Chromium | mg $kg^{-1}$ | 40.5 ± 2.1 | 52.3 | 160 |
| Arsenic | mg $kg^{-1}$ | 4.4 ± 0.1 | 7.2 | 41.6 |
| Mercury | mg $kg^{-1}$ | 0.01 ± 0.02 | 0.1 | 0.7 |
| Selenium | mg $kg^{-1}$ | 0.02 ± 0.02 | | |
| Molybdenum | mg $kg^{-1}$ | 1.3 ± 0.2 | | |

[a] TEL represents the concentrations of sediment-associated contaminants that are not considered to represent significant hazards to aquatic organism.
[b] PEL defines the lower limit of the range of contaminant concentrations that are usually or always associated with adverse biological effects.

parable with the surrounding natural soils (SNS), but were different and significantly higher than those plots with LDM additions. Soil compactions in plots LDM50, LDM75, and LDM100 were all comparable among each other in 2002 and in 2003, respectively (see Fig. 3).

### 3.3 Soil nutrient availability

Except for Na, the levels of soil pH, K, Ca, Mg, Zn, Mn, Cu, Fe, Al, and Si varied significantly ($p \leq 0.001$) among plots amended with different rates of LDM (**Tables 3 and 4**). Compared with the control plots, the soils in plots amended with LDM exhibited: (1) a decrease in the levels of soil K, Mn, Cu, Fe, Zn, and Al; (2) an increase in soil pH, Ca, Mg, and Si; and (3) no significant change in the level of Na in the soil.

Addition of LDM resulted in higher soil pH than those plots with 0% LDM. Soil pH (averaged across plots with LDM) of 8.4 ± 0.2 was higher than plots with 0% LDM, which had an average soil pH of 5.9 ± 0.1. The range of soil pH among plots with LDM was from 8.2 ± 0.09 to 8.5 ± 0.11 (see Table 3). The amount of soil Ca and Mg among plots with LDM were significantly higher than that in the control plots. However, the amount of soil Ca and Mg among plots with LDM were statistically comparable among each other. Addition of LDM had increased the levels of Ca and Mg by about 1811% and 211%, respectively when compared with the level of soil Ca and Mg among plots with no LDM application (see Table 3).

The levels of soil Mn, Cu, Fe, and Al were significantly lowered by the addition of LDM. Levels of Mn, Cu, Fe, and Al (averaged across treatments) were reduced from 2.9 to 0.3, 0.456 to 0.002, 15.61 to 0.01, and 187.23 to 0.07 mg $kg^{-1}$, respectively when compared with the levels of Mn, Cu, Fe, and Al for soils with 0% LDM (see Table 4). The levels of Si in plots with LDM were significantly higher than the levels of Si in plots with 0% LDM while the Na level in the soil was not affected by LDM additions (see Table 4).

Soil K levels, unlike other nutrients that were described above did not show any distinct trend and/or response to LDM additions. The highest average soil K levels of 3.6 ± 0.6 mg $kg^{-1}$ was observed from plots with 0% LDM while the lowest soil K value of 0.9 ± 0.1 mg $kg^{-1}$ was from plots with 25% LDM. Levels of soil K among plots with 0%, 50%, 75%, and 100% LDM were statistically ($p \leq 0.05$) comparable (see Table 3).

## 4 Discussion

Sediments that were dredged from LP have high $CaCO_3$ content (82%) and when these materials were incorporated into existing topsoil they would have the same favorable effects as liming the field. Thus, sediments with high $CaCO_3$ may improve the physical and chemical conditions of subtropical sandy pastures. It should be noted that Ca is not the only key to reducing soil acidity. Without the carbonate ($CO_3^{-2}$), the soil would still contain the acid ion and pH would not change. The LDM (82% $CaCO_3$) used in this study can be more effective liming materials than commercially available gypsum ($CaSO_4.nH_2O$) as an acidity reducer for soils. Gypsum will not reduce soil acidity. Calcium from soluble gypsum does not replace hydrogen on the soils. The hydrogen ions then react with sulfate in soil solution to form sulfuric acid. Sulfuric acid is stable in the soil system, thus there is no change in soil pH.

Addition of LDM had increased the levels of Ca and Mg by about 1811% and 211%, respectively when compared with the level of soil Ca and Mg among plots with no LDM application. Liming the field could have some direct and indirect effects on the chemical status of the soils. Perhaps the single direct benefit of liming is the reduction in acidity and solubility of aluminum and manganese (Peevy et al. 1972). Some of the indirect benefits of liming pasture fields among others would include: enhancing P and micronutrient availability, nitrification, nitrogen fixation, and improving soil physical conditions (Tisdale and Nelson 1975, Russel 1973, Nelson 1980). Addition of LDM resulted in higher soil pH than those plots with 0% LDM. The higher pH values for soils with LDM would favor hydrolysis reactions for Ca and Mg which increase the plant availability of these two nutrients. Higher pH values may well inactivate Al, Mn, Cu, and Fe. Our results have shown that the availability of soil Mn, Cu, Fe, and Al were significantly lowered by the addition of LDM (Tisdale and Nelson 1975).

**Table 3:** Levels of soil pH, K, Ca, Mg, and Zn in plots with or without addition of dredged materials

| Treatment Combination (NS + LDM) (%) | pH | K | Ca | Mg | Zn |
|---|---|---|---|---|---|
| | | | mg $kg^{-1}$ | | |
| LDM0 – (100 + 0) | 5.98 ± 0.10c† | 3.6 ± 0.6ab | 105.2 ± 5.4b | 4.4 ± 2.6b | 0.690 ± 0.128a |
| LDM25 – (75 + 25) | 8.39 ± 0.27ab | 0.9 ± 0.1c | 1962.7 ± 25.8a | 11.9 ± 0.7a | 0.010 ± 0.005b |
| LDM50 – (50 + 50) | 8.35 ± 0.14ab | 2.8 ± 1.4ab | 2040.3 ± 29.1a | 13.6 ± 1.1a | 0.006 ± 0.001b |
| LDM75 – (25 + 75) | 8.17 ± 0.09b | 1.8 ± 1.0bc | 2008.7 ± 87.1a | 14.6 ± 1.7a | 0.007 ± 0.001b |
| LDM100 – (0 + 100) | 8.54 ± 0.11a | 2.5 ± 0.7bc | 2030.0 ± 9.2a | 14.7 ± 0.6a | 0.005 ± 0.000b |

†Means on each column followed by same letter(s) are not significantly different from each other at $p \leq 0.05$.

**Table 4:** Levels of soil Mn, Cu, Fe, Al, Si, and Na in plots with or without addition of dredged materials

| Treatment Combination (NS + LDM) (%) | Mn | Cu | Fe | Al | Si | Na |
|---|---|---|---|---|---|---|
| | | | | mg $kg^{-1}$ | | |
| LDM0 – (100 + 0) | 2.86 ± 0.39a† | 0.456 ± 0.053a | 15.606 ± 5.598a | 187.23 ± 13.28a | 20.47 ± 2.02b | 20.21 ± 1.16a |
| LDM25 – (75 + 25) | 0.35 ± 0.05b | 0.001 ± 0.001b | 0.029 ± 0.051b | 0.19 ± 0.25b | 30.75 ± 8.82a | 23.52 ± 6.18a |
| LDM50 – (50 + 50) | 0.31 ± 0.01b | 0.002 ± 0.001b | 0.006 ± 0.001b | 0.03 ± 0.02b | 37.14 ± 1.10a | 21.31 ± 0.92a |
| LDM75 – (25 + 75) | 0.25 ± 0.01b | 0.002 ± 0.002b | 0.007 ± 0.001b | 0.01 ± 0.01b | 37.89 ± 2.20a | 22.51 ± 3.17a |
| LDM100 – (0 + 100) | 0.34 ± 0.04b | 0.003 ± 0.002b | 0.005 ± 0.000b | 0.04 ± 0.07b | 36.38 ± 1.11a | 22.14 ± 2.44a |

†Means on each column followed by same letter(s) are not significantly different from each other at $p \leq 0.05$.

Soil compaction was lowered significantly by the application of LDM. The least compacted soils in 2002 and 2003 were observed from plots with 75% LDM, while the most compacted soils in 2002 and 2003 were from the control plots (0% LDM). These results have shown the favorable influence that LDM had on soil compaction. The higher rate of LDM application may have had improved soil structure and soil tilth which can promote better water holding capacity, sufficient aeration, and creates more friable soils. The compaction of agricultural soils is a serious problem and growing concern because the productive capacity of the land could be seriously reduced. A compacted layer within the soil profile may restrict root growth and access to water and nutrients (Follet and Wilkinson 1995). The structure of fine-textured (typic quartzipsamments) soils in the study area (Coleman Landing) has shown improvement as a result of LDM addition. This is largely the result of an increase in the organic matter content and to a lesser extent to the flocculation of calcium-saturated colloids. Application of LDM may have had promoted intense biological activity, increased nitrogen fixation by soil microorganisms, and release of component elements by the more rapid decomposition of plant residues (Follet and Wilkinsin 1995, Pearson and Hoveland 1974).

## 5 Conclusions

Beneficial uses of dredged materials are both economical and environmental. Often these materials can be obtained at little or no cost to the farmers or landowners. Environmentally, dredging of sediments that are rich in $CaCO_3$ should restore the 19.4-sq km LP by removing natural sediments from the lake bottom to improve the fishery, water quality, and navigation of the lake. Addition of LDM had significant effects on soil physico-chemical properties. Compared with the control plots, the soils in plots amended with LDM exhibited: (1) an increase in soil pH, Ca, and Mg; (2) a decrease in the levels of soil Mn, Cu, Fe, Zn, and Si; (3) no significant change in the level of Na in the soil; and (4) a much lower degree of soil compaction.

The bottom sediment materials from lakes, rivers, and navigational channels usually are composed of upland soil enriched with nutrients and organic matter. These materials should be regarded as a beneficial resource to be used productively and not to be discarded as spoil materials. While preliminary efforts are underway to provide information to establish criteria for land disposal, testing procedures for possible land disposal of contaminated sediments are still in their developing stages.

## 6 Outlook

Land application of LDM from LP may not only provide substantial benefits that will enhance the environment, community, and society in south Florida, but also in other parts of the world especially those areas having tropical and subtropical climate with forage-based beef cattle pastures. The heavy and trace metal contents of LDM from LP were below the PEL and TEL. As such, the agricultural or livestock industry could utilize these LDM to produce forages (Part 2 of this study). LDM should be regarded as a beneficial resource, as a part of the ecological system. Further studies are still needed to determine whether the environmental and ecological implications of LDM application are satisfied over the longer term.

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