SOIL CONDITIONS AND PLANT ESTABLISHMENT ON RECLAIMED PHOSPHATE-MINED UPLANDS

by

Vimala D. Nair, Nancy J. Bissett, Kenneth M. Portier, Donald A. Graetz, Debra S. Segal, and Robert A. Garren

Abstract: The associations between upland reclamation construction techniques and related soil parameters on the establishment of native and exotic plants were investigated. Ten reclaimed sites were sampled representing different construction techniques - overburden (OB), sand tailings (ST), topsoil (TS), and mixtures, TS/OB and ST/OB. Soil parameters and vegetation community structure were evaluated on 9 to 24 transects (3 to 30 m length) at each site. Soil characteristics determined included pH, total C and N, CEC, available nutrients (Ca, Mg, K, P, Zn, Cu, Mn, Fe, and Na), and moisture index. The vegetation species were grouped into introduced aggressive grasses, wiregrass, lovegrasses, scrub species, and wetland species and the preferred soil conditions for these groups were evaluated. The relationship between the individual introduced aggressive grasses, cogongrass (*Imperata cylindrica*), natalgrass (*Rhynchelytrum repens*), bahiagrass (*Paspalum notatum*), bermudagrass (*Cynodon dactylon*) and torpedograss (*Panicum repens*), and soil characteristics was also evaluated. There are numerous complex factors and interactions causing variation in vegetation ground cover on the 10 sites. Introduction of native species and method of introduction were primary factors. Some general soil/plant relationships were noted, although soil characteristics were not the only critical factors for establishment of many of the vegetation types. Higher concentrations of soil nutrients and high pH promoted greater vegetative cover of introduced aggressive grasses. Therefore, soil amendments added to the soil to increase fertility may benefit undesirable aggressive grasses, at the expense of slow-growing native species. Areas with higher soil moisture retention such as low-lying pockets and overburden with high clay content near the surface may favor introduced aggressive grasses in communities where xeric species are targeted. However, high moisture retention capacity can favor native taxa indicative of mesic flatwoods or hydric flatwoods. Advancing the base knowledge for improving upland reclamation would require controlled experimentation to determine soil conditions best suitable for native taxa.

Additional Key Words: overburden, sand tailings, topsoil, aggressive grasses, wiregrass, lovegrasses, scrub species, wetland species.

Introduction

Mining of phosphate in central and northern Florida has involved more than 66,800 ha (165,000 acres) of land (Marion, 1986), and a much larger area will be mined in the future. While much of this land was used for agricultural production prior to mining, and much will be reclaimed for that purpose after mining, there remains a need for development of techniques for reclaiming native upland communities. The 1978 state law (Florida Statutes, Chapter 378) requiring reclamation of all lands mined after 1975 recognized the broad value of native ecosystems, such as the provision of habitat for fish and wildlife. Reclamation requirements were given in DNR rules (Chapter 16C-16, Florida Administrative Code, 1994) stating, in addition to numerous physical requirements for reclamation projects, that reclaimed wetlands area had to be equal to the area of land as they covered prior to mining, and a minimum of 10% of upland areas had to be replanted with a variety of indigenous hardwoods and conifers. To date, little research has been conducted on these upland landscapes of the reclamation plan. Uplands have not received the

[1]Paper presented at the 2000 National Meeting of the American Society for Surface Mining and Reclamation, Tampa, Florida, June 11-15, 2000.

[2]V.D. Nair, Research Assistant Professor, K.M. Portier, Associate Professor, D.A. Graetz, Professor, IFAS, University of Florida, Gainesville, FL 32611-0510; N.J. Bissett, Horticulturist, The Natives, Inc., Davenport, FL 33837; D.S. Segal, Senior Scientist, Jones, Edmunds & Associates, Gainesville, FL 32641; R.A. Garren, Ecologist, Gainesville, FL 32605. Florida Agricultural Experiment Station Journal Series R-07494.

Proceedings America Society of Mining and Reclamation, 2000 pp 35-48
DOI: 10.21000/JASMR00010035

https://doi.org/10.21000/JASMR00010035

same degree of legal protection as wetlands, but are now being recognized as vital ecosystems worthy of restoration. Reclamation of upland communities has been attempted by the phosphate industry, but unlike wetland reclamation, data on techniques and methodology for upland reclamation has not been compiled and synthesized. This study evaluates soil properties to determine which soil parameters influence successful reclamation of native upland taxa, as well as favor the growth and establishment of undesirable introduced aggressive grasses. The specific objectives for this study were to:

- Evaluate information on soils, vegetation, and hydrology based on systematic and detailed sampling of ten existing upland reclamation sites which have documented history of specific construction and planting techniques.
- Based on the above information, identify construction-related and soils-related parameters critical for the successful construction and establishment of native upland communities.

Materials and Methods

Site Selection

Reclamation specialists from phosphate industries, state agencies, and private companies were consulted to obtain information regarding sites that were mined and reclaimed to native upland plant communities. A total of 22 potential study sites were identified and evaluated in the field to determine suitability for this study. Criteria used for site selection included presence of native herbaceous species, lack of disturbance (such as cattle grazing or mowing), and known history of construction and planting methods. Ten sites were selected for this study. Nine sites are located in the tri-county area of Polk, Hillsborough, and Hardee Counties, and the tenth site, the PCS site, is located in Hamilton County. These sites were selected based on the criteria listed above, as well as to allow comparison of specific variables such as overburden vs. sand tailings, topsoil augmentation vs. no topsoil augmentation, and young sites vs. older sites (Table 1).

Quadrat selection

Distinct vegetation zones were identified at each study site and included high and low covers of desirable and weedy species. Desirable species were those species indicative of healthy scrub, sandhill, scrubby flatwoods, mesic flatwoods, and hydric flatwoods communities. Weedy species encompassed two vegetation categories; true weedy species that quickly colonize severely and a introduced aggressive species that quickly colonize a disturbed site and persist in a stable system. For simplicity, the term *aggressive species* will be used henceforth instead of *introduced aggressive species.*

Typically, three elongated quadrats were nonrandomly located in each vegetation zone at each study site. Some study sites did not support all four broad vegetation zones in sufficient area to replicate the quadrats. The quadrats were generally located in areas where vegetation reseeded or emerged from a nearby seed source, rather than in distinctly planted areas. At some sites, we expanded our sampling protocol to include species monocultures. For example, some areas contained stands exclusively of cogongrass, bahiagrass, natalgrass, or *Schizachyrium stoloniferum*. In those cases, we constructed replicate quadrats in the monostands to test the hypothesis that certain soil parameters promote colonization of undesirable species, or in the case of the *Schizachyrium stoloniferum*, support colonization of this desirable flatwoods species.

In this study, the physical location of the quadrats within each strata were not totally random, which introduced the potential for bias in the collected data. Differences observed are likely to be greater than would be observed from data collected at random locations. However, this sampling design was chosen to examine the full range in vegetation cover to provide the best chance of identifying relationships (regression) with soil parameters.

Vegetation Characterization

Vegetation monitoring followed methods outlined by Ecosystem Research Corporation (ERC, 1992). Quadrat lengths varied, and ranged from 3.0 to 24 m (10 to 80 feet) depending on extent of the vegetation community being characterized. Each quadrat was 0.6 m (2 feet) wide, and the length was divided into continuous 3-m (10-foot) intervals. The 3-m intervals were further divided into ten 0.3- x 0.6-m (1- x 2-foot) intervals. Species cover was determined on the basis of percent cover of each species within each 3- x 0.6- m(10- x 2-foot) cover interval. Frequency was determined by species on the basis of occurrence within each 0.3- x 0.6-m (1- x 2-foot) interval. Therefore, a maximum value of 10 was possible for each 3-m interval. Total Quadrat Area Probable Percent Cover Range (ERC, 1992) was then calculated for each individual quadrat.

Table 1. Location and characteristics of the study sites.

Site Name	Industry	Industry's designation	Latitude, Longitude	Topsoil Applied	Age[†] (Years)	Substrate[‡]
Bald Mountain	IMC-Agrico	IMC-KC-LB(2)	N27^0 47.18', W82^0 02.77'	No	4	ST with OB cap
Best-of-the-West	IMC-Agrico	IMC-NP-SWB(1)	N27^0 51.50', W81^0 54.51'	Yes	11	OB
Estec Topsoil Site	Estec	Parcel 188	N27^0 42.56', W81^0 44.25'	Yes	6 - 7	OB
Gopher Hills	IMC-Agrico	AGR-FG-SP(14)	N27^0 40.62', W81^0 50.65'	Yes	2 - 4	ST on OB
Hardee Lakes	IMC-Agrico	AGR-FG-PC(1)	N27^0 38.24', W81^0 54.29'	Yes	6 - 7	OB
Margaret Gilbert	IMC-Agrico	BP-L-SP(2a)	N27^0 47.74', W82^0 05.72'	No	12	OB and ST
Noralyn South	IMC-Agrico	IMC-N-5	N27^0 50.26', W81^0 50.20'	No [§]	15	ST amended with clay
PCS Site	PCS	PCS-SC-86(1)	N30^0 25.55', W82^0 53.40'	Yes	4 -5	OB
16-Acre Direct Seed Site	IMC-Agrico	AGR-FG-PC(2)	N27^0 44.39', W81^0 55.71'	No	3	OB/ ST mixture with OB cap
Wildlife Corridor	Cargill	SP-12	N27^0 39.44', W81^0 50.22'	No	8 - 11	OB and ST

† Years calculated to 1997 (when vegetation and soil analyses began)
‡ OB = Overburden, ST = Sand Tailings
§ Parts of the site received topsoil, but topsoil was not present in our quadrats.

Total Quadrat Area Probable Percent Cover Range =

$$\sum \frac{[(\text{freq. in each cover range}) \times (\text{min./avg./max. value for each range})]}{\text{total number of cover intervals in the quadrat}}$$

where total frequency is the total number of 0.3- x 0.6-m (1- x 2-foot) intervals where the species occurred.

The vegetation was initially categorized as desirable and weedy. These groups were further defined by species origin and species type as follows:

Origin:

Native: Species native to this region
Exotic: Species native to another continent or another region, but not to this region

Type:

Characteristic: Species that are found in mature ecosystems

Pioneer: Species that readily reseed in unnatural or severely disturbed areas but persist and are characteristic of mature ecosystems

Weedy: Species that depend on unnatural or severe disturbance to become established but do not persist in mature ecosystems

Aggressive: Species that out-compete weedy species and sometimes even out-compete characteristic species of mature ecosystems; these species are not native.

We once again divided the vegetation into specific groups that represent plants that occur in specific ecosystems of different levels of disturbance. Aggressive grasses are a group of exotic perennial grasses that enter a site during the weedy phase, expand their territory rapidly, and persist in competition with perennial natives. Wiregrass is the keystone species flatwoods and sandhills because of its ability to carry fire which is necessary to maintain these systems. Lovegrasses typify pioneer species or species found in mature ecosystems but readily reseed into disturbed areas and are therefore useful in restoration. The last two categories, scrub and wetland species, were an attempt to sort out moisture extremes of upland systems. The species contained in each group are listed in Table 2

Soil Profile Characterization and Sampling

"Soil" in this study was defined as the material upon which vegetation was established on reclaimed phosphate-mined lands and therefore included topsoil, sand tailings, overburden, clay, and mixtures of these materials. Soils were characterized along each quadrat at approximately 10-m intervals. Topsoil is typically a light. gray to dark gray fine sand that was removed from the surface of an unmined donor site. Sand tailings by definition is sand that was separated from the phosphate matrix or ore as the ore was processed. Sand tailings are typically fine sand, but unlike topsoil are white in color and resemble beach sand. Frequently, small black particles containing phosphate ore are present in the white sand tailings. Overburden by definition is all the soil that lies above the phosphate matrix, and is therefore the most variable matrix in terms of texture and color. Overburden ranges from sand to sandy clay loam, to clay, and can be yellow, orange, tan, brown, or any combination of these colors. Concretions, mottles, and pockets of clay are commonly found in overburden. Once the overburden has been removed it is referred to as "spoil."

One intact soil core (30 cm depth) was collected at every 9-m (30-foot) interval along each quadrat using a soil probe. Frequently, two or more soils were encountered in the 30 cm soil profile, such as topsoil and overburden, topsoil and sand tailings, or sand tailings and overburden. In these cases, a subsample of soil was collected from each soil type. Where no notable changes in soil type, color, or texture occurred within the upper 30 cm, then a surface sample (0 - 15 cm) and a subsurface sample (15 - 30 cm) of soil were collected from each soil profile. All samples were placed in plastic bags, labeled, and taken to the Soils Laboratory, Soil and Water Science Department at the University of Florida in Gainesville, Florida, for analyses of chemical parameters.

Table 2. Classification of specific vegetation groups.

Aggressive Grasses	Includes cogongrass (*Imperata cylindrica*), natalgrass (*Rhynchelytrum repens*), bahiagrass (*Paspalum notatum*), bermudagrass (*Cynodon dactylon*) and, torpedograss (*Panicum repens*).
Wiregrass	*Aristida beyrichiana*
Lovegrasses	Includes *Eragrostis elliottii, E. rafracta*, and *E. spectabilis.*
Scrub Species	Includes the following species usually found only in scrub soils: *Polygonella polygama, Chrysopsis floridana, Cladina evansii, Cladina subtenuis, Cladina leporina, Garberia heterophylla, Liatris chapmanii, Liatris ohlingerae, Nolina brittoniana, Persea humilis*, and *Balduina angustifolia.*
Wetland Species	Includes the following species: *Agalinis purpurea, Amphicarpum muhlenbergianum, Andropogon glomeratus* var. *glomeratus, A. glomeratus* var. *glaucopsis, A. glomeratus* var. *hirsutior, Blechnum serrulatum, Carex verrucosa, Celtis laevigata, Centella asiatica, Chaptalia tomentosa, Coreopsis floridana, Ctenium aromaticum, Cyperus brevifolius, C. globulosus, C. odoratus, C. polystachyos, C. surinamensis, Elyonurus tripsacoides, Fimbristylis dichotoma, F. puberula, Hydrocotyle umbellata, Iva microcephala, Juncus dichotomus, J. effusus, J. scirpoides, Lindernia grandiflora, Ludwigia maritima, L. peruviana, Panicum hemitomon, P. repens, P. tenerum, Persea palustris, Pluchea rosea, Polygonum hydropiperoides, P. punctatum, Rhynchospora fascicularis, R. plumosa, Salix caroliniana, Solidago elliottii, S. stricta, Thelypteris dentata, Xyris ambigua*, and *X. caroliniana*

Soil Analyses. Total weight and volume of each soil sample was recorded for bulk density calculations as soon as the samples were brought to the laboratory. The pH was determined on all samples (1:2 soil:water). Subsamples from each soil sample were oven dried at 105° C for a minimum of 24 hours for moisture content determination. Bulk density of all soil samples were then calculated based on the oven-dried weight. The samples were dried, pulverized, and passed through a 2-mm sieve, and analyzed for total C, total N, and available nutrients. Total C and N were measured using a Carlo Erba CNS Analyzer (Carlo Erba, Milan, Italy).

Available P, K, Ca, Mg, Zn, Mn, Cu, Fe, and Na were extracted using the Mehlich III procedure (Mehlich, 1984). The extracting solution was ammonium nitrate in an ammonium fluoride/EDTA mixture, and the resulting mixture acidified with an acetic acid/nitric acid solution to maintain a pH of 2.5. The elements were analyzed using an inductively coupled argon plasma (ICAP) emission spectrometer.

Cation exchange capacity (CEC) was determined on surface soils. The cation exchange sites were saturated with Na by equilibrating a subsample with 0.4 M NaOAc-0.1 M NaCl solution (pH 8.2) in 60% ethanol. The Na-saturated soil was then extracted with 0.5 M $MgNO_3$ solution (Rhoades, 1982) to determine total exchangeable Na. Sodium in the extract, which represents CEC of the soil, was analyzed using an atomic absorption spectrophotometer.

Moisture index was visually assessed at each quadrat based on soil type and vegetation characteristics. The visual assessment of the vegetation was based on species present, their dominance in the quadrat, and the type of community in which they were most likely to be found. This was a subjective assessment by the botonist. The moisture index was based on a 1 to 5 scale, with 1 being the driest, and 5 the wettest. The moisture index in general corresponded to the follow vegetation communities: 1 = Scrub, 2 = Sandhill, 3 = Scrubby flatwoods, 4 = Mesic flatwoods and 5 = Hydric flatwoods

Statistical Analyses

Preliminary data analysis consisted of computations of arithmetic averages and variances. One-way classification linear models (Littell et al., 1991; Sokal and Rolhf, 1969) were utilized to examine differences in soil parameter values across soil types and vegetation classes as previously defined. Where significant differences in average soil parameters were observed, a Waller-Duncan K-ratio t-test (k set at 100 which is equivalent to a 95% type I error rate) was used to indicate significant differences in class means (Waller and Duncan, 1969; SAS Institute Inc., 1989). Levenes test (Levene, 1960) was used to examine the data for heterogeneity of variance. Heterogeneity of variance and nonnormality were within ranges acceptable for normal-based analysis of variance procedures.

The probable percent cover range measurements computed for specific vegetation types were summed within a transect to produce a total cover index for vegetation within a vegetation class, e.g., aggressive species. Since much of the vegetation overlaps, it is quite common to find the total cover index extend beyond 100%. This precluded the use of a standard transformation, such as the square root of the arcsine of the total cover index as a proportion, in the statistical analysis. Examination of the distribution of total cover indicated acceptable normality so untransformed data were used in most analyses. One-way and two-way classification linear models and associated multiple comparison procedures of the same type used for the soils parameter analyses were also used to compare differences in total cover index.

Results and Discussion

Soil Physical and Chemical Characteristics

Numerous combinations of soil types were encountered within the upper 30 cm, however only seven soil combinations were documented with sufficient frequency to conduct meaningful statistical tests. These seven soil types include overburden, sand tailings, sand tailings on overburden, sand tailings/clay mixture, sand tailings/clay slurry mixture, topsoil, and topsoil on overburden.

Chemical parameters in soils also exhibited a high degree of variability. Overburden, which by definition includes all soil above the phosphate ore, visually contained the highest variability in soil physical properties. Similarly, chemical parameters in overburden were quite variable. This is best exemplified in the five study sites that contained overburden (Table 3). Of the 14 soil parameters, we detected a significant difference in all soil parameters except total C and N among the five sites. When comparing soil parameters in overburden to soil parameters in other soils, we found overburden to be intermediate in value compared to other soils (Table 4). However, two patterns were detected in overburden; first that available P concentrations were significantly higher, and second that Zn concentrations were significantly lower than most of the other soils.

Sand tailings, which by definition is sand that

Table 3. Variability in soil properties of overburden material from five reclaimed sites. (Note: These are mean values from 9 to 24 quadrats at each site).

Soil Properties	Site‡				
	PC	WC	HL	MG	SA
pH	5.32^{B}	6.01^{A}	5.91^{A}	5.17^{B}	6.06^{A}
C, %	0.93^{A}	1.08^{A}	1.06^{A}	0.47^{A}	0.39^{A}
N, %	0.04^{A}	0.05^{A}	0.05^{A}	0.03^{A}	0.01^{A}
Ca, mg kg^{-1}	1149^{A}	660^{B}	523^{B}	259^{B}	612^{B}
Mg, mg kg^{-1}	190^{A}	113^{AB}	56^{B}	22^{B}	76^{B}
K, mg kg^{-1}	71^{A}	12^{BC}	31^{B}	16^{BC}	8^{C}
P, mg kg^{-1}	187^{B}	274^{AB}	350^{A}	174^{B}	386^{A}
Zn, mg kg^{-1}	0.56^{B}	0.86^{AB}	0.73^{AB}	1.02^{A}	0.48^{B}
Cu, mg kg^{-1}	0.71^{A}	0.23^{B}	0.24^{B}	0.33^{AB}	0.17^{B}
Mn, mg kg^{-1}	1.8^{AB}	0.86^{C}	1.1^{BC}	2.3^{A}	0.40^{C}
Fe, mg kg^{-1}	110^{A}	33^{BC}	81^{AB}	30^{C}	76^{ABC}
Na, mg kg^{-1}	24^{A}	17^{AB}	10^{B}	13^{B}	15^{B}
CEC, cmol kg^{-1}	28^{A}	24^{AB}	25^{AB}	14^{B}	28^{A}
Moisture Index	4.0^{A}	2.9^{B}	4.0^{A}	2.4^{B}	3.2^{AB}

† Mean values for a given soil parameter followed by the same letter are not significantly different ($p < 0.05$) within a row of data.

‡ PC = PCS site in N. Florida, WC = Wildlife Corridor, HL = Hardee Lakes, MG = Margaret Gilbert, SA = Sixteen Acres

was separated from phosphate ore during processing, exhibited similar soil chemical properties to the sand tailings/overburden. Both straight sand tailings and sand tailings/overburden can be characterized as nutrient poor and droughty, as evidenced by a significantly lower total C, total N, Ca, Mg, Zn, Fe, CEC, and moisture index (Table 4). Mislevy and Blue (1981 a, b, c) found that although low in several nutrients, organic matter, and water retention capacity, sand tailings contain no phytotoxic substances. Adding sand tailings to a clay or clay slurry produced significantly higher pH, Ca, Mg, P, Zn Mn, Fe, CEC, and moisture index. Like sand tailings, clays also contain no phytotoxic substances, although they are low in organic matter, high in P, K, Ca, and Mg, and contain marginal concentrations of Mn, Cu, Zn, and Fe (Mislevy et al., 1989). Bromwell and Carrier (1989) reported higher CEC for phosphatic clay and sand/clay mixtures compared to sand tailings. Mehlich I extracts in their study showed high concentrations of Ca, Mg and P similar to high concentrations of these ions in the Mehlich III extracts in the current studies. Bromwell and Carrier (1989) concluded that due to low concentrations of micronutrients, corrective applications of micronutrients may be required for growing crops in soils derived from phosphatic clay. Topsoil and topsoil on overburden enhanced soil properties by decreasing pH, and increasing total C and N (Table 4). The addition of topsoil also resulted in a significantly lower Ca, Mg, P, Na, and CEC.

Using a scale of 1 to 5 based on vegetative and soil characteristics, a soil moisture index value was assigned to each quadrat at each site. The lowest value of

Table 4. Characteristics of soil matrices† for the surface horizon.‡ (Note: These are mean values from multiple transects at 10 study sites.)

Matrix Characteristics	OB	ST	ST/OB	ST/CL	ST/CS	TS	TS/OB
pH	5.88^{B}	5.80^{B}	6.16^{B}	6.85^{A}	7.04^{A}	5.09^{C}	4.99^{C}
C, %	0.67^{BC}	0.28^{C}	0.43^{C}	0.40^{C}	0.45^{C}	1.26^{A}	1.22^{A}
N, %	0.03^{AB}	0.02^{AB}	0.01^{B}	0.02^{AB}	0.02^{AB}	0.04^{AB}	0.05^{A}
Ca, mg kg^{-1}	661^{B}	299^{C}	280^{C}	996^{A}	1066^{A}	318^{C}	219^{C}
Mg, mg kg^{-1}	96^{BC}	12^{D}	25^{D}	135^{AB}	177^{A}	42^{CD}	18^{D}
K, mg kg^{-1}	18.0^{A}	8.05^{A}	10.7^{A}	14.1^{A}	16.7^{A}	17.4^{A}	13.5^{A}
P, mg kg^{-1}	312^{A}	135^{C}	226^{B}	289^{AB}	313^{A}	81^{C}	57^{C}
Zn, mg kg^{-1}	0.65^{C}	0.81^{C}	0.59^{C}	1.39^{B}	2.45^{A}	0.86^{C}	1.41^{B}
Cu, mg kg^{-1}	0.27^{A}	0.21^{A}	0.16^{A}	0.30^{A}	0.32^{A}	0.20^{A}	0.21^{A}
Mn, mg kg^{-1}	0.88^{B}	1.47^{B}	0.57^{B}	3.30^{A}	3.55^{A}	1.36^{B}	2.81^{A}
Fe, mg kg^{-1}	64A^{B}	22^{C}	16^{C}	78^{A}	81^{A}	44^{BC}	58^{AB}
Na, mg kg^{-1}	16.6^{AB}	15.6^{BC}	20.5^{A}	20.0^{AB}	17.5^{AB}	11.9^{C}	11.6^{C}
CEC, cmol kg^{-1}	25.7^{BCD}	13.8^{E}	19.9^{CDE}	48.9^{A}	30.3^{BC}	32.8^{B}	18.8^{ED}
Moisture index	3.15^{A}	1.38^{D}	1.90^{CD}	2.40^{BC}	3.33^{A}	3.02^{AB}	2.25^{C}

† OB = Overburden
ST = Sand tailings
ST/CL = Sand tailings with clay
ST/CS = Sand tailings/clay slurry mixture
ST/OB = Sand tailings/overburden mixture
TS = Topsoil
TS/OB = Topsoil/overburden mixture

‡ Mean values for a given soil parameter followed by the same letter are not significantly different ($p < 0.05$) within a row of data.

1 represented the driest habitat, which was equated to a scrub community, and 5 represented the wettest habitat, which was equated to a hydric flatwood habitat type. A comparison was made to determine how the moisture index changed between soils with a single soil type and soils comprised of two different soil types within the upper 30 cm.

Waller-Duncan statistical analyses showed that the soil moisture index did not change significantly between overburden (mean moisture index = 3.4) and overburden on sand tailings (mean moisture index = 3.0). The addition of sand tailings to an overburden soil (especially an overburden soil with high clay content) should lead to drier conditions, which would be indicative of a lower soil moisture index. This was the pattern observed at Bald Mountain, where sand tailings generally supported scrub and sandhill species. However, when overburden occurred together with sand tailings, nonscrub and nonsandhill species such as aggressive grasses and weedy species tended to occur. No significant difference in moisture index value between overburden and overburden on sand tailings was detected probably because the comparison included both sandy and clayey overburden, and variable thicknesses of both overburden and sand tailings. This variability in soil texture and soil thickness led to a high variability in soil moisture index of overburden on sand tailings, which resulted in no significant difference in moisture index between overburden and overburden on sand tailings.

The addition of topsoil to overburden resulted in a significantly higher soil moisture index (wetter soils; mean moisture index = 3.8) as compared to a thick horizon of only topsoil (mean moisture index = 2.9). Conversely, the addition of topsoil to sand tailings resulted in a significantly lower soil moisture index (drier soil; mean moisture index = 2.7) as compared to a thick (>30 cm) horizon of only topsoil (mean moisture index = 3.5). These observations are critical when transferring topsoil from a donor site to a site to be reclaimed consisting of either overburden or sand tailings.

Relationship between Species Origin and Soil Characteristics

When analyzing species origin (native, exotic) and species type (aggressive, weedy, pioneer, characteristic) data, we found native species occurred at high percent cover on topsoil and topsoil on overburden. (Table 5). In general, native species will only be present where they have been successfully introduced, either by topsoiling, direct seeding, or planting. These data reflect specific site conditions where native species were successfully introduced, such as topsoiling at the Hardee Lakes and Estec sites and direct seeding at the 16-Acre site (overburden sites) which produced a high cover of native species. Native species demonstrated the lowest average percent cover on sand tailings/clay and on sand tailings/clay slurry, the soil types found only at the Noralyn South site. Noralyn South was seeded with bahiagrass, which is an aggressive grass that has formed a monostand throughout much of the site. Exotic species favored the wetter substrates of sand tailings/clay slurry and sand tailings/clay, again an artifact of site construction where the exotic species bahiagrass was planted on these two soil types at the Noralyn South site. Native groundcover at Noralyn South not introduced by planting, seeding or topsoiling was extremely minimal. Although the whole site was seeded, native species (and not the bahiagrass) were generally located at the top of

Table 5. Average percent cover of species by origin and species type vegetation categories for each soil.

		Soil‡						
Vegetation grouping	n	OB (n=47)	ST (n=17)	ST/CL (n=5)	ST/CS (n=3)	ST/OB (n=10)	TS (n=37)	TS/OB (n=10)
Species Origin								
Native	127	42	34	17	3.3	28	70	60
Exotic	125	54	24	61	87	36	39	33
Species Type								
Characteristic	117	21	26	7	—	10	37	33
Pioneer	117	20	10	2	3	13	32	23
Weedy	107	29	13	9	—	17	7	10
Aggressive	115	36	22	59	87	25	40	34

‡ ST = Sand tailings
ST/CL = Sand tailings/Clay
ST/CS = Sand tailings/Clay Slurry
ST/OB = Sand tailings/Overburden
TS = Topsoil
TS/OB = Topsoil/Overburden

mounds which may have been drier and had less clay since the clay settled into the lower reaches of the site.

Relationship between Species Type and Soil Characteristics

Aggressive species such as cogongrass, bahiagrass, and natalgrass had a significantly higher vegetative cover on sand tailings/clay and sand tailings/clay slurry matrices, and a significantly lower cover on straight sand tailings (Table 5). Weedy species such as dogfennel (*Eupatorium capillifolium*) and crabgrass (*Digitaria* sp.) exhibited the highest average percent cover on overburden and lowest cover on topsoil, topsoil on overburden, and sand tailings/clay. The same caution mentioned above applies here; that bahiagrass was planted on sand tailings/clay slurry and sand tailing/clay, so these two matrices are expected to be heavily weighted towards exotic and aggressive species. Pioneer species such as *Andropogon virginicus* var. *virginicus*, *Paspalum setaceum*, *Solidago fistulosa*, and *Polypremum procumbens* favored topsoil, topsoil on overburden, and overburden over the other soils (Table 5).

Relationship between Specific Vegetation Groups and Soil Characteristics

Average percent cover of the specific vegetation groups (wiregrass, lovegrasses, scrub species, legumes, wetland species, aggressive grasses) were calculated for each soil types to illustrate relative occurrence of each plant group for each soil type (Table 6). Preference of individual aggressive grasses for soil type is also illustrated in Table 6. Additionally, soil parameters were recorded for each vegetation group and compared between the desirable plants (wiregrass, lovegrasses, scrub species, legumes, wetland species) and undesirable plants (aggressive grasses, aggressive grasses + weedy species). Important relationships found in this study are discussed here and details of this study are recorded in the final report for FIPR Project Number 96-03-122 (Segal et al.,1999).

Wiregrass (*Aristida beyrichiana*) was recorded on three of the seven soils; overburden, sand tailings/overburden, and topsoil. These soil types represent the sites where wiregrass was originally introduced during reclamation, and include Bald Mountain (planted), Estec (topsoiled), Gopher Hills (topsoiled and planted), Hardee Lakes (topsoiled), and Sixteen Acres (direct seeded). Average percent cover of wiregrass was low, and ranged from 5.77 at the overburden sites to 0.59 at the sand tailings/overburden sites (Table 6).

Wiregrass, as with other desirable species, was present at five of the study sites. The fact that wiregrass has persisted at those five sites for a relatively short time of five to 10 years suggests that this species is adapted to the wide range in soil conditions inherent at reclaimed mine sites. Perhaps in this short time frame, wiregrass has responded more successfully towards certain soil parameters. We compared soil parameters at the five sites which supported wiregrass to determine if certain soil parameters favored wiregrass as compared to the undesirable species consisting of aggressive grasses and weedy species. Wiregrass tended to be more strongly associated with a lower soil pH, Ca, P, Na, and CEC, and a higher total C, total N, K, and moisture index than the aggressive grasses. Additionally, wiregrass was more strongly associated with a higher total C, total N, and moisture index than aggressive grasses + weedy species.

The best fit multiple regression model (Table 7) showed that P, Ca, and moisture index were the three soil parameters that best explained average percent cover of wiregrass. In this model, these three soil parameters explained 25.6% of wiregrass cover variability, with soil type, only explaining 2.3% of the residual variability, and site, explaining 12.2% of the residual variability associated with wiregrass. Overall only 40.10% of the variability of wiregrass was explained by the best fit stepwise multiple linear regression that included soil parameters, soil type, and site.

The lovegrasses were recorded at low average percent covers, growing on five of the seven soils, and although not statistically significant, tended to favor sand tailings and sand tailings on overburden (Table 6). When comparing lovegrasses to aggressive grasses we found few significant differences in soil parameters between the two groups of plants. The exceptions were that the lovegrasses tended to be more strongly associated with higher Mg and K concentrations than the aggressive grasses. Every quadrat that contained lovegrasses also contained aggressive grasses and/or weedy species. The five soil parameters that best explained average percent cover of the lovegrasses were Mg, Zn, N, Mn, and pH (Table 7).

Scrub species, documented at five of the sites, demonstrated the greatest preference for straight sand tailings, and were recorded in low coverage on overburden, sand tailings\ on overburden, topsoil, and topsoil on overburden (Table 6). Scrub species, or those species found growing in the most xeric of conditions, were more strongly associated with a lower pH and P concentration, and higher total N and total C than aggressive grasses.

Table 6. Average percent cover of specific vegetation groups and individual aggressive grasses for each soil.

		Soil†						
Vegetation Grouping	n	OB (n=47)	ST (n=17)	ST/CL (n=5)	ST/CS (n=3)	ST/OB (n=10)	TS (n=37)	TS/OB (n=10)
Specific vegetation groups								
Wiregrass	34	6.01^A	-	-	-	0.590^A	3.59^A	-
Lovegrass	25	0.21^AB	4.19^A	-	-	3.44^AB	0.32^AB	1.00^AB
Scrub Species	24	0.11^B	14.2^A	-	-	0.21^B	0.77^B	3.20^B
Legumes	105	22.1^A	3.95^B	2.10^B	-	12.5^AB	9.49^AB	2.57^B
Wetland Species	55	8.18^A	0.04^A	-	-	0.13^A	3.56^A	0.34^A
Aggressive Grasses	115	31.3^BC	20.8^C	58.9^AB	86.7^A	25.2^BC	30.3^BC	27.1^BC
Individual aggressive grasses								
Bahiagrass	131	14.2^AB	-	13.8^AB	11.0^AB	0.51^B	38.3^A	28.3^AB
Bermudagrass	54	0.46^A	-	3.02^A	-	-	0.34^A	-
Cogongrass	52	6.83^B	24.7^B	7.12^B	2.65^B	4.17^B	4.0^B	58,3^A
Natalgrass	186	8.73^AB	2.38^B	9.08^AB	7.12^AB	20.5^A	16.3^AB	-
Torpedograss	10	0.12^A	-	0.03^A	-	-	-	-

† OB = Overburden
ST = Sand tailings
ST/CL = Sand tailings/Clay
ST/CS = Sand tailings/Clay Slurry
ST/OB = Sand tailings/Overburden
TS = Topsoil
TS/OB = Topsoil/Overburden

Note: Mean values of average percent cover within each vegetation grouping followed by the same letter are not significantly different according to a Waller-Duncan K-ratio t-test of means with K set to 100 (approximate 0.05 type I error rate).

Only two soil parameters were used in the linear regression model that best explained average percent cover of the scrub species, and included moisture index and pH (Table 7). These soil variables explained a relatively high amount of variability at 48.0%. The next variable, soil type, accounted for 10.2% of the residual variability, and site explained 25.9% of the residual variability associated with the scrub species. Overall, a high of 84.1% of the variability of scrub species was explained by the best fit stepwise multiple linear regression model that included soil parameters, soil type, and site. These data suggest that unlike the lovegrasses, the presence and coverage of scrub species is influenced more strongly by soil parameters, soil type, and site.

Wetland species found at seven of the 10 study sites, were also found on five of the seven soil types, with low average percent cover on all soils (Table 6). Wetland species occurred primarily on overburden (7.85%) with

Table 7. Regression equations and fit statistics relating vegetation "Average Percent Cover" to soil properties.

Response	Equation	R^2 (%)		
		Model	Soil Type	Site
	Species origin			
Native	178.65** - 20.763(pH)** - 27.180(Moisture Index)* + 7.281(Moisture Index^2)**	33.3	4.6	16.2**
Exotic	-3.180 + 0.221(P)** + 929.347(N)** - 9.204(C^2)* - 2.74E-4(P^2)*	20.8	6.1	12.1
	Species type			
Characteristic	446.057** - 135.795(pH)** - 12.647(Mn)** - 345.288(N)* + 21.362(C)** + 10.764(pH^2)** + 1.625(Mn^2)**	36.7	3.7	17.8**
Pioneer	23.217** + 0.368(K)** - 15.921(Zn)** - 0.0393(P)** + 1.147(Moisture Index)** + 0.621(Mn^2)*	36.0	6.0	21.6**
Weedy	2.735 + 0.0849(P)* - 4.635(Mn)** + 0.204(Mg)** + 0.0316(Ca)* - 0.847(MI^2)** + 519.644(N^2)* - 1.28E-4(P^2)* - 3.55E-5(Ca^2)**	37.6	8.8	19.5**
Aggressive	-64.007** + 19.619(Mn)** + 115.558(Cu) + 38.977(Moisture Index)** - 5.534(MI^2) - 0.0143(K^2)** - 2.699(Mn^2)**	31.1	7.0	7.4
	Specific vegetation groups			
Wetland	6.737 - 0.040(Mg)** + 0.0188(P)** - 10.737(Moisture Index)** + 3.017(Moisture Index^2)** * 3.457(Cu^2)*	44.8	2.1	8.1
Scrub	39.694** - 21.941(Moisture Index)** - 0.179(pH^2)** + 3.380(Moisture IndexI^2)**	48.0	10.2*	25.9**
Legumes	-13.710 + 0.231(Mg)** + 21.639(Moisture Index)** - 0.599(Mn^2)** + 650.909(N^2)** - 2.014E-5(Ca^2)** - 4.667(Moisture Index^2)**	32.1	8.1	19.6**
Wiregrass	0.300 - 0.0293(P)* - 0.00452(Ca)* + 1.901(Moisture Index)** + 9.741E-5(P^2)**	25.6	2.3	12.2
Lovegrass	-3.609* - 0.0681(Mg)** - 3.329(Zn)** + 30.587(N)* + 0.777(Mn)* + 0.251(pH^2)** + 1.71E-4(Mg^2)**	21.6	6.3	4.2
Aggressive grasses	-63.973** + 19.632(Mn)** + 115.579(Cu)** + 38.928(Moisture Index)** - 2.701(Mn^2)** - 5.526(Moisture Index^2)* - 0.0143(K^2)**	31.1	7.0	7.4

Statistical significance of model coefficients indicated by *= 0.01 < p <0.05 and ** p <0.01. Model R^2 is multiple regression coefficient considering only significant soil properties in the model. Soil Type and Site R^2 values represent proportion of residual variation explained by these factors added last in the model.

the second highest average percent cover on topsoil (3.56) (Table 7)

Wetland species were more strongly associated with a lower soil pH and P concentration and a higher K, Cu, and moisture index. Wetland species tended more strongly than aggressive grasses + weedy species to grow at a lower pH and P concentration, and a higher total C, total N, and moisture index. Consistent in both of these comparisons is the preference of wetland species over the undesirable species of aggressive grasses and weedy species to a lower soil pH, lower P concentration, and higher moisture index. Four soil parameters were used in the linear regression model that best explained average percent cover of the wetland species, and included Mg, P, moisture index, and Cu (Table 7).

Aggressive grasses were measured at a higher average percent cover on all seven soils as compared to the other plant categories (Table 6). Bahiagrass was planted on sand tailings/clay and sand tailings/clay slurry, which would partially explain why aggressive grasses were so prevalent on these two soil types. Aggressive grasses showed the least preference for straight sand tailings, however they grew at a higher percent cover on straight tailings as compared to the other plant groups (Table 6). The linear regression model that best explained average percent cover of the aggressive grasses, species, and included Mn, Cu, moisture index, and K (Table 7). The model in Table 7 suggests that, similar to wetland species, there is roughly an equal chance that aggressive grasses will occur based on soils and site, and an equal chance that aggressive grasses will occur either randomly or respond to variables other than the soils and site variables, measured in this study.

Individual aggressive grasses. Because this category called aggressive grasses includes a diverse group of species, they are best considered individually. Bahiagrass, for example, was seeded onto several sites and natalgrass is usually found growing at a much lower moisture index such as is found on sand tailings or soils of scrub or sandhills.

Cogongrass grew in luxuriant levels in most all soil conditions and in all soil types. Soil parameters were compared between cogongrass and other plant groups (wiregrass, lovegrasses, scrub species, wetland species). In many cases, there were no significant differences between cogongrass and the other plant groups, or the sample size was too small to yield conclusive results. However, cogongrass tended more strongly than wiregrass to grow at a higher Zn, Mn, and CEC, and a lower Mg and moisture index. Cogongrass grew on soils with a significantly higher CEC than scrub species and a lower CEC and moisture index than wetland species.

Like cogongrass, bahiagrass is widespread at almost all of the reclaimed mined sites, is opportunistic and will colonize open disturbed areas from stolons spread in the original site formation and possibly by seed dropped by birds. Bahiagrass was found growing under a wide range of soil conditions, with few significant differences in soil parameters between bahiagrass and other plant groups. Bahiagrass tended to be more strongly associated with a higher Mn concentration than wiregrass, and a higher Fe concentration and moisture index than lovegrasses, and a higher Na concentration, CEC, and moisture index than scrub species. Compared to wetland species, bahiagrass favored a lower CEC and lower moisture index.

Natalgrass is similar to cogongrass and bahiagrass in that it is ubiquitous and problematic at reclaimed upland sites. However, unlike cogongrass and bahiagrass which have a wide moisture tolerance, natalgrass appears to be less tolerant of wetter soils with a higher clay content. Natalgrass was recorded at all of our study sites except the two wettest sites. Natalgrass was strongly associated with low fertility and droughty soils as compared to the other plant groups. Natalgrass grew in soils with a significantly higher pH and CEC, and a lower total C, total N, K concentration, and moisture index than wiregrass. When compared to the lovegrasses, natalgrass favored a significantly higher pH, and a lower K concentration and moisture index. Natalgrass appears to favor many of the same soil conditions as scrub and sandhill species and therefore is most problematic at sites reclaimed to scrub and sandhill communities. Natalgrass appeared to favor higher pH and P concentrations than scrub species. When compared to wetland species, natalgrass was more strongly associated with a higher pH, a lower K concentration, and predictably a lower moisture index. Therefore, natalgrass might intrude into those soil systems which have a high pH and a low moisture index.

Conclusions and Recommendations

Overburden exhibited a high degree of variability in chemical parameters, while sand tailings were characterized as nutrient poor and droughty. Depending on soil conditions and introduction of plant material, a large number of vegetation types were established in these reclaimed upland soils.

The site sampling protocols were chosen to produce a wide range of "typical" vegetation types in the hopes that this would also reflect a wide range of soil physical and chemical values. Strong correlations between soil parameters and vegetation cover would have been immediately identified in the resulting data. However, vegetation cover and composition were only moderately correlated with soil parameters suggesting that soil physical and chemical parameters are not the only critical factors for many of the vegetation types examined. After soil parameter effects were factored into the relationship, some of the residual variability could be explained by either soil type or site characteristics.

Matching moisture regimes between a reclaimed site and the targeted vegetative community moisture requirements was perhaps the factor we most frequently encountered while evaluating the success of a reclamation site with respect to native vegetation. If a xeric scrub or sandhill community is targeted to be reclaimed, then the soils should be droughty sand tailings with a low moisture holding capacity and low fertility. Recruitment appears to be more successful if the moisture regime at the reclaimed site closely matches the moisture regime from the donor topsoil site. In order to closely match moisture conditions, topsoil removed from a xeric scrub or sandhill donor site should be added to droughty sand tailings. Conversely, topsoil removed from a mesic flatwoods or hydric flatwoods could be added to a sandy or loamy overburden. Likewise, if the reclamation area consists of a mixture of sand tailings and overburden, the topsoil should come from a sandhill, scrubby flatwoods, or mesic flatwoods.

A higher concentration of soil nutrients promoted higher coverage of weedy species, particularly aggressive grasses. Also, aggressive grasses tended to grow more successfully than desirable taxa at a higher pH. In particular, natalgrass appeared to favor higher pH and P concentrations. Soil fertility and soil moisture are important factors in promoting aggressive grasses. Our results suggest that there is roughly an equal chance that aggressive grasses will establish on a random basis irrespective of soil and site conditions. The plants that establish early have an availability of nutrients, space, and moisture with which to spread. For this reason it may be advantageous to irrigate during the first growing season after topsoiling or seeding, so that the slower growing characteristic native plants can germinate or resprout and compete successfully with weedy and aggressive species that may need only a single rain event to become established. Reclaiming an upland with overburden material over sand tailings will lower the moisture conditions of overburden material, and thus make the site more suitable for vegetation that require less moisture.

Wiregrass is an example of an important cover grass in upland communities that serves the significant function of carrying fire which is essential in maintaining the community. Wiregrass showed tendencies to grow at lower soil pH, Ca, P, Na, and CEC and higher total C, total N, and K than aggressive grasses. However, we need to be especially cautious about interpreting these data since wiregrass cover depended highly on methods of introduction to the sites. Controlled research on soil parameters for wiregrass is needed.

The lovegrasses were compared to aggressive grasses because they have shown potential as pioneer species that reseed easily and may offer quick competition against the exotic aggressive grasses. Few significant differences in soil parameters between these two groups were shown which may indicate that these lovegrasses can accept many of the same soil conditions as the aggressive species. Controlled research to determine the soil parameters of this group may be especially useful if these species are developed as seed crops for restoration.

If these early-established plants are tolerant of a wide range of soil conditions, as is the case with aggressive species such as cogongrass or bahiagrass, then their spread can occur irrespective of soil conditions. Therefore, targeting fast-growing, easy colonizing desirable species such as *Schizachyrium stoloniferum* or *Panicum anceps* can help to displace or discourage the encroachment of aggressive grasses. Even pioneer species such as the three *Eragrostis* spp., *Paspalum setaceum*, or *Dichanthelium portoricense* can be particularly useful in planning restoration since they can be more easily established and compete with the weedy or aggressive species.

As a logical next step, the current study suggests that the effects of soil moisture and soil type on seed germination should be examined under more controlled conditions. Determining the soil parameters best suited to native taxa under controlled experimentation is needed for advancing the base knowledge to improve upland site reclamation as a whole.

Literature Cited

Bromwell and Carrier, Inc. 1989. Production of high-value cash crops on mixtures of sand tailings and waste phosphatic clays. FIPR Publication No. 03-075-080.

Ecosystem Research Corporation. 1992. A methodology for measuring woody and herbaceous vegetation in Florida. Unpublished.

Florida Administrative Codes Chapter 16C-16. Mandatory phosphate mine reclamation. Florida Department of Natural Resources, Adopted 10-6-80 (*Repealed and superseded by:* Chapter 62C-16 FAC. Florida Department of Environmental Protection, Adopted 10-20-96).

Florida Statutes, Chapter 378. Land Reclamation.

Levene, H. 1960. Robust Tests for the Equality of Variances, in Contributions to Probability and Statistics, ed. I. Olkin, Palo Alto, CA:Sanford University Press, 278-292.

Littell, R. C., R. J. Freund, and P. C. Spector. 1991. SAS System for Linear Models, Third Edition, Cary NC: SAS Institute Inc., 329 pp.

Marion, W.R. 1986. Phosphate Mining: Regulation, Reclamation, and Revegetation. Florida Institute of Phosphate Research. Publication No. 03-043-040. Barotw, FL 72 pp.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. In Soil Sci. Plant Anal., 15 (12): 1409-1416. https://doi.org/10.1080/00103628409367568

Mislevy, P. and W.G. Blue. 1981a. Reclamation of quartz sand tailings from phosphate mining: I. Tropical forage grasses. J. Environ. Qual. 10:449-453. https://doi.org/10.2134/jeq1981.00472425001000040005x

Mislevy, P. and W.G. Blue. 1981b. Reclamation of quartz sand tailings from phosphate mining: II. Forage legumes. J. Environ. Qual. 10:453-456. https://doi.org/10.2134/jeq1981.00472425001000040006x

Mislevy, P. and W.G. Blue. 1981c. Reclamation of quartz sand tailings from phosphate mining: III. Summer annual grasses. J. Environ. Qual. 10: 457-460. https://doi.org/10.2134/jeq1981.00472425001000040007x

Mislevy, P., W.G. Blue and C.E. Roessler. 1989. Productivity of clay tailings from phosphate mining: I. Biomass Crops. J. Environ. Qual. 18:95-100. https://doi.org/10.2134/jeq1989.00472425001800010017x

Rhoades, J.D. 1982. Cation Exchange Capacity. *In* Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties-Agronomy Monograph no. 9 (2nd Edition).

SAS Institute Inc., 1989. SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2, Cary NC: SAS Institute Inc., 846 pp.

Segal, D. S., V. D. Nair, D. A. Graetz, K. M. Portier, N. J. Bissett, and R. A. Garren. 1999. Post mine reclamation of native upland communities. Final Report to Florida Institute of Phosphate Research for Project No. 96-03-122, Bartow, Florida [in press].

Sokal, R. R. and F. J. Rohlf. 1969. Biometry: The Principle and Practice of Statistics in Biological Research. Chapter 9: Single Classification Analysis of Variance, W. H. Freeman and Company, San Francisco. pp 204-252.

Waller, R.A. and D.B. Duncan. 1969. A Bayes Rule for the Systematic Multiple Comparison Problem. Journal of the American Statistical Association 64:1484-1499.