TESTING THE EFFICACY OF SEED AND PLANT TRANSFER BY TOPSOIL AUGMENTATION ON RECLAIMED PHOSPHATE-MINED UPLANDS

by

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Abstract: Topsoil was collected from a burned flatwoods and an unburned flatwoods and applied as a thick layer and a thin layer to a reclaimed overburden site and a reclaimed sand tailings site. One donor site was burned in the growing season to stimulate seed production of fire-dependent species such as wiregrass (*Aristida beyrichiana*). After seed had dispersed, topsoil was removed from both burned and unburned donor topsoil sites and transferred to a reclaimed overburden site and a nearby reclaimed sand tailings site and applied as 16 cm and 8 cm thick layers in a random split plot design that included untreated control plots at each site. Soil parameters were analyzed from topsoil, overburden, and sand tailings collected two months after addition of topsoil. The addition of topsoil to the overburden site decreased bulk density and C:N ratio, and increased total C, total N, Ca, Mg, K, Zn, Mn, and Na of the surface soil. The pH, C:N ratio, Ca, P, and Zn concentrations decreased while the total C and N increased in the surface soil at the sand tailings site. Vegetation was monitored at the end of the first and second growing seasons. Transfer of topsoil resulted in a high species richness of desirable species at both the overburden and sand tailings sites at the end of the first growing season. A higher density and coverage of desirable species persisted through the end of the second growing season at the overburden site but not the sand tailings site. The sand tailings site contained a high weed cover of natalgrass (*Rhynchelytrum repens*) and torpedograss (*Panicum repens*) in adjacent areas which presumably contributed to a heavy weed cover within the experimental plots during the second year. The effect of an extreme drought experienced in 1998 was also more pronounced on the droughty sand tailings soils. A more favorable moisture regime at the overburden site may have contributed to both greater reproduction rates and more successful establishment of mesic flatwoods species. Wiregrass was more frequently associated with topsoil from burned flatwoods whereas saw palmetto (*Serenoa repens*) was more frequently associated with topsoil from unburned flatwoods. *Dichanthelium aciculare* was also more prevalent in the burned plots while *D. portoricense* was more common at the unburned plots. Thickness of topsoil affected establishment of some species, however, this effect was not as pronounced as were burning, soil type, and year.

Additional Key Words: topsoil, overburden, sand tailings, aggressive grasses, wiregrass

Introduction

Reclamation of phosphate-mined uplands in central and northern Florida has not received as much attention as wetland reclamation (Nair et al., 2000). Several obstacles hinder the successful reclamation of native upland communities. First, encroachment of exotic aggressive grasses such as cogongrass (*Imperata cylindrica*), natalgrass (*Rhynchelytrum repens*), and bahiagrass (*Paspalum notatum*) can quickly reverse any attempts at establishing native upland taxa. The Florida Institute of Phosphate Research (FIPR) has recognized this as a significant problem and recently funded a research study *Ecology, Physiology, and Managment of Cogongrass* (*Imperata cylindrica*) (Shilling et al., 1997) to address these concerns. That study has increased our understanding of cogongrass biology, physiology, plant-herbicide interactions, and management practices aimed at controlling cogongrass. Additional studies to address control of aggressive grasses are being conducted, which will significantly increase our knowledge of reclaiming

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upland communities.

Another major obstacle in reclamation of native upland communities is to provide enough native seed to meet the state's reclamation and land management needs. FIPR is again funding a research study with the U.S. Natural Resource Conservation Service (NRCS) to identify the hardiest seed sources and develop the technology for harvesting native seed plots. Currently, there are no commercial seed sources for native Florida upland species, and the logistics for obtaining seed are complicated at best. Many native taxa produce a low quantity of seed, have low seed viability, and may undergo an initial dormancy. Traditional mechanical seeding implements are often ineffective as the native seeds are light and chaffy.

Once native plants have been introduced to a reclaimed site, either by seeding, planting, or topsoiling, they are generally poor competitors with aggressive non-native grasses. Native xeric scrub and sandhill species typically grow slow and are well adapted to the stressful conditions of low moisture and low fertility inherent in xeric soils. Low coverage combined with bare ground and open spaces are natural attributes of xeric communities. Flatwood species cover a wide range of moisture regimes from scrubby flatwoods to hydric flatwoods. As moisture increases, native ground cover grows denser and some of the weedy aggressive grasses are not as competitive. On the other hand, some non-native perennial grasses that we identified as aggressive grasses, are very opportunistic, fast growing, and probably adapted to a wide range of reclaimed soil conditions.

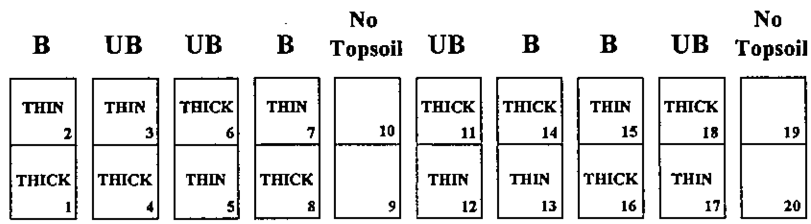
This field experiment was designed to statistically test the effect of topsoil augmentation on the revegetation success of two reclaimed phosphate mined areas located at CF Industries in Hardee County, Florida, one consisting of overburden soil and the other capped with sand tailings. This study is part of a larger research project investigating the relationships between vegetation and soils on ten reclaimed phosphate mined upland sites in north and central Florida (Nair et al., 2000). The results from the companion study have been presented elsewhere in this document. Experimental treatments were established by using topsoil collected from both burned and unburned pine flatwoods and applying it as thick and thin layers to the overburden and sand tailings sites. Permanent vegetation monitoring quadrats were installed within each experimental treatment plot and the results from two sampling events (October 1997 and September 1998) were statistically analyzed in order to evaluate the potential effects of soil type, burning, topsoil application thickness, and monitoring year.

Methodology

Approximately 5 acres of unmined flatwoods located at CF Industries in northwestern Hardee County, Florida were burned in early June 1996. The prescribed burn occurred during the growing season to stimulate seed production of fire-dependent species such as wiregrass *(Aristida beyrichiana)*. The adjacent unmined flatwoods, approximately 10 acres in size, were not burned. The burned and unburned flatwoods then served as topsoil donor sites for this project. The burned flatwoods were examined after the fire to qualitatively assess production of wiregrass seeds. Seeds were observed maturing in November 1996 and had fully dispersed by January 1997.

In mid-January 1997, when wiregrass seeds had dispersed, topsoil was removed from both burned and unburned donor topsoil sites and transferred to two nearby mined and reclaimed sites; an overburden site (Range 24E, Township 33S, Section 09) and a sand tailings site (Range 24E, Township 33S, Section 06). 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. Sand tailings, on the other hand, consist of sand that was separated from the phosphate matrix as the ore was processed. Sand tailings are typically fine sand and are white in color and resemble beach sand. Frequently, small black dots containing phosphate ore are present in the white sand tailings. Thus, the substrates of the two recipient sites vary greatly in that the overburden site consist of a compacted, firm matrix while the sand tailings site is a loosely compacted, well-drained matrix. This difference between the two sites provided a major treatment of the experimental design of this study.

Topsoil was applied to both the overburden and sand tailings sites at two different thicknesses: a thick layer approximately 16 cm in depth and a thin layer approximately 8 cm in depth. A control (no topsoil) and four treatments (burned, unburned, thin topsoil, thick topsoil) were replicated four times in 10 m x 10 m plots at both the overburden and sand tailings sites for a total of 20 plots each at both sites (Figures 1 and 2). This field experiment was designed as a randomized split plot design to evaluate the transfer of flatwoods seeds and plant parts in topsoil from unmined pine flatwoods to both a reclaimed overburden site and reclaimed sand tailings site. This study allowed us to evaluate vegetation characteristics in topsoil from burned and unburned sites, thick vs. thin layers of topsoil, and overburden vs. sand

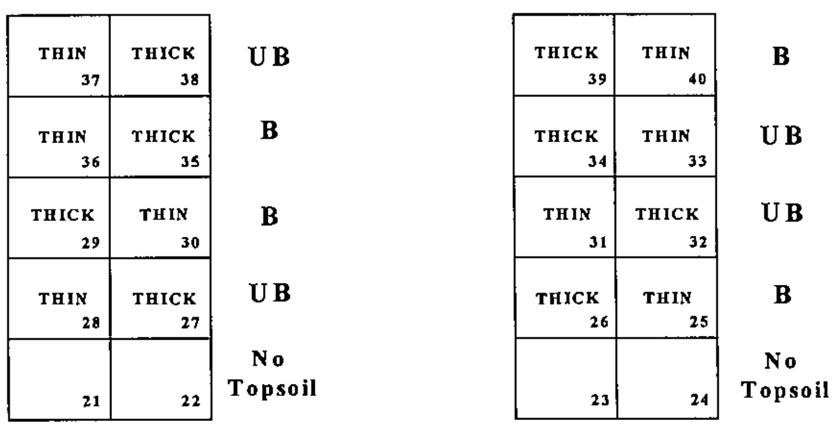


B = Topsoil from Burned Site
UB = Topsoil from Unburned Site
THICK = Topsoil Approximately 16 cm Thick
THIN = Topsoil Approximately 8 cm Thick

Each plot is 10 meters x 10 meters
Plot Numbers are shown in the lower right hand corner of each plot

Spaces between blocks depend on space needed for moving equipment

Figure 1. Schematic drawing of plot layout at the overburden topsoil augmentation site.



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THIN = Topsoil Approximately 8 cm Thick

Each plot is 10 meters x 10 meters
Plot Numbers are shown in the lower right hand corner of each plot

Space in between blocks = 15 meters

Figure 2. Schematic drawing of plot layout at the sand tailings topsoil augmentation site.

tailings. The effects of topsoil were also evaluated by comparing vegetation in topsoil plots to vegetation in randomly assigned control plots (no topsoil).

A plant inventory and estimated relative abundance of each species was obtained at both the burned and unburned donor flatwoods. Wiregrass seeds were collected from the burned flatwoods donor site on two occasions. In November 1996 collection was performed when the seeds were still attached to the plants. For random samples, one spikelet was randomly taken from each culm; for full samples, one spikelet was collected from each culm that had developed a full caryopsis. Wiregrass seeds were collected a second time in January 1997, just one week before the topsoil was transferred to the reclaimed sites, by collecting spikelets from the ground. Random and full selections were made, but after the random samples were taken we could only find 26 spikelets in our collection with full seeds. The seeds were then sent to the USDA Natural Resource Conservation Service (NRCS) Plant Materials Center, Brooksville, Florida, for germination tests, which were conducted at 20° to 30° C for 32 days, using potassium nitrate as a wetting agent.

Topsoil was transferred from the donor burned site and donor unburned site by using a bulldozer to scrape up soil and plant parts to roughly one to two feet depth and then loading the topsoil with a front-end loader onto dump trucks. The dump trucks then transferred the topsoil to the recipient overburden and sand tailing sites. Two dump-truck loads of topsoil were added to the plots labeled as "thick" topsoil, which when spread out equated to a layer approximately 16 cm thick. One dump-truck load was added to the plots labeled as "thin" topsoil, which equated to approximately 8 cm in thickness when smoothed out. Four plots at each site received no topsoil and were designated as controls. On the day of topsoil transfer, topsoil samples were collected from burned and unburned study plots at both the overburden and sand tailings sites. Topsoil samples were analyzed for pH, total C, total N, and available nutrients (P, K, Ca, Mg, Zn, Mn, Cu, Fe, and Na). Duplicate samples of overburden and sand tailings were taken from the control plots (no topsoil) and also analyzed for the same soil parameters. The topsoil was allowed to "settle" for two months. Intact soil cores were then collected in triplicate from each plot, and separated into surface (topsoil) and subsurface (overburden or sand tailings) samples. For each plot, the three surface soil samples were composited as well as the three subsurface soil samples. A fourth intact soil core was collected at each plot and analyzed for bulk density measurements. The depth of surface and subsurface soils was noted. The central point around which the four cores were sampled was marked so future vegetation monitoring would coincide with the location of soil sampling.

Soils were characterized to determine differences in soil properties among topsoil from a burned flatwoods, topsoil from an unburned flatwoods, and plots with no topsoil. Soil comparisons were also made between plots that received a thick layer of topsoil (16 cm) and plots that received a thin layer of topsoil (8 cm). These comparisons were made for both surface and subsurface soils, and at both the overburden and sand tailings site. Control plots received no topsoil and consisted of either overburden (at the overburden site) or sand tailings (at the sand tailings site).

Vegetation monitoring was conducted in October 1997 and September 1998 to document vegetative composition at the end of the first and second growing season, respectively, following topsoil augmentation. Vegetation monitoring followed methods outlined by Ecosystem Research Corporation (ERC, 1992). Established quadrats were 30 feet in length and were positioned down the center of each plot. Each quadrat consisted of a two foot wide band, the length of which was divided into three contiguous 10-foot intervals. The 10-foot intervals were further divided into ten 1-foot by 2-foot intervals (Figure 3). Species cover was determined on the basis of percent cover of each species within each 10- foot by 2-foot cover interval. Seven vegetation cover categories were assigned to estimate ranges of percent cover that were visually discernable (Table 1). In addition, frequency was determined by species on the basis of occurrence within each 1 x 2 foot interval. Therefore, a maximum frequency value of 10 was possible for each 10-foot interval. The following vegetation parameters as outlined by Ecosystem Research Corporation were then calculated for each individual quadrat, each vegetation zone at each site, and each vegetation zone for all sites combined.

Percent cover of bare ground was also estimated along with the vegetation at each quadrat so that an accurate measure of the extent of community establishment was recorded over time. Bare ground is present in almost all ecosystems to some extent and is particularly important in native scrub or sandhill systems, regardless of age. Bare ground is functionally defined as all ground surface not covered by some form of live vegetation when viewed from above. Leaf litter was not measured separately but was considered as bare ground.

The field data for each individual plot (quadrat) were analyzed using a custom written spreadsheet macro

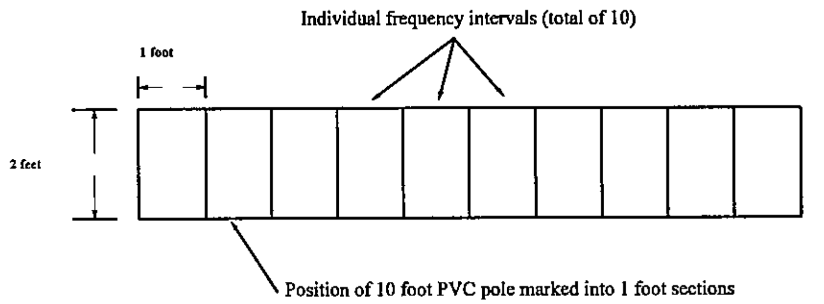

Figure 3. Plan view representation of a single elongated herbaceous monitoring quadrat interval. Note the position of the 10 foot long PVC pole at the bottom of the interval. The pole is divided into 1 foot frequency sub-intervals (for a total of 10) while percent cover is estimated over the entire 10 foot length. The 10 foot pole is systematically moved down the entire quadrat while frequency and percent cover data are recorded for all plant species as well as bare ground and standing water.

which calculates a set of summary parameters (Table 2) for each species in addition to bare ground. This basic analysis was then used as the framework for more detailed statistical analyses. The parameter "Total Quadrat Area Probable Percent Cover - Average" (Table 2) was extracted from the resultant basic analysis and used to prepare a set of *pooled* summary statistics upon which detailed statistical tests were then performed. The pooled datasets were developed by merging the basic summary parameters for individual plots together by whatever treatment was being tested. For example, at the overburden site, all unburned control plots were merged together to create a single composite plot with which to compare with all (merged) burned control plots. These composite or pooled plots could be visualized as single larger plots which occur across a given treatment combination. For a given plant species which occurred in a merged plot grouping, the pooled "Total Quadrat Area Probable Percent Cover - Average" parameter was calculated simply by averaging all the corresponding individual values recorded for that taxon within the pooled grouping.

Table 1. Cover class values, corresponding percent cover ranges, and cover range midpoints for numerical cover classes used for herbaceous monitoring methodology.

Cover Class Value	Percent Cover Range	Midpoint of Cover Range
1	<1%	0.5%
2	>1% and ≤10%	5%
3	>10% and ≤30%	20%
4	>30% and ≤50%	40%
5	>50% and ≤70%	60%
6	>70% and ≤90%	80%
7	>90%	95%

Geroud Wilhelm developed an approach to vegetation monitoring in northeastern Illinois that eventually became known as the Floristic Quality Assessment (Swink and Wilhelm, 1979). Coefficients of conservation were assigned to each species using a scale of 0 to 10, with 0 indicating an introduced species and rare plants ranging up to 10. Variations of this system have been used throughout the Midwest (Nachlinger and Reese, 1996) and are now being implemented in the West and Southeast (Reese et al., 1994).

A Floristic Natural Quality Assessment Index (FQAI) for flora in the Upper Lakes Basin Watershed of south central Florida was prepared for the Southwest Florida Water Management District (Bridges and Reese, 1996). This report provided a "Coefficient of Community" system, with values ranging from 0 for introduced species up to 12 for rare or unusual species.

Table 2. Basic summary parameters calculated from frequency and percent cover data collected for each monitoring quadrat. The parameter "Total Quadrat Area Probable Percent Cover Range - Average" was used to compare vegetation data between the various replicated experimental treatments in this study.

PARAMETER	DESCRIPTION
Total Frequency	Total number of 1 foot sub-intervals a species occurred in for a given 10 foot interval
Relative Frequency	Total frequency for a species divided by the total number of possible sub-intervals in the entire quadrat
Frequency of Cover Category	A frequency distribution of cover class values for each species encountered
Total Quadrat Area Probable Percent Cover Range - Minimum	Minimum predicted percent cover for a given species calculated over the entire quadrat
Total Quadrat Area Probable Percent Cover Range - Average	Average predicted percent cover for a given species calculated over the entire quadrat
Total Quadrat Area Probable Percent Cover Range - Maximum	Maximum predicted percent cover for a given species calculated over the entire quadrat
Total Occurrence Area Probable Percent Cover Range - Minimum	Minimum predicted percent cover for a given species calculated for the area where it occurred only
Total Occurrence Area Probable Percent Cover Range - Average	Average predicted percent cover for a given species calculated for the area where it occurred only
Total Occurrence Area Probable Percent Cover Range - Maximum	Maximum predicted percent cover for a given species calculated for the area where it occurred only
Frequency Rank	Ranking for a given species based on its total frequency within the quadrat
Cover Rank	Ranking for a given species based on its total quadrat area average probable percent cover

We compared the plant species and their Coefficient of Community values listed by Bridges and Reese with species identified in our study and found close agreement between their species listings and values we thought were indicative of aggressive, weedy, pioneer, and characteristic species. In some instances there was disagreement over species origin. Our view of pioneer species was more easily related to disturbed systems undergoing restoration rather than mature systems evaluated by Bridges and Reese. For example, using their scale from 0 to 12, they probably rated wiregrass as a 4 because of its dominance in a natural system, but we would consider it in the characteristic rather than pioneer category because it does not spread easily into disturbed areas or reseed easily. *Aristida gyrans*, which they assigned a 5, we frequently find reseeding readily in disturbed or restoring systems and would call it a pioneer species.

After reviewing these above studies, we devised a modified floristic species classification system based on species type and species origin. This modified classification system might compare to a 10 point FQAI as follows:

Aggressive and Exotic Weedy Species	0 points
Native Weedy Species	1 - 2 points
Pioneer Species	2 - 5 points
Characteristic Species	4 - 10 points

The definitions for the species type and species origin are as follows:

Type

Aggressive	Species that out-compete weedy species and sometimes will even out-compete characteristic species of stable ecosystems; these species are not native.
Weedy	Species that depend on unnatural[3] or severe disturbances to become established.
Pioneer	Species that readily reseed in unnatural or severely disturbed areas but persist and are characteristic of mature ecosystems also.
Characteristic	Species that are found in mature ecosystems.

Origin

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

Each species was assigned a type and origin designation based on the above definitions. In the above modified classification system, only exotic species were considered aggressive. We also tended to give the benefit of doubt to questionable native species, as we felt there should be documented proof of species introduction. From quadrat monitoring data, the average percent vegetative cover data within the various plant origin and plant type categories was then statistically compared to determine if a particular species origin or type was favored within a specific experimental treatment. In addition, important target species such as wiregrass (*Aristida beyrichiana*) and saw palmetto (*Serenoa repens*) were also statistically compared within the various experimental treatments. One-way classification linear models (Littell et al., 1991; Sokal and Rolhf, 1969a) were used to compare differences in vegetative cover between the various treatments.

Two-way classification linear models (Littell et al., 1991; Sokal and Rolhf, 1969b) were used to analyze soil parameter differences. Initial analyses indicated very strong differences between sand tailings and overburden, hence these data were analyzed separately. Since many analyses produced significant soil type X burn interactions, data were recoded to allow a one-way classification model to be employed with subsequent use of the Waller-Duncan K-ratio t-test (Waller and Duncan, 1969; SAS Institute, Inc., 1989) to separate out interaction means. Levenes test (Levene, 1960) was used to examine the data for heterogeneity of variance. Heterogeneity of variance and non-normality were within ranges acceptable for normal-based analysis of variance procedures.

Results and Discussion

Vegetation

Topsoil transfer from a mesic pine flatwoods resulted in a rich assortment of desirable native pioneer and native characteristic species at both the overburden and sand tailings recipient sites (Figure 4). Species richness at the topsoil recipient sites reflected the high species richness at the donor mesic flatwoods site (Table 3). In general, species richness was highest at the topsoil from burned sites, intermediate on topsoil from unburned sites, and lowest at the control plots where no topsoil was added (Figure 4). Total numbers of desirable plant species increased from 1997 to 1998 for all treatments (burned and unburned; thin topsoil and thick topsoil; overburden and sand tailings), except for the thin and thick layer of topsoil from the burned donor site at the sand tailings plots, where a decline was noted.

The transfer of topsoil not only produced a high number of species but also a high percent of desirable species. Over 80% of the species documented at the overburden site that received topsoil were desirable native pioneer or native characteristic species (Figure 5). These results were irrespective of thickness of topsoil (thick or thin), burn treatment (burned or unburned), and monitoring year (1997 or 1998). In contrast only 28% of the plant species in 1997, and 50% in 1998, at the control plots (no topsoil added) were considered desirable species.

A similar pattern in desirable species was also documented at the sand tailings site. All treatments of topsoil at the sand tailings site contained over 63% desirable species, except for the treatment of thin layer of topsoil from the unburned site (Figure 5). In contrast,

[3]Unnatural or severe disturbances are caused by such means as bulldozing, disking, herbiciding, animal digging, severe long-term flooding followed by recession of water, etc., which open up areas of soil to new colonization. Natural changes due to fire or fire exclusion or changes in hydrology are not considered here. Therefore, species such as wax myrtle *(Myrica cerifera)* colonizing flatwoods, or oaks colonizing sandhills indicate a shift in ecosystems because of changes in natural events which can be reversed by natural events.

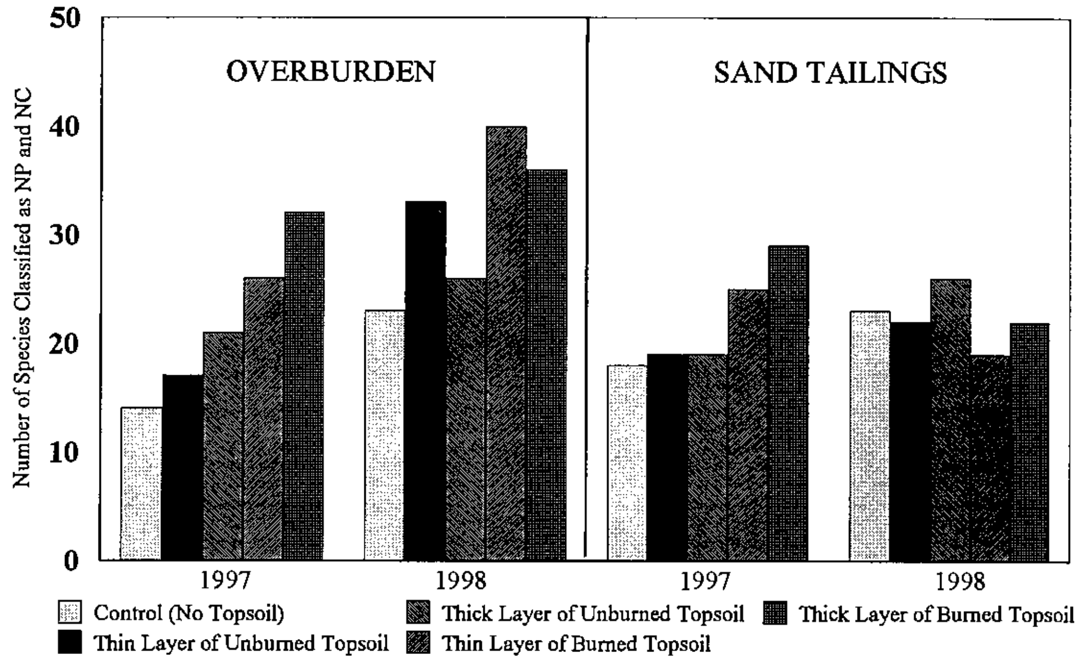

Figure 4. Total Number of Species Classified as Native Pioneer (NP) and Native Characteristic (NC) at the Topsoil Augmentation Plots.

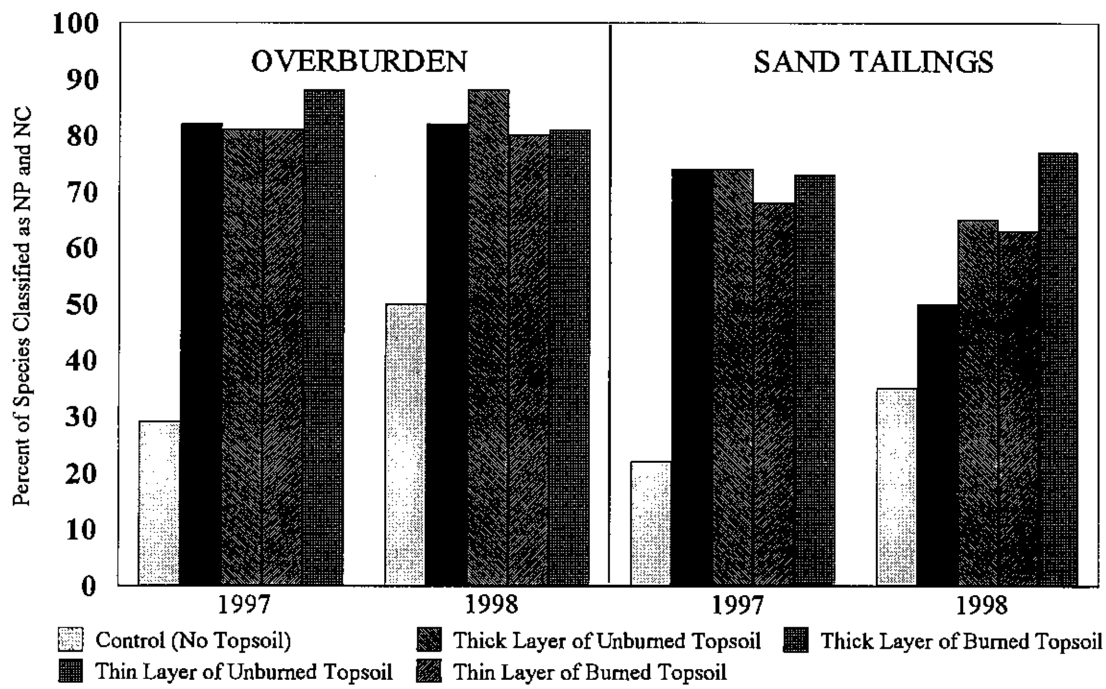

Figure 5. Percent of Desirable Species Classified as Native Pioneer (NP) and Native Characteristic (NC) at the Topsoil Augmentation Plots.

Table 3. Plant species and estimated abundance at the burned and unburned topsoil donor sites prior to topsoil transfer.

Botanical Name	Common Name	Estimated Abundance in Burned Flatwoods†	Estimated Abundance in Unburned Flatwoods†
Andropogon brachystachyus	Shortspike Bluestem	O	F
Andropogon glomeratus	Bluestem	O	O
Andropogon gyrans var. gyrans, common variant	Elliott's Bluestem	R	O
Andropogon ternarius	Splitbeard Bluestem	O	O
Angdropogon virginicus	Broomsedge	O	O
Andropogon virginicus var. *glaucus*	Broomsedge	O	F
Aristida beyrichiana	Wiregrass	A	A
Aristida purpurascens	Arrowfeather	R	O
Aristida spiciformis	Bottlebrush Threeawn	-	O
Asimina reticulata	Flatwoods Pawpaw	O	O
Bulbostylis stenophylla	Sandyfield Hairsedge	F	-
Callicarpa americana	Beautyberry	-	R
Carphephorus corymbosus	Large-Headed Carphephorus	O	O
Chamaecrista fasciculata	Partridge-Pea	R	-
Cladina subtenuis	Reindeer Lichen	-	O
Cladonia leporina	Cup Lichen	-	O
Cyperus retrorsus	Pinebarren Flatsedge	F	F
Dichanthelium aciculare	Needle-leaf Witchgrass	F	F
Eleocharis sp. (small fine viviparous)	Spikerush	-	O
Elephantopus elatus	Florida Elephant's Foot	R	-
Eragrostis refracta	Coastal Lovegrass	-	R
Eupatorium capillifolium	Dogfennel	-	O
Euthamia tenuifolia	Flat-top Goldenrod	O	F
Gaylussacia dumosa	Dwarf Huckleberry	F	F
Gratiola hispida	Scrub Hedge-Hyssop	O	F
Hypericum tetrapetalum	Heart-Leaved St. Peter's-Wort	-	O
Helianthemum corymbosum	Clustered Rock-Rose	F	O
Juncus scirpoides	Needle-Pod Rush	-	R
Lachnocaulon beyrichianum	Little Bog-Button	F	A
Lechea torreyi	Piedmont Pinweed	O	O
Licania michauxii	Gopher Apple	F	O
Lyonia fruticosa	Staggerbush	A	F
Momordica balsamina	Southern Balsampear	O	-
Myrica cerifera	Wax Myrtle	R	-

Table 3. (continued).

Botanical Name	Common Name	Estimated Abundance in Burned Flatwoods†	Estimated Abundance in Unburned Flatwoods†
Myrica pusilla	Dwarf Wax Myrtle	O	O
Paspalum setaceum	Thin Paspalum	R	R
Phytolacca americana	Pokeweed	O	-
Piloblephis rigida	Pennyroyal	-	O
Pinus palustris	Longleaf Pine	O	-
Pityopsis graminifolia var. *tracyi*	Silk-Grass	O	-
Polygala grandiflora	Large-Flowered Polygala	R	-
Pterocaulon pycnostachyum	Black Root	O	R
Quercus minima	Dwarf Live Oak	F	O
Quercus virginiana	Live Oak	-	O
Rhus copallina	Winged Sumac	O	O
Rhynchelytrum repens	Natalgrass	R	-
Rhynchospora breviseta	Shortbristle Beaksedge	O	F
Rhynchospora fernaldii	Fernald's Beaksedge	-	O
Schizachyrium stoloniferum	Creeping Bluestem	O	O
Serenoa repens	Saw Palmetto	A	A
Solidago fistulosa	Pinebarren Goldenrod	-	O
Sorghastrum secundum	Lopsided Indiangrass	R	O
Stipulicida setacea	Wire Weed	O	-
Syngonanthus flavidulus	Shoe Buttons	-	O
Vaccinium myrsinites	Shiny Blueberry	F	F
Vitis rotundifolia	Muscadine	O	-
Xyris difformis	Pink-Leafed Yellow-Eyed-Grass	-	R
Yucca filamentosa	Adam's Needle	R	-

† A = Abundant
F = Frequent
O = Occasional
R = Rare

control plots at the sand tailings sites (no topsoil added) produced only 22% desirable species in 1997 and 35% in 1998. Overall, the sand tailings site produced an almost equivalent number of species as the overburden site, but a lower percentage of desirable species.

Average percent cover was compared by site and year for each treatment for selected plant species or plant groups (Table 4). Statistical comparison of average percent cover among treatments was calculated for desirable species or plant groups such as pioneer and characteristic species as well as individual target species such as wiregrass, saw palmetto, *Dichanthelium aciculare*, and *Dichanthelium portoricense*. Average percent cover was also calculated for undesirable species or plant groups such as exotic aggressive and weedy species, natalgrass, and torpedograss. Lowest percent cover of pioneer and characteristic species was consistently documented at the control plots for both study years (1997 and 1998) and both the overburden and sand tailings sites (Table 4). Pioneer and characteristics species exhibited an increase in cover from 1997 to 1998 at the overburden site and a decrease in cover from 1997 to 1998 at the sand tailings site. Highest percent cover of

Table 4. Average percent cover of select plant and plant groups for each treatment at the topsoil augmentation study. Treatments include topsoil from burned and unburned sites, thin and thick topsoil, and overburden and sand tailings soils.

Treatment†	Pioneer & Charac. Species	*Aristida beyrichiana* (Wiregrass)	*Serenoa repens* (Saw Palmetto)	*Dichanthelium aciculare*	*Dichanthelium portoricense*	Exotic, Aggressive & Weedy Species	*Rhynchelytrhum repens* (Natalgrass)	*Panicum repens* Torpedograss
				Overburden, 1997				
UB/T	67.81^{A}	0^{C}	3.81^{A}	4.38^{B}	32.50^{A}	36.94^{AB}	1.94^{B}	0
UB/Tk	90.31^{A}	0^{C}	3.75^{A}	3.13^{B}	42.50^{A}	32.06^{AB}	2.56^{B}	0
Control	2.75^{B}	0^{C}	0.00^{B}	0.00^{C}	0.00^{C}	18.13^{B}	5.00^{B}	0
B/T	62.06^{A}	0.69^{B}	0.00^{B}	6.88^{AB}	3.25^{BC}	36.56^{AB}	2.56^{B}	0
B/Tk	62.88^{A}	3.19^{A}	0.63^{B}	12.5^{A}	6.25^{B}	59.00^{A}	17.50^{A}	0
				Sand tailings, 1997				
UB/T	57.31^{AB}	0^{A}	1.56^{A}	3.75^{C}	4.44^{B}	30.75^{AB}	1.88^{A}	13.13^{A}
UB/Tk	71.63^{A}	0^{A}	2.62^{A}	5.00^{BC}	16.88^{A}	8.19^{B}	0^{A}	2.5^{A}
Control	3.81^{C}	0^{A}	0^{A}	0.00^{D}	0.00^{C}	66.06^{A}	3.85^{A}	32.5^{A}
B/T	48.81^{B}	0.75^{A}	0.69^{A}	8.75^{AB}	2.00^{B}	16.13^{B}	5.63^{A}	1.88^{A}
B/Tk	55.63^{B}	1.31^{A}	0.75^{A}	16.25^{A}	2.63^{B}	27.88^{AB}	1.94^{A}	10.0^{A}
				Overburden, 1998				
UB/T	91.20^{B}	0.63^{AB}	5.20^{A}	1.40^{BC}	35.00^{B}	1.55^{B}	1.33^{C}	0
UB/Tk	139.30^{A}	0^{B}	0.90^{B}	3.13^{B}	55.00^{A}	3.20^{B}	1.95^{BC}	0
Control	7.45^{C}	0^{B}	0.00^{B}	0.00^{C}	0.00^{D}	44.65^{A}	16.25^{A}	0
B/T	103.40^{B}	3.13^{A}	0.00^{B}	16.88^{A}	4.38^{C}	39.03^{A}	6.88^{ABC}	0
B/Tk	105.05^{B}	3.13^{A}	0.00^{B}	18.75^{A}	4.45^{C}	13.50^{B}	10.63^{AB}	0
				Sand tailings, 1998				
UB/T	14.68^{B}	0^{A}	1.40^{A}	0^{A}	0^{A}	57.25^{A}	9.38^{A}	16.88^{A}
UB/Tk	38.45^{AB}	1.25^{A}	0.75^{AB}	0.63^{A}	0.63^{A}	77.18^{A}	5.0^{A}	15.00^{A}
Control	16.15^{B}	0^{A}	0.00^{B}	0^{A}	0^{A}	66.38^{A}	8.83^{A}	25.00^{A}
B/T	38.90^{AB}	1.25^{A}	0.00^{B}	0.63^{A}	0^{A}	40.85^{A}	21.25^{A}	1.25^{A}
B/Tk	59.60^{A}	1.25^{A}	0.00^{B}	1.25^{A}	0.63^{A}	46.95^{A}	27.5^{A}	12.50^{A}
Significant Effects	Burn** Soil** Year/Soil ** Burn/Soil **	Burn**	Year * Burn **	Year** Burn** Soil** Year/Soil** Burn/Soil*	Year** Burn** Soil** Year/Soil** Burn/Soil**	Soil** Year/Soil* * Burn/Soil*	Year ** Burn ** Year/Soil *	Soil**

* p = *0.05 - 0.01*, ** p < *0.01*. Mean values for select plant and plant groups for different treatments followed by the same letter are not different according to a Waller-Duncan K-ratio t test of means with K set to 100 (approximate 0.05 type I error rate).
† UB/T = Unburned/Thin, UB/Th = Unburned/Thick, B/T = Burned/Thin, B/Th = Burned/Thick

this desirable plant group was documented in 1998 at the overburden site. Burning, soil type, year/soil type interaction, and burning/soil type interaction were all highly significant factors affecting percent cover of this desirable plant group.

Wiregrass transferred with the topsoil from the burned site was documented at a low average percent cover at both the overburden and sand tailings sites in 1997 (Table 4). Wiregrass persisted, albeit at low percent cover, in the topsoil plots from the burned site in 1997 and 1998 at both sites. Wiregrass was also recorded in some of the unburned topsoil plots. Thick topsoil tended to produce slightly higher coverage of wiregrass than thin topsoil in 1997 at both the overburden and sand tailings sites (Table 4). Wiregrass plant parts, and seeds were transferred in the topsoil from the burned sites, whereas only plant parts were transferred in the topsoil from the unburned site. One important goal of this field experiment was to compare establishment of wiregrass with two different burn treatments, two different topsoil thicknesses, and two different soil types. These percent cover data may underestimate the future wiregrass populations in the study plots as wiregrass seedlings are very small and slow growing, so that even a high density of wiregrass seedlings would also tend to produce a low percent cover. These data are inconclusive in determining the effects of various topsoil treatments on the establishment of wiregrass. Additional long-term quantitative vegetation monitoring at these two sites is needed to assess the effects of burning, topsoil thickness, and soil type on the establishment of wiregrass.

Saw palmetto (*Serenoa repens*) was recorded in the overburden plots with topsoil from the unburned site in 1997, and at both the overburden and sand tailings plots with topsoil from the unburned sites in 1998 (Table 4). Although the 1997 data from the sand tailings plots were too small to allow comparisons, saw palmetto was present in the unburned sand tailings plots in 1997. Saw palmetto was also recorded in the burned thick topsoil plots at the overburden site in 1997 but not in 1998. In contrast to wiregrass, this species was more common at the unburned plots than the burned plots. Because a very heavy crop of palmetto seeds was produced in the unburned flatwoods during the summer of 1996, palmettos were consequently transferred in unburned topsoil as large numbers of seeds and plant parts to the recipient sites. Saw palmetto seeds were not produced after the summer burn in the burned flatwoods areas, so palmettos were transferred in the topsoil from the burned sites only via plant parts. Saw palmetto will typically begin producing seeds about two years after a burn; thus the burned plots would not have contained saw palmetto seeds. Saw palmetto successfully transferred in the topsoil from the unburned plots as evidenced by a high density of saw palmetto seedlings. The percent cover of palmetto was low in the plots because it takes several years before even a palm-shaped frond is produced. Like wiregrass, long-term quantitative vegetation monitoring is needed to assess the effects of burning, topsoil thickness, and soil type on the establishment of saw palmetto at these two study sites.

We noticed during vegetation monitoring that *Dichanthelium aciculare* was noticeably more common in the topsoil from the burned site while *D. portoricense* was more common in the topsoil from the unburned site. Therefore, we decided to explore these two desirable witchgrass species in greater detail. *Dichanthelium aciculare* was recorded in both the burned and unburned plots at both sites in 1997, however, at a higher percent cover in the plots with topsoil from the burned site than in the plots with topsoil from the unburned site (Table 4). This species increased in percent cover from 1997 to 1998 in the overburden plots with topsoil from the burned sites, but decreased in percent cover from 1997 to 1998 in the overburden plots with topsoil from the unburned sites. The reverse pattern was documented for *D. portoricense* at both the overburden and sand tailings sites, where higher cover was documented in the plots with topsoil from the unburned sites compared to the plots with topsoil from the burned site (Table 4). This species maintained similar cover values from 1997 to 1998 at the overburden site. Both species decreased in cover at the sand tailings site.

Exotic, aggressive, and weedy species were abundant at both the overburden and sand tailings sites in 1997 (Table 4). This undesirable plant group was most problematic in the control plots (that received no topsoil) on the sand tailings site in 1997, with an average percent cover of 66%. These species declined in most of the treatment plots at the overburden site between 1997 and 1998, and increased substantially from 18% to 45% in control plots over the same period of time. These species increased at all of the treatment plots at the sand tailings site. It is interesting to note that where pioneer and characteristic species were heavy and increasing, the aggressive and weedy species were diminishing. Conversely, where the space was not occupied successfully by characteristic species, the aggressive species had increased. In future monitoring, it would be interesting to separate the weedy from the aggressive species in the analyses.

Natalgrass and torpedograss were two aggressive grasses that were observed at the sand tailings topsoil augmentation plots. We analyzed percent cover of the two species for each of the treatments, however, the mean separation of the data was not significant for either 1997 or 1998.

Perhaps the most obvious qualitative difference observed between soil types was the persistence and dominance of undesirable species at the sand tailings site compared to the overburden site (Tables 5 and 6). Regardless of whether or not topsoil was from a burned or unburned site, thick or thin, or even applied at all, the sand tailings site was dominated by weedy and/or exotic taxa including torpedograss, natalgrass, and southern crabgrass (*Digitaria ciliaris*). While some desirable native species were recorded in moderate percent coverages on the sand tailings site in 1997, by 1998 they were markedly reduced in nearly all plots regardless of treatment. The initial weed cover around the sand tailings site was quite high and presumably contributed to the heavy cover of natalgrass

Table 5. Average percent cover of the most abundant vegetation in topsoil from burned sites on sand tailings.

Scientific Name	Average Percent Cover						Vegetation Category			
	No Topsoil		Thin Topsoil		Thick Topsoil					
	1997	1998	1997	1998	1997	1998	Desirable or Weedy	Origin and Type		Ecosystem Category
Bare Ground	40.0	35.6	40.0	35.0	17.6	19.4	—	—		—
Ambrosia artemisiifolia		11.3		10.0			W	Native	Weedy	—
Bulbostylis stenophylla				3.8		5.1	D	Native	Characteristic	—
Conyza canadensis	5.0	3.4		7.5			W	Native	Weedy	—
Cyperus retrorsus	2.5	2.6	8.8	3.8	5.0	6.9	D	Native	Pioneer	—
Cynodon dactylon	5.0	15.0					W	Exotic	Aggressive	Aggressive Grass
Dactyloctenium aegyptium	5.0				2.5		W	Exotic	Weedy	---
Dichanthelium aciculare			8.8	2.5	16.3	5.0	D	Native	Pioneer	—
Digitaria ciliaris	3.8	3.8	5.9	3.3	26.3	3.8	W	Exotic	Weedy	—
Diodia teres	2.5	2.5	16.9	18.1	18.8	40.8	W	Native	Weedy	—
Eragrostis refracta			5.0	11.3	2.7	9.2	W	Native	Pioneer	Lovegrass
Heterotheca subaxillaris	10.6	2.6		5.7	0.3	5.1	W	Native	Weedy	—
Indigofera hirsuta	9.5	8.2	3.9	5.7		5.0	W	Exotic	Weedy	Legume
Panicum repens	65.0	50.0	3.8	2.5	40.0	50.0	W	Exotic	Aggressive	Aggressive Grass/ Wet. Sp.†
Paspalum setaceum			3.1	12.5	2.6	3.3	D	Native	Pioneer	—
Rhynchelytrum repens	7.5	11.8	7.5	21.3	3.9	55.0	W	Exotic	Aggressive	Aggressive Grass

† Wetland Species

Table 6. Average percent cover of the most abundant vegetation in topsoil from unburned sites on sand tailings.

Scientific Name	Average Percent Cover						Vegetation Category			
	No Topsoil		Thin Topsoil		Thick Topsoil					
	1997	1998	1997	1998	1997	1998	Desirable or Weedy	Origin and Type		Ecosystem Category
Bare Ground	40.0	35.6	23.1	35.0	20.0	17.5	—	—		—
Ambrosia artemisiifolia		11.3		2.5			W	Native	Weedy	—
Aristida purpurescens			11.3	2.5	10.6	6.3	D	Native	Characteristic	—
Axonopus affinis			2.5		8.8	12.5	D	Native	Pioneer	—
Conyza canadensis	5.0	3.4		1.0		2.5	W	Native	Weedy	—
Crotalaria pallida				10.0			W	Exotic	Weedy	Legume
Cynodon dactylon	5.0	15.0					W	Exotic	Aggressive	Aggressive Grass
Cyperus retrorsus	2.5	2.6	21.3	3.4	16.3	6.9	D	Native	Pioneer	—
Dactyloctenium aegyptium	5.0						W	Exotic	Weedy	—
Dichanthelium aciculare			5.0		5.0	2.5	D	Native	Pioneer	—
Dichanthelium portoricense			4.4		16.9	2.5	D	Native	Pioneer	—
Digitaria ciliaris	3.8	3.8	4.2	11.7	5.0	28.2	W	Exotic	Weedy	—
Diodia teres	2.5	2.5	6.3	6.4	5.0	5.0	W	Native	Weedy	—
Eragrostis sp.				10.0		2.5	—	—		Lovegrass
Eupatorium capillifolium	0.3	0.3			2.5	6.4	W	Native	Weedy	—
Euthamia tenuifolia			4.3	3.8	7.6	7.5	D	Native	Pioneer	—
Heterotheca subaxillaris	10.6	2.6	1.8	15.6	2.5	9.4	W	Native	Weedy	—
Indigofera hirsuta	9.5	8.2	15.0	3.4	3.9	20.8	W	Exotic	Weedy	Legume
Panicum repens	65.0	50.0	17.5	16.9	10.0	30.0	W	Exotic	Aggressive	Aggressive Grass/
Paspalum setaceum			4.4	5.0	4.4	7.5	D	Native	Pioneer	—
Rhynchelytrum repens	7.5	11.8	2.5	12.5		6.7	W	Exotic	Aggressive	Aggressive Grass
Vitis rotundifolia			5.0				D	Native	Pioneer	—

and torpedograss. The extended drought of 1998 was an extreme and highly unusual weather event. In a normal spring drought, the *Dichantheliums* and other native species that were lost on the sand tailings site would probably have survived, as many of these species do occur on fairly dry sites. Although native species were recorded at low coverages, it is important to note that cover in more xeric systems is usually less dense than in moist communities, and a higher percent cover does not necessarily indicate greater success. These limited datasets suggest that while the seed source for desirable species was present at the sand tailings site (at least in the topsoil plots), unfavorable conditions such as a lack of sufficient water during the extended drought, and a large seed source for aggressive grasses in adjacent areas, contributed to the failure of desirable taxa to persist and instead favored some of the aggressive grasses noted above.

Results from the overburden site indicated a much higher percent cover of desirable species. Though some of the more dominant species are definitely pioneer species such as *Dichanthelium spp.* (Tables 7 and 8), the overall cover generally consists of a good mix of a large

Table 7. Average percent cover of the most abundant vegetation in topsoil from burned sites on overburden.

Scientific Name	Average Percent Cover						Vegetation Category			
	No Topsoil		Thin Topsoil		Thick Topsoil					
	1997	1998	1997	1998	1997	1998	Desirable or Weedy	Origin and Type		Ecosystem Category
Bare Ground	83.8	50.0	30.6	21.9	16.3	30.1	—	—		—
Chamaecrista nictitans			10.1	14.3	2.5		D	Native	Pioneer	Legume
Cyperus globulosus	0.3		12.5		12.5		D	Native	Pioneer	—
Cyperus retrorsus	3.4	2.2	15.0	8.8	8.1	12.5	D	Native	Pioneer	—
Dichanthelium aciculare			6.9	16.9	12.5	18.8	D	Native	Pioneer	—
Dichanthelium portoricense			3.3	4.4	6.3	4.4	D	Native	Pioneer	—
Digitaria ciliaris	5.0		33.1	1.4	40.0		W	Exotic	Weedy	—
Diodia teres		0.3	15.0	12.5	5.0	2.8	W	Native	Weedy	—
Elephantopus elatus			1.4	2.6	2.5	5.1	D	Native	Characteristic	—
Euthamia tenuifolia			20.0	15.2	6.7	23.8	D	Native	Pioneer	—
Indigofera hirsuta	1.8	20.6	0.9	26.9	1.1	0.3	W	Exotic	Weedy	Legume
Panicum anceps					5.0	10.3	D	Native	Characteristic	—
Paspalum setaceum			3.8	12.5	4.4	20.1	D	Native	Pioneer	—
Pityopsis graminifolia			2.5	0.3	5.0	5.0	D	Native	Characteristic	—
Pterocaulon pycnostachyum				5.0	0.3	2.5	D	Native	Pioneer	—
Rhynchelytrum repens	5.0	16.3	3.4	6.9	17.5	10.6	W	Exotic	Aggressive	Aggressive Grass
Sabatia brevifolia				5.0			D	Native	Characteristic	—
Hedyotis corymbosa	5.0						W	Exotic	Weedy	—

Table 8. Average percent cover of the most abundant vegetation in topsoil from unburned site on overburden.

Scientific Name	Average Percent Cover						Vegetation Category			
	No Topsoil		Thin Topsoil		Thick Topsoil					
	1997	1998	1997	1998	1997	1998	Desirable or Weedy	Origin and Type		Ecosystem Category
Bare Ground	83.8	50.0	15.0	28.8	10.1	9.6	—	—		—
Cyperus globulosus	0.3		0.3	0.3	5.0		D	Native	Pioneer	—
Cyperus retrorsus	3.4	2.2	8.8	6.9	15.6	4.4	D	Native	Pioneer	—
Dichanthelium portoricense			32.5	35.0	42.5	55.0	D	Native	Pioneer	—
Digitaria ciliaris	5.0		35.0		28.8	2.5	W	Exotic	Weedy	—
Euthamia tenuifolia			5.8	12.5	4.2	37.6	D	Native	Pioneer	—
Hedyotis corymbosa	5.0						W	Exotic	Weedy	—
Hedyotis sp.		0.3		5.0			—	—		—
Indigofera hirsuta	1.8	20.6		0.3			W	Exotic	Weedy	Legume
Myrica cerifera						10.0	D	Native	Pioneer	—
Paspalum setaceum			5.0	8.8	5.0	6.3	D	Native	Pioneer	—
Rhus copallina			5.0	3.8	3.8	4.5	D	Native	Characteristic	—
Rhynchelytrum repens	5.0	16.3	1.9	1.8	3.4	2.6	W	Exotic	Aggressive	Aggressive Grass
Scleria ciliata				1.1		5.0	D	Native	Characteristic	—
Serenoa repens			3.8	5.2	5.0	1.2	D	Native	Characteristic	—
Solidago fistulosa		0.3	2.8	3.9	9.2	12.5	D	Native	Pioneer	—

number of flatwoods species. It will be interesting to see whether future monitoring will document a shift toward increased cover by characteristic species and at what rate this change occurs. Several of the species actually attained dominance in some of the treatment plots (Tables 7 and 8). The ability of overburden soil to retain moisture longer than sand tailings probably played an important role in providing favorable conditions for emerging donor seedlings, particularly where topsoil was applied. Additionally, the moisture conditions provided by the overburden probably more closely matched the moisture conditions at the donor mesic flatwoods site as compared to the moisture conditions at the sand tailings site. Thus, the more favorable moisture conditions at the overburden site probably contributed not only to more successful germination, but to more successful establishment of mesic flatwoods species. Additionally, the overburden site lacked the high initial weed cover of adjacent areas as was the case at the sand tailings site, so presumably less weed seed was introduced to the overburden site.

Results of seed germination tests from samples analyzed at the NRCS Plant Materials Center showed a wide range in wiregrass seed germination (Table 9). The highest germination of wiregrass occurred from full spikelets collected from the plants (70%), while a low germination rate of 4% was measured from random samples collected from the ground. These laboratory-generated germination rates represent potential seed germination under ideal conditions, and thus can overestimate true germination in field conditions. Most wiregrass germination tests are performed on spikelets, whether or not they contain a developed caryopsis. These tests indicate that if there are developed seeds then the germination rate may be fairly high. Though the developed seeds are difficult to see in the field, we can

Table 9. Germination of wiregrass seed from three studies: the current FIPR topsoil augmentation study, a related FIPR site preparation study, and an unrelated CFI upland reclamation study.

Field Experiment	Date Seed Collected	Seed Source	Full or Random Spikelets	Number of Spikelets Tested	% Germination
FIPR Topsoil Augmentation	11/20/96	Hardee County	Random	400	30
FIPR Topsoil Augmentation	11/20/96	Hardee County	Full	300	70
FIPR Topsoil Augmentation	1/14/97 (one week before topsoiling)	Hardee County	Random from ground	400	4
FIPR Topsoil Augmentation	1/14/97 (one week before topsoiling)	Hardee County	Full from ground	26	23
FIPR Site Preparation	11/25/96	Okeechobee County	Random	400	42
FIPR Site Preparation	11/25/96	Okeechobee County	Full	400	77
CFI Upland Reclamation	11/20/96	Hillsborough County	Full	400	81
CFI Upland Reclamation	11/20/96	Hillsborough County	Random from middle of stem	400	53

easily field test a potential wiregrass harvest by bending spikelets. A developed seed will break or snap, and an empty spikelet will just fold over. We do not fully understand what happens to wiregrass seeds after they have fallen from the culms and are exposed to heat and moisture over time. The small sample of full seed collected from the ground in mid-January one week before topsoiling, tested at 23%, while random seed tested at only 4% (Table 9).

Soils

The addition of topsoil improved soil properties in the surface layer at the overburden site by decreasing bulk density and C:N ratio, and increasing total C, total N, Ca, Mg, K, Zn, Mn, and Na (Table 10). There were no changes in Fe concentrations or CEC values between the topsoil and the control plots. Improvements to soil properties were generally irrespective of whether topsoil originated from a burned or unburned flatwoods, or if topsoil was applied as a thick layer or thin layer. Only one difference was detected in soil properties between thick and thin topsoil in the surface soil layer at the overburden site; Ca concentrations in the surface were higher in the thin topsoil plots. Topsoil from the unburned flatwoods exhibited a higher total N content than topsoil from burned flatwoods (Table 10) likely as a result of N volatilization during the burning process. The C:N ratio in the surface layer was decreased by addition of topsoil, dropping from over 50 in the control sites to between 24 and 32 in the amended sites. Mineralization and immobilization processes are balanced at a C:N ratio of approximately 23. However, any differences noted for N concentrations and C:N ratios must be interpreted with caution since low N values encountered in most of these soils would result in significant error in the calculation of C:N ratios.

Table 10. Comparison of soil properties† at the overburden site.

Soil Properties	Soil Layer	Control (No Topsoil)	Topsoil from Burned Flatwoods		Topsoil from Unburned Flatwoods	
			Thin	Thick	Thin	Thick
BD, g cm^{-3}	Surface‡	$1.53^{A\dagger}$	1.26^{B}	1.32^{B}	1.30^{B}	1.30^{B}
pH		4.82^{AB}	5.03^{A}	4.99^{AB}	4.84^{AB}	4.69^{AB}
C, %		0.83^{B}	2.28^{A}	1.97^{AB}	2.23^{A}	2.61^{A}
N, %		0.017^{C}	0.067^{B}	0.077^{B}	0.087^{AB}	0.108^{A}
C:N		51.4^{A}	32.1^{B}	27.9^{B}	25.5^{B}	24.1^{B}
Ca, mg kg^{-1}		81.5^{C}	382^{A}	203^{BC}	246^{AB}	224^{BC}
Mg, mg kg^{-1}		13.3^{B}	69.5^{A}	39.8^{AB}	41.5^{AB}	37.5^{AB}
K, mg kg^{-1}		15.8^{B}	27.0^{AB}	34.5^{A}	34.3^{A}	37.0^{A}
P, mg kg^{-1}		155^{A}	77.5^{B}	39.3^{B}	87.3^{B}	48.3^{B}
Zn, mg kg^{-1}		0.38^{B}	0.77^{A}	0.87^{A}	0.87^{A}	0.97^{A}
Cu, mg kg^{-1}		0.20^{B}	0.28^{AB}	0.30^{AB}	0.26^{AB}	0.34^{A}
Mn, mg kg^{-1}		0.280^{B}	1.43^{A}	1.59^{A}	1.17^{A}	1.19^{A}
Fe, mg kg^{-1}		33.2^{A}	38.2^{A}	33.5^{A}	55.6^{A}	55.6^{A}
Na, mg kg^{-1}		24.4^{B}	36.3^{AB}	36.1^{AB}	46.4^{A}	50.2^{A}
CEC, cmol kg^{-1}		10.4^{A}	7.52^{A}	6.15^{A}	6.97^{A}	8.17^{A}
BD, g cm^{-3}	Sub-surface¶	1.53^{A}	1.47^{A}	1.40^{A}	1.49^{A}	1.31^{A}
pH		4.82^{B}	5.01^{AB}	4.99^{AB}	5.06^{A}	4.97^{AB}
C, %		0.83^{A}	0.98^{A}	1.06^{A}	0.93^{A}	0.97^{A}
N, %		0.017^{A}	0.031^{A}	0.030^{A}	0.029^{A}	0.036^{A}
C:N		51.4^{A}	34.4^{AB}	41.9^{AB}	34.4^{AB}	27.9^{B}
Ca, mg kg^{-1}		81.5^{A}	335^{A}	192^{A}	224^{A}	168^{A}
Mg, mg kg^{-1}		13.3^{A}	17.3^{A}	18.0^{A}	14.8^{A}	15.0^{A}
K, mg kg^{-1}		15.8^{A}	15.5^{A}	19.8^{A}	16.3^{A}	17.0^{A}
P, mg kg^{-1}		155^{A}	286^{A}	222^{A}	260^{A}	254^{A}
Zn, mg kg^{-1}		0.38^{A}	0.59^{A}	0.59^{A}	0.57^{A}	0.54^{A}
Cu, mg kg^{-1}		0.20^{A}	0.26^{A}	0.22^{A}	0.30^{A}	0.20^{A}
Mn, mg kg^{-1}		0.28^{A}	0.50^{A}	0.32^{A}	0.34^{A}	0.32^{A}
Fe, mg kg^{-1}		33.2^{A}	34.9^{A}	34.8^{A}	33.7^{A}	34.5^{A}
Na, mg kg^{-1}		24.4^{A}	28.2^{A}	30.8^{A}	29.2^{A}	30.8^{A}

† Mean values for a given soil property followed by the same letter are not different within a row of data according to a Waller-Duncan K-ratio t-test of means with K set to 100 (approximate 0.05 type I error rate).

‡ Surface depth varies with topsoil thickness. Thin layer of topsoil has a depth of approximately 8 cm and a thick layer of topsoil has a depth of approximately 16 cm.

¶ Subsurface is overburden material.

In the subsurface layer at the overburden site, there were also few significant differences among control plots, topsoil from the burned site, and topsoil from unburned site, presumably because all samples were collected from the underlying overburden material (Table 10). All soils were collected two months after topsoil application, and differences in soil properties of the overburden material would not be expected during this short period. The only differences were a lower pH in the control plots and a lower C:N ratio in thick unburned topsoil plots. A lower C:N ratio beneath a thick layer of topsoil suggests there is a possibility that the topsoil is enriching the overburden material through leaching of organics from above.

Addition of topsoil at the sand tailings site changed soil properties in the surface layer by decreasing pH, C:N ratio, Ca, P, and Zn concentrations, and increasing total C and total N (Table 11). Nitrogen concentrations in topsoil from a burned flatwoods (thin application) were lower than from an unburned flatwoods at the sand tailings site, again due to the loss of N during

Table 11. Comparison of soil properties† at the sand tailings site.

Soil Properties	Soil Layer	Control (No Topsoil)	Topsoil from Burned Flatwood		Topsoil from Unburned Flatwoods	
			Thin	Thick	Thin	Thick
BD, g cm^{-3}§	Surface ‡	1.57^{A}	1.51^{A}	1.49^{A}	1.53^{A}	1.41^{A}
pH		7.25^{A}	5.48^{B}	4.87^{D}	5.29^{BC}	5.19^{C}
C, %		0.28^{B}	1.37^{A}	1.51^{A}	1.56^{A}	2.25^{A}
N, %		0.007^{C}	0.047^{B}	0.054^{AB}	0.06^{AB}	0.075^{A}
C:N		45.8^{AB}	28.4^{B}	27.7^{B}	26.2^{B}	29.9^{B}
Ca, mg kg^{-1}		968^{A}	521^{B}	284^{D}	488^{BC}	336^{CD}
Mg, mg kg^{-1}		155^{B}	87.8^{AB}	43.0^{AB}	57.3^{AB}	38.8^{B}
K, mg kg^{-1}		16.3^{A}	36.8^{A}	29.5^{A}	27.5^{A}	26.5^{A}
P, mg kg^{-1}		294^{A}	115^{B}	58.3^{C}	126^{B}	72.5^{C}
Zn, mg kg^{-1}		1.65^{A}	0.91^{B}	0.73^{B}	0.81^{B}	0.69^{B}
Cu, mg kg^{-1}		0.44^{A}	0.32^{AB}	0.30^{AB}	0.24^{B}	0.18^{B}
Mn, mg kg^{-1}		1.55^{A}	1.47^{A}	1.13^{A}	1.07^{A}	0.99^{A}
Fe, mg kg^{-1}		69.8^{A}	46.7^{A}	38.8^{A}	46.2^{A}	46.4^{A}
Na, mg kg^{-1}		22.2^{A}	39.7^{A}	35.1^{A}	32.5^{A}	38.5^{A}
CEC, cmol kg^{-1}		11.8^{A}	13.7^{A}	18.9^{A}	17.1^{A}	20.3^{A}
BD, g cm^{-3}	Sub-surface ¶	1.57^{A}	1.61^{A}	1.51^{A}	1.50^{A}	1.58^{A}
pH		7.25^{B}	7.52^{A}	7.59^{A}	7.49^{A}	7.44^{AB}
C, %		0.28^{A}	0.35^{A}	0.17^{A}	0.31^{A}	0.18^{A}
N, %		0.007^{A}	0.005^{A}	0.002^{A}	0.013^{A}	0.005^{A}
C:N		45.8^{C}	111^{A}	87.5^{AB}	35.0^{C}	52.0^{BC}
Ca, mg kg^{-1}		968^{A}	1078^{A}	828^{A}	887^{A}	868^{A}
Mg, mg kg^{-1}		155^{A}	259^{A}	97.3^{A}	145^{A}	109^{A}
K, mg kg^{-1}		16.3^{A}	21.0^{A}	10.0^{A}	18.0^{A}	12.5^{A}
P, mg kg^{-1}		294^{A}	267^{A}	274^{A}	268^{A}	286^{A}
Zn, mg kg^{-1}		1.65^{A}	1.05^{A}	0.87^{A}	1.15^{A}	1.15^{A}
Cu, mg kg^{-1}		0.44^{A}	0.32^{AB}	0.16^{B}	0.22^{B}	0.28^{AB}
Mn, mg kg^{-1}		1.55^{A}	2.40^{A}	1.13^{A}	1.53^{A}	1.21^{A}
Fe, mg kg^{-1}		69.8^{A}	51^{A}	27.6^{A}	42.3^{A}	45.7^{A}
Na, mg kg^{-1}		22.2^{B}	29.0^{A}	23.0^{B}	24.8^{AB}	25.6^{AB}

† Mean values for a given soil property followed by the same letter are not different according to a Waller-Duncan K-ratio t-test of means with K set to 100 (approximate 0.05 type I error rate).

‡ Surface depth varies with topsoil thickness. Thin layer of topsoil has a depth of approximately 8 cm and a thick layer of topsoil has a depth of approximately 16 cm.

¶ Subsurface is sand tailings.

burning. Few differences in soil properties were noted between thick topsoil and thin topsoil applications at the sand tailings site. The pH, Ca, and P concentrations were significantly higher in thick topsoil than thin topsoil from a burned flatwoods. Likewise, P concentration was higher at the thick topsoil plots from unburned flatwoods (Table 11).

In the subsurface layer at the sand tailings site, there were also few differences among control plots, topsoil from burned sites, and topsoil from unburned sites, and these differences were generally not significant (Table 11). One difference worth noting was a significantly lower pH in subsurface soils from control plots, which is opposite from surface soils in which the pH was significantly higher (Table 11). The above soil tests were performed by separating thick and thin topsoil from the burned site from thick and thin topsoil from the unburned site for both the overburden and sand tailings sites. Differences in soil parameters were then reexamined by combining topsoil data from the burned and unburned sites and testing for differences in topsoil thickness, and by combining thick and thin topsoil and testing for differences in topsoil from burned vs. unburned sites (Table 12). These tests were performed for surface and subsurface soils at both the overburden and sand tailings sites. Comparison of soil properties for surface soil at the overburden site indicated differences in pH, total N, Fe and Na between topsoil from burned and unburned flatwoods (Table 12). The topsoil from the burned site had higher pH (5.01 *vs* 4.76) but lower Fe (35.8 *vs* 55.6 mg kg^{-1}) and Na (36.2 *vs* 48.3 mg kg^{-1}) concentrations. No differences in soil properties were noted for topsoil thickness on overburden material (Table 12). Differences were not expected since the thick topsoil came from the same donor site as the thin topsoil. Neither were there any interactions between topsoil from burned and unburned sites and soil thicknesses.

Comparison of soil properties for surface soil on sand tailings indicated differences in pH and Cu concentrations between topsoil from burned and unburned site treatments (Table 12). Topsoil from the burned site had a higher pH (5.33 *vs* 5.08), and Cu concentration (0.31 mg kg^{-1} *vs* 0.21 mg kg^{-1}) than the topsoil from the unburned site. Additionally, pH of the topsoil was greater (pH=5.38) for thin topsoil compared to thick topsoil (pH=5.04). Calcium and P concentrations were also higher in thin topsoil than thick topsoil (Table. 12), probably due to contamination with sand tailings in the thin topsoil plots. Differences in soil properties between topsoil thicknesses were not expected, and any differences can probably be explained in terms of heterogeneity in soil properties at the donor site. There were no interactions among topsoil from burned and unburned sites and soil thicknesses.

Table 12. Comparison of surface soil properties for two treatments; topsoil from burned *vs*. topsoil from unburned flatwoods, and thin topsoil *vs* thick topsoil. (Significant differences occurred when $p < 0.05$).

Subsurface soil = Overburden

Effect	BD	pH	C	N	C:N	Ca	Mg	K	P	Zn	Cu	Mn	Fe	Na	CEC
	g cm^{-3}		%	%						mg kg^{-1}					cmol kg^{-1}
Burn/Unb	NS	**0.0128**	NS	**0.0068**	NS	NS	NS	NS	NS	NS	NS	NS	**0.0025**	**0.0487**	NS
Thickness	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	1.29	4.89	2.27	0.0833	27.4	264	47.1	33.2	63.1	0.87	0.295	1.35	45.7	42.2	7.2
Burned		5.01											35.8	36.2	
Unburned		4.76											55.6	48.3	

Subsurface soil = Sand tailings

Effect	BD	pH	C	N	C:N	Ca	Mg	K	P	Zn	Cu	Mn	Fe	Na	CEC
	g cm^{-3}		%	%						mg kg^{-1}					cmol kg^{-1}
Burn/Unb	NS	**0.015**	NS	NS	NS	NS	NS	NS	NS	NS	**0.0362**	NS	NS	NS	NS
Thickness	NS	**0.0025**	NS	NS	NS	**0.0037**	NS	NS	**0.0049**	NS	NS	NS	NS	NS	NS
IA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mean	1.483	5.21	1.675	0.059	28.0	407	56.7	30.1	92.9	0.78	0.26	1.14	44.5	36.4	17.5
Burned		5.34									0.31				
Unburned		5.08									0.21				
Thickness 1		5.38				504			120.5						
Thickness 2		5.04				310			65.4						

NS indicates not significant, value in table indicates significance probability value.
Means associated with significant model effect presented below table.
IA = Interactions among topsoil from burned and unburned flatwoods, and thickness of topsoil application.
BD = Bulk Density.

The greatest number of differences in soil properties in the topsoil augmentation study were detected between overburden and sand tailings sites. Soil differences for BD, pH, C, N, C:N, Ca, Mg, Zn, Mn, and Na were highly significant (comparison of controls) between the overburden and sand tailings (Table 13). Potassium, P, Cu, Fe, and CEC were not significantly different between the two soils. The pH for sand tailings was much higher (pH=7.25) than overburden material (pH= 4.82), and these differences can be attributed to high Ca and Mg concentrations in the sand tailings (Ca = 968 mg kg^{-1}, Mg = 155 mg kg^{-1}) compared to that in the overburden (Ca = 82 mg kg^{-1}, Mg = 13 mg kg^{-1}). Zinc and Mn concentrations were also higher in sand tailings compared to overburden.

Table 13. Differences in soil properties between control plots at the overburden site and control plots at the sand tailings site.

Soil Parameter	Overburden Control	Sand Tailings Control	Sig. Diff.[†]
Bulk Density (g cm^{-3})	1.53	1.57	*
pH	4.82	7.25	*
Total C (%)	0.832	0.284	*
Total N (%)	0.017	0.007	*
C:N	51.4	45.8	*
Ca (mg kg^{-1})	82	968	*
Mg (mg kg^{-1})	13	155	*
K (mg kg^{-1})	15.8	16.3	NS
P (mg kg^{-1})	155	294	NS
Zn (mg kg^{-1})	0.38	1.65	*
Cu (mg kg^{-1})	0.20	0.44	NS
Mn (mg kg^{-1})	0.280	1.553	*
Fe (mg kg^{-1})	33.2	69.8	NS
Na (mg kg^{-1})	24.4	22.2	*
CEC (cmol kg^{-1})	10.4	11.8	NS

[†] * p = *0.05 - 0.01*, NS = No significant difference

The addition of topsoil to overburden and to sand tailings changed the soil characteristics of the control soil. However, the basic characteristics of the control are altered in different ways due to the great differences in soil characteristics between overburden and sand tailings (Table 12). The type of vegetation that would successfully grow in topsoil-amended plots will depend on soil conditions required for a given plant species, and will depend on the underlying soil material and the source of topsoil. Burning an area prior to removing topsoil could result in loss of N, and high N-requiring species may not grow well in low N soils. The impact of the thickness of topsoil application was not apparent at this stage of the study.

The data presented above were obtained from soil sampling two months after the addition of topsoil to the overburden and the sand tailings. Although some differences in subsurface soil characteristics were noted during this short period, it is probable that the soil properties will continue to change. The changes in soil characteristics will also be reflected in changes in the vegetation characteristics over a period of time. It will therefore be necessary to monitor both the soil and vegetation characteristics over an extended period of time.

Summary and Conclusions

Several conclusions can be drawn from the results from this field experiment. First and perhaps most importantly is that while topsoil augmentation appears to greatly benefit establishment of desirable species, the donor soil type should be matched as closely as possibly to the intended recipient site soil for best results. Specifically, establishment and growth of desirable species were most favorable when pine flatwoods donor soils were transferred to clay overburden rather than sand tailings. In addition, application of scrub donor soils on reclaimed sand tailings sites, while not evaluated in the current study, may provide better results on droughty sand tailings sites.

Control of exotic aggressive and weedy taxa during initial site preparation is also critical for encouraging the rapid spread of desirable species. This was particularly evident on the sand tailings site where several nuisance species dominated many of the experimental plots. Burning of donor soils prior to transfer suggested mixed results depending on the plant species. For example, while wiregrass transfer was apparently favored by burning, saw palmetto was negatively affected.

Analytical detection of differences in recipient soil chemistry due to topsoil application was not clear possibly because of the short time frame between topsoil application and soil sampling. While some chemical and physical changes were noted, most statistically significant differences were observed between sites (overburden *vs* sand tailings) rather than within sites. Additional sampling over time may reveal longer term developing changes.

Literature Cited

Bridges, E. L. and G. A. Reese. 1996. Upper Lakes Basin Watershed Natural Resource Inventory, a project of the Natural Resource Inventory of Save our Rivers, Lands for the South Florida Water Management District, Orlando, FL.

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

Levene, H. 1960. Robust Tests for the Equality of Variances, *in:* Contributions to Probability and Statistics, ed. I. Olkin, Palo Alto, California, Sanford University Press, pp. 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.

Nachlinger, J. and G. A. Reese. 1996. Plant Community Classification of the Spring Mountains National Recreational Area. Vol. 1: Summary Report. The Nature Conservancy, Nevada Chapter, Northern Nevada Field Office, Reno, NV. (Unpublished report to the U.S. Forest Service, Las Vegas, NV).

Nair, V. D., N. J. Bissett, K. M. Portier, D. A. Graetz, D. S. Segal, and R. A. Garren. 2000. Soil conditions and plant establishment on reclaimed phosphate-mined uplands. Proceedings of the 2000 Annual Meeting of the American Society for Surface Mining and Reclamation, Tampa, Florida.

https://doi.org/10.21000/JASMR00010035

Reese, G. A., E. L. Bridges, and S. L. Orzell. 1994. Floristic Natural Quality Assessment as a Tool for Evaluating Biodiversity Significance of Natural Areas in Central Florida. Annual Meeting, Natural Areas Association, Palm Beach Gardens, FL. Oct. 1994 (Abstract).

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

Shilling, D. G., T. A. Bewick, J. F. Gaffney, S. K. McDonald, C. A. Chase, and E. R. R. L. Johnson. 1997. Ecology, physiology, and management of cogongrass (*Imperata cylindrica*). Final report. Florida Institute of Phosphate Research Publication No. 93-03-107, Bartow, Florida.

Sokal, R. R. and F. J. Rohlf. 1969a. 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.

Sokal, R. R. and F. J. Rohlf. 1969b. Biometry: The Principle and Practice of Statistics in Biological Research. Chapter 1: Two-Way Analysis of Variance, W. H. Freeman and Company, San Francisco. pp 229-342.

Swink, F. and G. Wilhelm.1979. Plants of the Chicago Region. The Morton Arboretum, Lisle, IL.

Waller, R. A. and D. B. Duncan. 1969. A Bayes Rule for the Symmetric Multiple Comparison Problem. Journal of the American Statistical Association 64: 14841499.