RECLAMATION OF PRIME FARMLAND FOLLOWING MINERAL SANDS MINING IN VIRGINIA

by

W.L. Daniels, P.D. Schroeder, S.M. Nagle, L.W. Zelazny, and M.M. Alley

Abstract: Significant deposits of mineral sands were discovered in Virginia's Upper Coastal Plain in 1989. The Old Hickory Deposit is the largest ore body in the state (>2000 ha) and supports a productive rowcrop agriculture on prime farmlands. Field experiments were installed on pilot-scale (25 m X 60 m) mining pits in the late summer of 1995 and replicated on an adjacent undisturbed area. Half of each mining pit was topsoiled (25 cm) while the remaining half was left as either (1) mixed tails/slimes or (2) re-graded subsoil over tails/slimes to simulate various pit closure scenarios. Both non-topsoiled areas received 112 Mg/ha of yard waste compost as a soil building amendment. The entire area was ripped/disced to ameliorate compaction and incorporate lime and fertilizer additions. The experiment was cropped through a wheat/soybeans/corn/cotton rotation over the 1995 to 1998 growing seasons. Taken as a whole, these combined results clearly indicate that mining and reclamation of these prime farmlands will lead to a substantial decrease in rowcrop productivity, at least over the initial years following pit closure and reclamation. For the rotation studied, post-mining productivity was estimated by this experiment to be reduced by 23%, 3%, 27%, and 20% for each crop (wheat/soybeans/corn/ cotton) in sequence. For a given crop in a given year, response to topsoiling versus compost addition to the surface varied, and neither treatment appeared superior. Corn and cotton yields on the mined land treatments were reduced despite the application of irrigation. Cotton quality was also adversely affected by the mining reclamation treatments. Results of these controlled experiments are somewhat encouraging. However, the implementation of our protocols will be complicated in practice if tailings and slimes cannot be re-blended to generate a reasonably uniform final reclaimed surface.

Additional Key Words: Topsoiling, Compost, Tailings, Slimes.

Background and Literature Review

Mineral sand deposits were discovered along the Upper Coastal Plain of Virginia in the late 1980's (Berquist and Goodwin, 1989; Carpenter and Carpenter, 1991) and two major ore bodies were leased for mining. Much of the recoverable mineralized area occurs under prime farmlands. The Old Hickory deposit in Dinwiddie and Sussex Counties was leased by RGC Mineral Sands (USA) and overlies approximately 2000 ha of recoverable ore. A smaller ore body to the south in Greensville County was also leased by Southeast TiSands Joint Venture and subsequently acquired by RGC. This is an important peanut, soybean, tobacco, and (recently) cotton producing region. Traditionally high crop yields necessitate the development of a sound reclamation plan if this major mineral resource is to be developed.

Currently, the only active large-scale mineral sands mining operations in the USA are in central Florida at mines operated by RGC (Saunders and Clemons, 1991) and others. These lands generally support pine plantations before and after mining, but are occasionally reclaimed to grazing and forage production. Reclaimed mine soils redevelop rapidly in this region, and significant subsoil horizonation can be detected within five to ten years after mining (Daniels et al., 1992). Rooting is generally limited to 50 cm or less due to compaction of subsurface tailings and the high seasonal water table. Bulk densities as high as 1.80 g/cc are common due to wet settling and bulldozer consolidation of the tailings coupled with final reclamation grading and topsoiling activities.

[1]Paper presented at the 1999 National Meeting of the American Society for Surface Mining and Reclamation, Scottsdale, Arizona, August 13-19, 1999.

[2] W. Lee Daniels, Professor, Phil Schroeder, Nutrient Mgt. Spec., Steve Nagle, Research Specialist, Lucian Zelazny, Professor, and Mark Alley, Professor, respectively, Dept. Of Crop and Soil Environmental Sciences, Virginia Tech, Blacksburg, VA 24061-0404.

Proceedings America Society of Mining and Reclamation, 1999 pp 146-156
DOI: 10.21000/JASMR99010146

https://doi.org/10.21000/JASMR99010146

Mineral sands processing in high clay deposits such as those found in Virginia generates coarse sand tailings along with an abundance of slimes (very fine sand, silt and clay) which must be recombined for effective disposal and reclamation (Brooks, 1989). In a parallel research effort to our own in Virginia, Stolt et al. (1995) evaluated several rehabilitation alternatives at the Southeast TiSands site in Greensville County, and found that mineral sands mine tailings could be successfully rehabilitated with composted yard waste. They observed corn yields which exceeded five-year county averages on spoils amended with 4, 6, and 12% compost. Peanut yields, on spoils amended with 6% compost, greatly exceeded those of the natural soils in the study. They also observed higher cation exchange capacity, base saturation, porosity, water holding, and saturated hydraulic conductivity with compost addition. Treatment effects were observed for three full growing seasons in this study. In a precursor study to the work reported here, Daniels et al. (1991, 1996) evaluated reblended tailings:slimes mixtures in the greenhouse and found that the simulated mine soils could serve as suitable plant growth media if significant levels of P were added to offset fixation potentials along with appropriate pH adjustment via liming.

Clearly, the most challenging aspect of developing effective rehabilitation strategies for the Old Hickory deposit is the fact that much of this deposit underlies prime farmland. Prime farmland is cropland that has the most favorable combination of chemical, physical and environmental properties for the production of food, fiber, and oil crops (Grandt, 1988). While little research on the rehabilitation of mineral sands mining to prime farmland status has been conducted to date in the USA, considerable work has been reported for the return of coal mined lands to prime farmland status as required by federal regulations. In general, soil physical conditions such as compaction, water holding, and permeability are limiting to rowcrop production in restored prime farmlands in the USA. Jansen and Dancer (1981) reported that corn yields on replaced topsoil depended on the quality of the topsoil and its thickness. Compaction has been reported as the most limiting factor in many mine reclamation studies. Barnhisel and Gray (1990) observed that compaction reduced yields in nearly all crops and in mine soils, respectively. A number of prime farmland rehabilitation studies have focused on topsoil replacement alternatives and/or successful spoil and soil blending strategies. Hossner et al. (1992) concluded that mixing of subsoil and topsoil increased productivity in two clayey Texas soils. In contrast, Semalulu and Barnhisel (1992) concluded that acidic subsoils may fix phosphorous (P) in quantities large enough to cause significant yield reduction. These findings were supported by Mankolo (1994) in studies of P- uptake by corn on mineral sand mine soils at Southeast TiSands, where even with P application rates as high as 289 kg/ha P as triple-superphosphate, corn ear leaves were deficient in P.

We designed the field experiments reported in this paper to carefully evaluate rowcrop growth response to different pit closure strategies, topsoiling, and organic amendments. The results of these experiments formed the basis for the rehabilitation strategies employed at Old Hickory when mining commenced in 1997. This "first generation" field experiment was installed in 1995 and its overall design was based upon findings from our greenhouse experiments as discussed by Daniels et al. (1996), and upon our review of other studies, particularly Stolt et al. (1995). The objectives of the field experimental program were twofold: (1) To characterize and compare the physical and chemical properties of adjacent undisturbed and reclaimed mine soils; (2) To evaluate the crop productivity of reconstructed mine soils and adjacent undisturbed soils amended with organic matter (yard waste compost) or reclaimed via topsoil replacement. The results discussed here focus primarily on the second objective, the potential rowcrop productivity of these mine soils over time.

Materials and Methods

Plot Construction and Preparation

In the fall of 1994 RGC Minerals Inc. initiated excavation on the first of three test pits at the Old Hickory site in Dinwiddie County Virginia (Fig. 1). Stockpiled ore was separated in a pilot plant with a series of cyclones and spirals. The slimes were flocculated with an anionic polymer in a thickener in an attempt to improve recombination. Recombined slimes and tailings were then pumped back into the pits. Significant resegregation of the tails and slimes occurred leaving a spatially variable material at the final pit surfaces, despite company efforts to minimize segregation. Zones of nearly pure sand tailings were deposited immediately below the discharge pipe which graded into mixtures of tailings and slimes (v.f. fine sand, silts, and clays) in deeper water portions of the mining pits. In general, the pH of the materials was moderate (> 5.0), but exchangeable nutrients were very low. Detail on the physical and chemical properties of the reclaimed mine soils are provided by Daniels et al. (1991, 1996) and by Schroeder (1997).

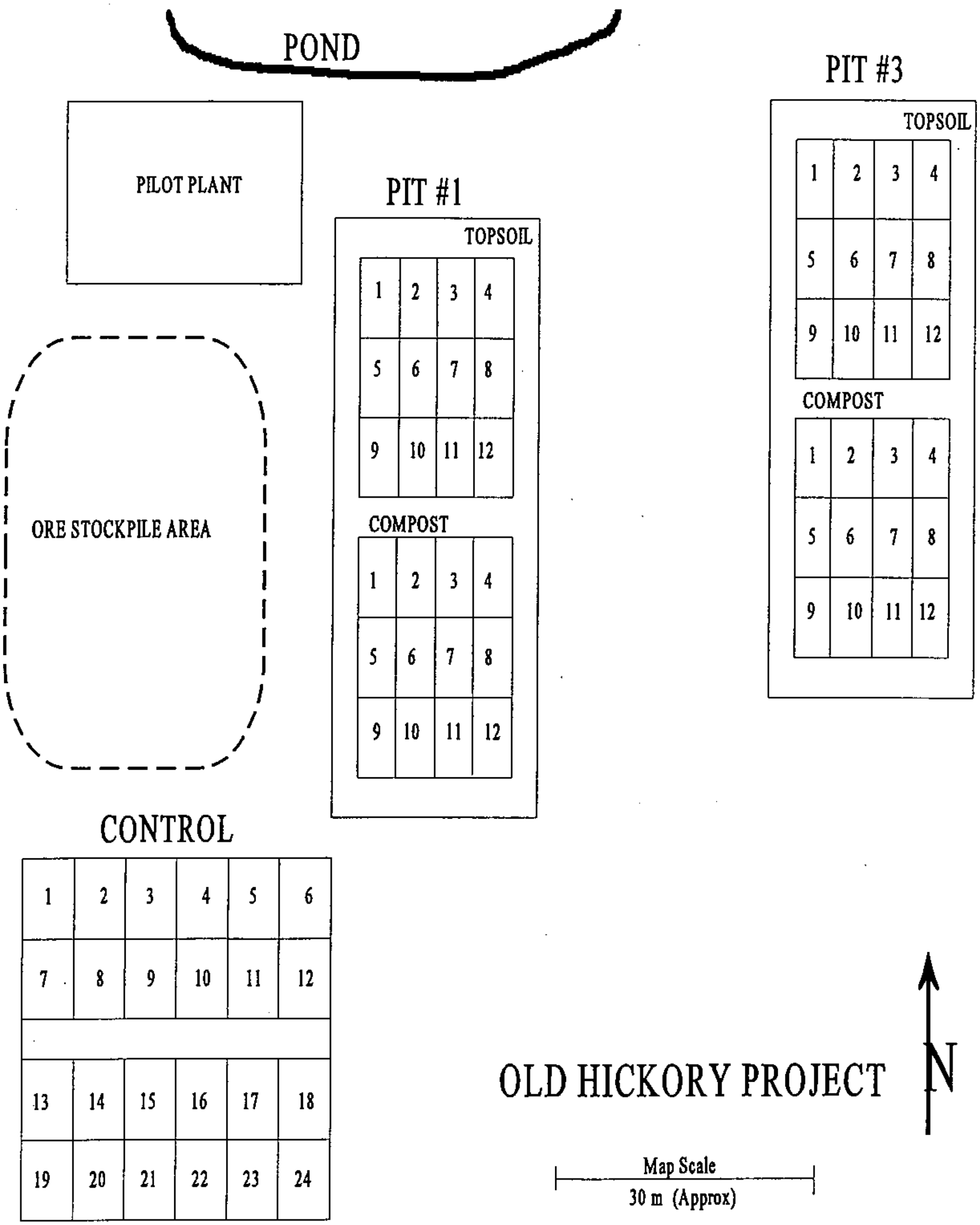

Figure 1. Diagram of field experimental area at Old Hickory. Two mining pits (#1 and #3) were backfilled with mixed tailings/slimes. Pit #1 was subsequently capped with graded subsoil while pit #3 was left as mixed tailings/slimes. One half of each pit was then topsoiled (25 cm) while the other half received yard waste compost. The two control areas are on undisturbed land with the same soil type as that removed, processed, and backfilled into the pits. Each of the six treatment areas contains 12 experimental plots.

Upon completion of mining, two pit closure scenarios were followed. Pit #1 was covered with approximately 1 m of subsoil from the dikes which had surrounded it. This scenario will be likely in areas where the enclosing dike materials are graded back over mining pits at closure. In contrast, pit #3 was brought up to original grade with recombined slimes and tails. The segregated materials were physically mixed with a track excavator prior to final grading. This closure scenario will be likely for large pits where enclosing dike materials are limited or are processed for their mineral content upon pit closure. After back-filling was completed (early April, 1995) the entire surface of Pit #3 was hydroseeded with a mixture of annual rye (*Secale cereale*) and redtop fescue (*Agrostis alba*) in an effort to speed dewatering and control erosion around the dikes. Pit # 2 was not completely filled with processed materials and is not included in this study. Subsequent to the dewatering of pits #1 and #3, all pit surfaces received 560 kg/ha P_2O_5 and 168 kg/ha K_2O to satisfy predicted P-fixation demands and supplement low native K levels. All pit surfaces and control areas then received agricultural lime at 2.2 Mg/ha. Fertilizer and lime were incorporated and surface compaction eliminated by ripping all experimental areas to a depth of 25 cm with multiple passes of a V-ripper. The V-ripping was then followed by a through discing.

Replicated treatment areas were then set up on three areas (Fig. 1). Two treatment blocks (the undisturbed control) were installed on an area of natural soil (Faceville series - clayey, kaolinitic, thermic Typic Kandiudults) immediately adjacent to the mined area. The second and third treatments were set up on pit #1 which was divided into halves, one receiving 25 cm of topsoil while the other half received composted yard waste at 112 Mg/ha which was worked directly into the tailings/slimes surface. Pit #3 was similarly split between a topsoiled treatment half vs. incorporated yardwaste compost. Chisel plowing was then performed to break up any compaction of the topsoil due to bulldozer placement. After all amendments were added, all twelve plots in each treatment block (6) received supplemental NPK fertilizer as prescribed for crop establishment. The topsoil replacement areas also received 2.2 Mg/ha agricultural lime to balance their pH against the limed tailings/slimes mixes.

Cropping System Establishment and Management

On October 27, 1995, wheat (*Triticum vulgare* var. Coker 9803) was drilled at a rate of 134 kg ha^{-1}. This was accomplished with a conventional grain drill on a 18 cm row spacing. Wheat was harvested on June 18, 1996. This was accomplished with a Hedge 140 research plot combine. The center 2 m of each plot was harvested. On June 22, 1996, soybeans (*Glycine max* var. Hutcheson) were planted with a no-till drill in 43 cm rows. The soybeans were harvested from the Topsoil treatment on Pit 3 on November 17-24, 1996. After soybean harvest, pits were dug on selected plots for soil description, sampling, and root mapping as described by Schroeder (1997). Prior to corn planting, lime was applied according to soil test recommendation from soil samples taken February 3, 1997. On March 25, 1997, pelletized dolomitic limestone was applied to all plot areas at the rate of 2.24 Mg ha^{-1}. On April 5, 1997, corn (*Zea mays* var. Pioneer 3140) was planted in 91 cm (36 in) rows. Corn was hand-harvested from two, 3.1 m row sections in each plot on September 23, 1997. On April 29, 1998, we strip-till planted of cotton (*Gossypium hirsutum* var. Roundup™ Ready Paymaster 1244). The cotton was hand-harvested on October 13 and 14, 1998, from two 2.4 m (8 foot) rows. The individual samples were ginned on November 4, 1998 at the NCSU lab in Raleigh, NC. The ginned cotton was then delivered to the USDA AMS cotton lab for lint quality determination on November 4, 1998. An overall summary of the crop rotation and planting/harvest dates in presented in Table 1.

All crops in all years were managed with best management practices as recommended by the Virginia Tech Cooperative Extension Service. This included weed and pest scouting and pesticide/herbicide applications as necessary. All management practices were applied similarly to all treatments. Irrigation was applied to the experimental area in 1997 and 1998. The 1998 drought in central Virginia was particularly severe. For a given crop yield sampling date, the experiment was analyzed with a one-way completely randomized design with six treatments and 12 replications within each treatment. Means were separated with Fisher's protected LSD when the ANOVA indicated significant treatment effects for a given cropping date.

Experimental Results

Winter Wheat and Soybean Yields in 1996

Wheat establishment, measured in Nov. 1995, was affected by treatment (Schroeder, 1997) but not to an extent where yield reductions or treatment yields would be expected to vary due to plant population effects. Strong treatment affects on total wheat yield (Table 2) were noted in June, 1996, however. Average wheat yield across all four reclamation treatments was 77% of the Control. The highest wheat yields were observed in the Control and Pit 1 Topsoil treatments; the Pit 3 Topsoil

Table 1. Summary of crops and harvest dates for Old Hickory experiment (1995-1998)

Year	Crop	Plant Date	Harvest Date
1995	Winter Wheat	10/27/95	6/18/96
1996	Soybeans (double-crop)	6/22/96	11/17-24/96
1997	Corn	4/5/97	9/23/97
1998	Cotton	4/29/98	10/13-14/98

Table 2. Double-crop wheat/soybean yield data in kg/ha for the 1995/1996 growing seasons at Old Hickory

Treatment	Wheat Yield	Soybean Yield
Control	3750 a	2449 ab
Pit #1 Topsoil	3573 a	1810 c
Pit #1 Compost	2892 b	2386 b
Pit #3 Topsoil	2756 bc	2684 a
Pit #3 Compost	2375 c	2594 ab

Mean values followed by the same letter are not different at p= 0.05.

and both Compost treatments were significantly lower. The lowest overall yield was observed on the Pit 3 Compost treatment plots. We believe that these differences in yield among the mining pit treatments were most likely due to differences in drainage and subsoil wetness and described in detail by Schroeder (1997). Wheat yield was linearly related to root length, which was presumably limited by compaction and stratification in both the Compost and Topsoil treatments. This most likely interacted with poor internal drainage and subsoil wetness, particularly in Pit 3 (downhill), to further limit rooting depth and yield potential.

Soybean establishment was significantly affected by treatment, but no consistent relationship was observed between establishment and yield data taken later in the fall. There were no differences in fall, 1996, soybean yield (Table 2) among the Control, Pit 3 Topsoil and Pit 3 Compost treatments. Overall yields were lower on the Pit 1 Compost treatment,, while the Pit 1 Topsoil treatment produced the lowest yield. However, all treatments exceeded the ten-year county average of 1716 kg ha^{-1}, and the four reclamation treatments combined produced an average yield of 97% of the Control. Schroeder (1997) also conducted exhaustive root system studies in the fall of 1996 following soybean harvest and found that rooting in all reclamation treatments was significantly reduced when compared with the Control treatment. Overall soybean yield was also linearly related to surface soil bulk density. The summer of 1996 was wet, and drought stress was not a major factor in differentiating yield response to treatments. Therefore, it appears that the combination of reclamation treatments applied in the various combinations tested did a good job of modifying soil conditions for soybean growth in the absence of drought.

Corn Response to Treatment and Drought in 1997

Corn establishment was acceptable across all treatments in the spring of 1997, with a slight reduction noted on the Pit 3 Topsoil plots. Unlike the 1996 growing season, a regional drought gripped central Virginia by early June, 1997, and we decided that it was necessary to irrigate the plots to ensure that valid treatment effects on the corn yield could be determined. We applied only enough water to simulate "normal summer rainfall conditions" of approximately 2.5 cm per week over the summer, and we withheld irrigation in those weeks where rainfall was received. The benefits of our periodic irrigation were readily observable in the planted areas around the plots which did not receive water and were withered brown by late July.

Corn yields (Table 3) on all mined treatments were significantly lower (average of 27%) than the control plots, even though all treatments received identical irrigation. The control area's yield of 137 bu A^{-1} (8553 kg ha^{-1}) is somewhat lower than what would be considered for this soil in a "good year", but is similar to average corn yields across Old Hickory as measured by our research program in 1991 and 1992. On each pit, compost amendment to the tailings surface appeared to result in a higher yield than topsoil over tailings, but the difference appears to be only marginally significant. Overall yields on Pit 3 were the lowest observed in the experiment, probably due to the sandy nature of the tailings in the subsoil and resultant lower water holding capacities compared to the clayey and loamy materials underlying the surface of Pit 1. Over the hot and dry summer of 1997, the distinct physical boundary between the base of the topsoil layer and the underlying tails (Pit 3) or graded subsoil (Pit 1) probably limited corn root penetration and associated water availability. Corn grain yield is particularly drought sensitive, especially when the drought occurs in the critical mid-summer grain-filling period. The combination of compost additions plus the finer textured surface materials on Pit 1 resulted in the best "corn response" of any of the reclamation treatments. Within-treatment variance (SD in Table 3) was very similar for the control and topsoiled plots, but the compost-treated pit halves exhibited much higher variation in yield, presumably due to high point-to-point variance in physical properties as documented by Schroeder (1997). The topsoil treatment "smoothed out" much of this variance, even though it resulted in lower overall yields.

Cotton Performance in 1998

The 1998 growing season proved to be even drier than 1997, with near record drought recorded across the region. Only 2.5 cm of rain were recorded between mid-June and early August. Fortunately, our in-row trickle irrigation system performed in outstanding fashion, evenly supplying water directly to the cotton rows. Cotton is also noted for its deep taproot and strong drought tolerance, so we are confident that the overall yields reported in Table 4 accurately reflect the potential performance of this crop in the Old Hickory area. These yields are similar to other experimental plot values recently reported by Daniel (1997) for the 1995 and 1996 seasons at nearby Blackstone.

Cotton established well across all treatment areas in 1998 with no differences attributable to treatment (Table 4). The control plot yield of 2.58 bales A^{-1} was approximately 17% higher than the highest

Table 3. Corn establishment (# per 30 ft^2) and final grain yields in 1997.

Treatment	Plant Count	SD	-------- Yield -------- kg/ha	bu/ac	SD bu/ac
Control (n=24)	22.2 bc	3.3	8553 a	136.6 a	18.2
Pit #1 Topsoil (n=12)	25.1 a	1.8	6587 b	102.4 b	16.2
Pit #1 Compost (n=12)	22.7 ac	1.8	7589 b	118.8 b	31.5
Pit #3 Topsoil (n=9)	19.9 d	4.7	4987 c	76.1 c	20.7
Pit #3 Compost (n=11)	23.6 ab	1.9	6620 b	100.9 b	25.1

Mean values followed by the same letter are not different at p= 0.05. SD= Standard Deviation.

Table 4. Average seedling establishment plant counts per 30 ft^2 and yield in kg ha^{-1} and bales A^{-1} for cotton harvested from experimental plots on October 13, 1998.

Treatment	Plant Counts	SD[a]	Yield [b]kg ha^{-1}	SD	Yield [c]bales A^{-1}	SD
Control	12.0 a[d]	2.1	1384 a	193	2.58 a	0.36
Pit 1 Topsoil	12.2 a	2.0	1194 b	177	2.22 b	0.33
Pit 1 Compost	10.8 a	2.1	1088 b	250	2.02 b	0.46
Pit 3 Topsoil	11.1 a	2.7	1004 b	233	1.87 b	0.43
Pit 3 Compost	11.2 a	2.3	1130 b	335	2.10 b	0.62

[a] SD = standard deviation.
[b] Yield kg ha^{-1} is kilogram of lint per hectare.
[c] Yield bales A^{-1} is 480 pounds of lint per bale per acre.
[d] Means followed by the same letter are not different at p=0.05.

observed reclamation treatment, Pit 1 Topsoil, and the average yield across all four reclamation treatments was 80% of the Control. No differences in overall cotton yield were observed across any of the reclamation treatments. Presumably, the deep rooting and drought tolerance of this crop were sufficient to overcome any reclamation treatment effects on overall yield. However, the higher yield on the control plots does indicate that the cotton was negatively affected by the overall condition of the reclaimed soils when compared to unmined ground. This was most likely a combination of adverse soil physical properties such as differential compaction and stratification as discussed earlier. As with the preceding corn crop, variance in yield (SD in Table 4) was much higher for the compost treated pit halves in comparison to the topsoiled pit halves. It is interesting to note, however, that the variance in the Pit 1 Topsoil treatment was actually less than that observed in the control plots.

Cotton quality (Table 5) was significantly reduced in all reclamation treatments versus the control, and in the Topsoil treatments when compared to their matching Compost treatments. Micronaire (Table 5) is an important measure of cotton fineness and maturity, which in turn affects manufacturing parameters, dyeing, etc.. Values of less than 3.5 or greater than 5.0 units result in discounted value. Thus, cotton produced on both of the topsoiled reclamation treatments would have been docked value at market, and the quality of the cotton on the Compost treatments was also reduced relative to the control plots. While average fiber length and strength were also affected by treatment (Table 5), the range of the effects was small and not of economic importance.

Analysis and Conclusions

Our earlier laboratory and greenhouse results (Daniels et al. 1991; 1996) clearly indicated that recombined tailings and slimes can serve as productive soil materials if they are limed, fertilized, and placed properly following mining. In the greenhouse, however, we uniformly reblended tailings with slimes to prescribed ratios and then wet-slurried them into pots or barrels without mechanical compaction. In actual mining practice at Old Hickory (and elsewhere in the World) it is clear that tailings and slimes will segregate upon deposition into water-filled pits and that extreme lateral variability in texture and associated soil properties will be the norm under current mining and processing practice. It is also clear that mining traffic and operations around the active pits and then over the closed pits as topsoil is returned will lead to significant soil compaction. Thus, following regular "closure practices", the post-mining soil landscape is going to be characterized by (1) lateral variability in texture in response to the deposition sequence (discharge points etc., water levels and volumes, etc., in a given pit), (2) vertical stratification due to sedimentary processes in the pits and final grading or topsoil or dikes over the pit, and (3) differential compaction. In contrast, the undisturbed pre-mining soils are much less variable laterally and vertically than are the mine soils, and are less likely to exhibit the same extent of short range differential compaction seen in the mine soils. Common sense would indicate that the most effective reclamation procedures would be those which most effectively mitigate these differences.

In this experiment we attempted to mitigate the presumed negative effects of mining and pit closure on the soil profile in several ways. First, we mechanically mixed the surface of Pit 3 with a track loader in an effort to "homogenize" some of the extreme tailings/slimes segregation observed in the surface. While this might occur operationally to some extent when bulldozers mix and grade the final surface after mining, it is unlikely that the economics of mining will allow for this to be a routine practice. Despite this effort, the short range textural variability observed in the surface of the Pit 3 Compost treatment was high, and caused the observed variance in crop yields. Secondly, we ripped and chisel-plowed the entire experimental area in an effort to offset grading effects on soil compaction. We have no doubt that this improved the overall quality of these mine soils, but our subsequent rooting investigations (Schroeder, 1997) indicate that (1) significant compacted and massive zones remain in these soils, (2) that rooting below the immediate surface in limited in the mine soil compared to the Control, and (3) that differential compaction directly limits crop yield. Finally, the Topsoil treatment represents the "best management practice" for any rowcrop reclamation strategy.

Our results indicate that topsoil return mitigates short range variability in crop yield response, but does not always improve total yield production when compared to the alternative Compost treatment. The compost material used here was a high-quality yardwaste derived product that was very stable, and we therefore expected it to create an "optimal topsoil substitute" in this design. On an operational scale, compost additions would be expensive, but probably not as costly as full topsoil salvage and return, particularly when the value of extracted mineral is factored into the equation. It is also likely that alternative organic amendments such as sewage biosolids and animal manures could be utilized as lower cost alternatives with similar long-term results. We also believe that over a period of several years, a carefully designed green manuring program could be developed to rebuild the topsoil resource. However, any decision to waste topsoil to the mining process must carefully weigh the evidence cited above with regard to the positive effect of topsoiling in mitigating short-range subsoil variability, and the large volume of literature (e.g. Dunker et al., 1992) that supports the use of topsoil in prime farmland reclamation.

Taken as a whole, these combined results clearly indicate that mining and reclamation of these prime farmlands will lead to a substantial decrease in rowcrop productivity, at least over the initial years following pit closure and reclamation. For the rotation studied, post-mining productivity was estimated by this experiment to be reduced by 23%, 3%, 27%, and 20% for each crop (wheat/soybeans/corn/cotton) in sequence. For a given crop in a given year, response to topsoiling versus compost addition to the surface varied, and neither treatment appeared superior.

These results were not unexpected, and are consistent with observed crop response following coal mined prime farmland reclamation in the midwestern USA. This reduction in mine soil productivity is almost certainly due to less desirable subsoil physical properties when compared to natural soils. In time, as the mine soil profile redevelops and as rooting and wet/dry-shrink/swell processes work to re-aggregate these subsoils, crop productivity may improve. On a positive note, we can state that we were able to produce row-crops on these reclaimed lands at reasonable levels of productivity, and that with appropriate management, post-mining productivity would be expected to increase over time.

Table 5. Average cotton quality characteristics for cotton harvested from experimental plots on October 13, 1998.

Treatment	Micronaire[a] Value	SD[d]	Length[b] g tex^{-1}	SD	Strength[c] 100th in	SD
Control	4.4 d[e]	3.9	107.6 bc	1.4	31.7 bc	0.8
Pit 1 Topsoil	5.1 a	2.3	108.9 a	1.2	32.1 ab	0.9
Pit 1 Compost	5.0 ab	2.5	108.6 ab	1.6	32.3 a	0.7
Pit 3 Topsoil	5.2 a	2.0	108.1 ac	1.9	32.4 ac	0.7
Pit 3 Compost	4.8 b	2.9	105.8 d	1.6	31.3 c	0.8

[a] Micronaire is a measure of cotton fineness and maturity, which affects processing speeds and dye absorbency. Fiber micronaire measurements of less than 3.5 or more than 5.0 are discounted in value.
[b] Length is fiber length measured in hundredths of an inch.
[c] Strength is the force in grams required to break a bundle of fibers one tex unit in size. A tex unit is equal to the weight in grams of 1,000 meters of cotton fiber. Higher cotton fiber strength has greater durability throughout the manufacturing process and results in stronger yarn. Fiber strength of 31 and above is considered very strong.
[d] SD = standard deviation.
[e] Means followed by the same letter are not different at p=0.05.

Acknowledgments

We deeply appreciate the financial, technical, and in-kind support of RGC Mineral Sands (USA) in our continuing cooperative research efforts. In particular we want to thank Denis Brooks, Russell Clark, Lamar Clemons, Elliott Mallard, Geoff Moore, and Chee Saunders for their assistance over the years. At Virginia Tech, we are indebted to Ozzie Abaye, Ron Alls, Mike Genthner, and Jim Hammons for their assistance in the field.

Literature Cited

Barnhisel, R.I., and R.B. Gray, 1990. Managing restored prime farmland for corn production. *In*: J. Skousen et al. (Eds.) Proceedings of the 1990 Mining and Reclamation Conf. and Exhibition. p.143-149. (W. Va. Univ., Morgantown).
https://doi.org/10.21000/JASMR90010143

Berquist. C.R., Jr., and B.K. Goodwin. 1989. Terrace gravel, heavy mineral deposits, and faulted basement along and near the fall zone in southeast Virginia. Guidebook No. 5, (Dept. of Geology, College of William and Mary, Williamsburg, VA).

Brooks, D.R. 1989. Reclamation in Australia's heavy mineral sands industry. In D.G. Walker et al. (eds.) Proceedings of the Conference: Reclamation, a Global perspective. p. 11-26 Rpt. RRTAC 89-2. (Alberta Land Cons. And Reclamation. Council).
https://doi.org/10.21000/jasmr89010010

Carpenter, R.H. and S.F. Carpenter. 1991. Heavy Mineral Deposits in the Upper Coastal Plain of North Carolina and Virginia. Economic Geol. 86:1657-1671.
https://doi.org/10.2113/gsecongeo.86.8.1657

Daniel, J.B. 1997. Using Winter Annual Cover Crops in a Virginia No-till Cotton Production System. M.S. Thesis, Virginia Tech, Blacksburg, 95 pp.

Daniels, W.L., L.W. Zelazny, M.M. Alley and K.C. Haering, 1991. The development of restoration strategies for prime agricultural soils following mineral sands mining in the Coastal Plain of the eastern USA. *In*: Proc., Aust. Mining Ind. Coun. Env. Workshop, p. 26-37 (AMIC, Dickson, ACT, Australia).

Daniels, W.L., M.H. Genthner, and R.L. Hodges. 1992. Soil development in sandy tailings derived from mineral sands mining in Florida. In: Proc., 1992 Annual Meeting of the Amer. Soc. Surf. Mining and Rec., Duluth, MN., p. 37-47, (IRRB, Chisolm, MN).
https://doi.org/10.21000/JASMR92010037

Daniels, W.L., M.M. Alley, L.W. Zelazny, Y.Z. Lei, V.A.L. Groover and P.D. Schroeder. 1996. Strategies for rehabilitating prime farmlands following mineral sands mining in Virginia, USA. p. 412-427 *In:* D. Brooks et al. (Eds.), Proc., (Vol 2) Third International Minerals Council of Australia Environmental Workshop, Newcastle - NSW, Oct. 14-18, Minerals Council of Australia, Dickson, ACT, Australia.

Dunker, R.E., R.I. Barnhisel and R.G. Darmody. 1992. Prime Farmland Reclamation. Proc., 1992 National Symposium on Prime Farmland Reclamation St. Louis. University of Illinois at Urbana Champaign, 284 pp.

Grandt, A.F. 1988. Productivity of reclaimed lands - cropland. *In:* L.R. Hossner (ed.) Reclamation of Surface Mined Lands. pp. 1321-135 (CRC Press, Boca Raton, FL).

Hossner L.R.,S.G. Tipton, and D.G. Purdy. 1992. Reclamation of alluvial valley soils in Texas using mixed overburden. *In:* Dunker et al., Proc. 1992 National Symposium on Prime Farmland Reclamation St. Louis. p 25-30. (University of Illinois at Urbana Champaign).

Jansen, I.J., and W.S. Dancer. 1981. Rowcrop yield response to soil horizon replacement after mining. *In:* Proceedings of the Symposium on Surface Mining Hydrology, Sedimentation and reclamation. p. 357-362. (Univ. Of Kentucky, Lexington, Ky).

Mankolo, R.N. 1994. Nutrient availability in mineral sand tailings amended with yard waste compost and wood ash. Masters Thesis, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, USA.

Saunders, C.L. and C.L. Clemons. 1991. Mineral sand extraction and land reclamation on a relict beach ridge clay county, Florida. In: Proc. The National Association of State Land Reclamationists Annual Conference. Orlando, FL. 1991.

Schroeder, P.D. 1997. Restoration of Prime Farmland Disturbed by Mineral Sand Mining in the Upper Coastal Plain of Virginia. M.S. Thesis, Virginia Tech, Blacksburg, 164 pp.

Semalulu O., and R.I. Barnhisel. 1992. Phosphorus availability as affected by topsoil and subsoil mixing. *In:* Dunker et al., Proc. 1992 National Symposium on Prime Farmland Reclamation St.Louis, p. 93-91. (University of Illinois at Urbana Champaign).

Stolt, M.H., J.C. Baker, D.C. Martens and J.R. McKenna. 1995. Reclamation of prime agricultural land after surface mining mineral sands from the Virginia Coastal Plain: Variability in physical and chemical properties of tailings. *In:* Proc., 12th Annual Meeting., Amer. Soc. Surf. Mining and Rec. p. 175-185 (ASSMR, 21 Grandview Dr., Princeton, WV).

https://doi.org/10.21000/JASMR95010175