HIGH VALUE CROP POTENTIAL OF RECLAIMED PHOSPHATIC CLAY SOIL[1]

by

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Abstract. Phosphatic clay soil is a byproduct of phosphate mining. Approximately 120,000 acres of phosphatic clay have been created in Florida. Clay is washed from phosphate ore and pumped, at about 3-5% solids, to settling areas. During reclamation, a crust is formed on the soil surface while the sub-surface remains plastic. Experience demonstrated that reclaimed clays will support conventional agricultural equipment and operations. A ten year research program, funded largely by the Florida Institute of Phosphate Research, studied production of high value agricultural crops. Phosphatic clay has many desirable characteristics including high fertility and water holding capacity. Soil pH ranges from 7.0 to 8.3 with high levels of P, Ca, Mg, and K, plus adequate levels of minor elements. After reclamation, much of the soil surface is flat and poorly drained. Low water infiltration rates indicate a need for additional surface drainage for crop production. Radium (^{226}Ra) averaged 574 Bq/kg in phosphatic clay soils vs. 30 Bq/kg on unmined sandy soil. Crops grown on phosphatic clay were generally higher in ^{226}Ra than crops grown on undisturbed mineral soils. Studies found that risk levels associated with radionuclides in foods to be insignificant. A water quality study found both sediment and total phosphorus to be of environmental concern in storm water runoff from cropped areas. Alum was found to be the most effective coagulant chemical. A wide variety of crops were successfully grown on phosphatic clay soil. Major impediments to growing high value crops was cost of building additional drainage, mitigating stormwater runoff water quality, inadequate land leases, and both a lack of markets and market capacity for agricultural products.

Additional Key Words: soil fertility, crop production, radionuclide, drainage, machine development, water quality.

Introduction

Phosphatic clay is a by-product of phosphate mining operations. Phosphate occurs in a matrix of sand, clay and phosphate ore. Clay is washed from the matrix in the beneficiation process and pumped to large settling areas at 3 to 5% solids at a rate of 20,000 to 80,000 gpm. Individual settling areas vary in size from around 300 to 800 acres. The clay, often called slimes, is allowed to settle while the water is decanted and reused. The clays consolidate to 12 to 15% solids in 3 to 30 months (Zang & Albarelli, 1995). Depth of the clay can vary from a few feet to 60 ft or more. Phosphatic clay consists mostly of clay particles less than 2 microns in size with about half, by weight, less than 0.2 microns. Phosphate minerals, mainly apatite make up the medium size fractions while clay minerals, mainly montmorillonite, make up the finer fractions. Composition of phosphatic clay includes 50 - 60% clay, 30 - 40% quartz and 2 - 5% heavy minerals and miscellaneous (Hawkins, 1973)

Until the mid 1980's it was believed that clay settling areas, once filled, would become waste lands because of the difficulty of drying the clay. It was generally believed that a clay settling area would take 20 to 30 years or more to dry naturally to the point of supporting conventional farm equipment. In the early 1980's Agrico Chemical Co. (now IMC-Agrico Co.) introduced the use of high flotation tractors with rotary ditching plows to drain the clay surface and speed reclamation. A ditch was dug around the interior rim of a settling area dike. Tractors with ditching plows were used to create lateral ditches connecting to the rim ditch. This technique allowed water to drain and a crust to form on the soil surface. Observation has shown that, once the crust becomes 10 to12 in. or more in thickness, the clay surface is able to support conventional farm equipment and operations. However, if the crust is penetrated or

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removed, the plastic subsurface is exposed and will no longer support equipment, until a new crust is formed. In addition, once a crust is formed the clay in the crust does not revert to a plastic state as a result of rain or irrigation. Agrico Chemical Co. also introduced the use of alfalfa, a deep rooted perennial legume, to further hasten the drying process. In this way, reclamation time has been reduced to as little as three to five years (Presnell, 1987). Recently, more specialized, light-weight equipment has been developed to reclaim clay settling areas but the basic technique of the rim ditch with lateral ditches has not changed.

Phosphate was first discovered in the Peace River, near Arcadia in 1881, and mining has continued since that time (Hood, 1984). Phosphate is also mined in the area of Hamilton County in north Florida. Phosphate is mined by an open pit method. Phosphate occurs as a matrix of sand, clay, and phosphate in about equal proportions. The phosphate matrix is covered with overburden, made up of sand and clay, ranging in thickness from 6 to 60 ft. Large draglines remove the overburden from the top of the phosphate matrix and deposit it in adjacent mined areas. The dragline then scoops up the matrix and deposits it in a pit, beside the mine cut, where water under high pressure is used to make a slurry of about 25 to 30% solids (Mislevy, et al., 2000). The slurry is pumped to a beneficiation plant where the clay is separated and pumped to settling areas, the sand is pumped to fill mine cuts, and the phosphate stockpiled in preparation for shipping. By the end of 1998 a total of 294,500 acres had been mined in Florida. Three land forms remain after mining: overburden, sand tailings, and clay settling areas (In addition, a relatively small area of sand/clay mix soil has been created). Clay settling areas cover about 40% of the mined area or about 120,000 acres (Roger Martin & Steve Partney, Fla. DEP, Bureau of Mine Reclamation, Tallahassee, FL, Jan 5, 2000, Personal communication).

Mined Lands Agricultural Research/Demonstration Project

The need for a research and education program dealing with the use of reclaimed phosphate land was identified in the early 1980's by Ernie Caldwell, a local County Commissioner. The Commissioner recognized that mining operations in Polk County would be winding down around the turn of the century as phosphate reserves were depleted. In the early 1980's phosphate reserve land was generating ad valorem tax revenue to the County of around $60 per acre and about 12,000 people were employed both directly and indirectly by mining. After mining, the land generated only $1 to $2 per acre in ad valorem taxes and it was anticipated that depletion of phosphate reserves would result in loss of jobs as mining moves out of the County. By the end of 1998 employment had declined to 8,000 statewide (Florida Phosphate Council, Lakeland, FL, Jan 6, 2000, personal communication). Additional layoffs were announced by the industry in 1999. The vast majority of reclaimed land, especially clay settling areas, are in low intensity uses such as pasture, forestry, or wildlife. These uses generate few jobs and little economic activity to replace jobs and economic activity being lost as mining dwindles.

The Polk County/University of Florida Cooperative Extension Service and the University of Florida, Institute of Food and Agricultural Sciences (IFAS) became involved in the issue in 1983. Discussions were held with staff of the Florida Institute of Phosphate Research, a state granting agency funded through a severance tax on phosphate ore. It was determined that clay settling areas presented the greatest challenge. A research proposal and budget were developed and submitted to the institute. The initial concept included a one year startup and ten year research program. In October, 1985 the Institute approved funding for the first year of operation. In addition, the Polk County Board of County Commissioners (BoCC) funded an office, laboratory/shop building and leased two research sites. The program continued until August 1995.

The Mined Lands Project involved the BoCC, University of Florida IFAS, Florida Institute of Phosphate Research and the Phosphate Industry. The overall objectives of the project included:

- Identify crops and/or cropping systems that can be grown on phosphatic clay soils.
- Develop drainage strategies and systems to fit clay settling areas.
- Modify tillage and planting equipment to work with phosphatic clay soils.
- Solve production and harvesting problems associated with producing crops on phosphatic clay soils.
- Determine if crops produced on phosphatic clay soils are safe for inclusion in the human food chain.
- Determine market potential and production costs for selected crops and/or cropping systems and compare with costs for crops grown on native soils.
- Encourage private enterprise to apply the

knowledge gained through research to commercial agricultural ventures on reclaimed phosphatic clay soils.

At the height of the project, a total of twenty University of Florida, IFAS research faculty from seven academic departments and two agricultural research centers were involved in the research effort. Highlights of the findings of the Mined Lands Project are described below.

Soil Characteristics

Physical. Phosphatic clay as a soil is unique in Florida where natural soils are typically sandy or organic in nature. The clay has many desirable characteristics including high water holding capacity. It was determined that phosphatic clay has the capacity to supply approximately 4.7 inches of water to a growing crop compared with a Myakka fine sand, a native flatwoods type soil, which can only hold enough water to supply 1.9 inches, and Lakeland sand, 1.2 inches. Phosphatic clay's ability to hold water will greatly reduce the need for supplemental irrigation for growing crops. One of the most important characteristics, from a soil management perspective, is the shrinking/swelling nature of the clay. This results in large clods breaking into smaller pieces through the process of wetting and drying. Referred to locally as "mellowing", the clay swells when wet and shrinks as it dries creating fracture lines on the surface of clods, aiding seedbed preparation. A major disadvantage is that the clay cannot be worked when wet. The wet sticky nature of the clay can limit field access during wet periods and limit maintenance and harvest operations during critical periods for some crops (Jerez, et al.,1996; Shibles, et al.,1994; Stricker,1991).

Fertility. Phosphatic clay is naturally fertile (Table 1) with high levels of phosphorus, calcium, magnesium and potassium. Adequate amounts of the minor elements are also present. Soil pH varies from 7.0 to 8.3 which is slightly higher than optimum for most crops. Mild manganese deficiency symptoms were observed in some legume crops, however, with the exception of legume seed production, no yield response has been documented as a result of foliar applications of manganese (Jerez, et al., 1996; Stricker, 1991; Baltensperger, 1989). The only fertilizer required for non-legume crops was nitrogen, while legume crops did not require additional fertilizer to be productive on phosphatic clay soil. In addition, soil test procedures were developed to more accurately reflect the fertility status of phosphatic clay. A stronger acid extract was used to overcome the highly buffered alkaline nature of the soil. Soil test results were then correlated with yield response of crops (Schwandes et al., 1996)

Drainage. Clay settling areas are typically built on previously mined land. Little attention is given to the bottom contour of the settling area during construction. Holes from old mine cuts and spoil piles, not needed for dike construction, are left in place (Fig. 1). Once the settling area is filled with clay and reclaimed, the clay continues to consolidate and settle. The clay consolidates in proportion to its depth, so that deeper areas of clay sink lower than shallower areas. This results in a clay surface that begins to mirror the bottom contour of the settling area.

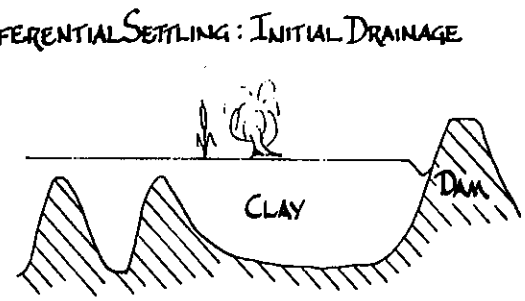

Figure 1. Cross section of clay settling area before drainage and reclamation (from Hanlon et al., 1994).

Production of high value agricultural crops, except rice, in Florida requires good soil drainage. Standing water, around the base of crop plants, should be removed within 24 hours (Stricker, 1993). In Florida's typically sandy soils, water can move rapidly through the soil profile. If a clay lens or hardpan is encountered water can move laterally to a ditch or natural drain. However, water doesn't penetrate phosphate clay soil readily (Hanlon & Ford, 1994). Laboratory tests have shown that the saturated conductivity of water through phosphatic clay is less than .06 in. per hr. By comparison, the saturated conductivity for a Myakka fine sand soil is more than 13 in. per hr. As a result, surface drainage is required if phosphatic clay is to be used for high value agricultural crops. A surface relief of 1 ft. to 2 ft. of fall per 100 ft. (1%-2% slope) is needed for good drainage (Hanlon, et al., 1994(a)). On the other hand, slopes of greater than 2% may permit erosion of bare soil. Where the slope is less than 1% a system of lateral drainage ditches will be needed. These ditches (or low flat grassed swales) should connect directly with the rim ditch built during the initial reclamation process. These lateral

Table 1. Fertility comparison between a typical Florida sand soil and phosphatic clay.

Soil	pH	Ca	Mg	K	P	Zn	Mn
	ppm						
Sand[1]	4.8	63	10	67	166	1	0.3
Phosphatic Clay[2]	7.2	5923	2569	332	586	5.6	6.3

[1] Mehlich I extractant
[2] Mehlich III extractant

ditches should be part of a land forming process, which is made up of a series of large beds (macrobeds) approximately 200 ft. wide and 1 ½ to 2 ft. high in the center (Fig. 2). In areas where old spoil piles are left beneath the surface the differential settling can create natural drainage.

Several methods of macrobed construction were evaluated including use of a small (Cat D3) bulldozer, repeated plowing with a moldboard plow, in one direction, a whirlwind terracer, and a motor grader (Hanlon et al., 1996; Hanlon et al., 1994(b)). Construction with the bulldozer was time consuming and required a drying period between passes. The terracer was not an effective soil mover so its use was discontinued. Repeated use of the moldboard plow was satisfactory but construction wasn't as fast as with the motor grader under dry soil conditions. The combination of the plow and motor grader proved to be effective under dry soil conditions. Estimated cost for building a macrobed 200 ft. wide and 2 ft. high in the center, from a flat surface, moving soil with the combination of motor grader and plow was about $440.00 per acre.

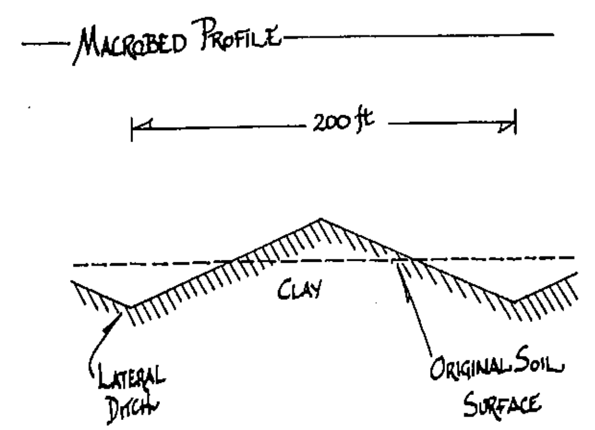

Figure 2. Example of a macrobed designed to provide positive drainage to flat areas (from Hanlon, *et al.*, 1994).

Crop Production

Vegetable Crops. A large number of vegetable crops were studied on phosphatic clay soil. Cultural practices and fertility needs for optimum production were identified. Some of the most promising vegetable crops, from a production standpoint, were cole crops such as broccoli, cabbage, and cauliflower which can be grown in the winter. Cucumbers and yellow squash were also productive and lend themselves to multiple cropping with cole crops. Sweet corn produced marketable yields in excess of state averages but problems with stand establishment and plant vigor were observed especially in the early spring. Okra was unusually productive on phosphatic clay soil as was zucchini squash and southern peas. One notable failure was sweet peppers. Numerous trials with sweet peppers resulted in low yields and poor quality of both plants and fruit. No cause or explanation has been found.

Turf and Ornamental Crops. Both ornamental trees and St. Augustinegrass sod were grown successfully on phosphatic clay soil. Once established, trees didn't require supplemental irrigation. It was determined that both irrigation and fertility needs of St. Augustinegrass grown for sod would be substantially less than growing this crop on sandy soils. Both trees and sod were successfully transplanted to typical sandy soils. No difference was observed in the rooting strength of clay-grown St. Augustinegrass vs. sand-grown. Trees grown on clay rooted as well as sand-grown trees when transplanted to a sandy soil (Gilman, 1994; Dudeck, 1990). An ornamental type of perennial peanut was also grown for sod on phosphatic clay. When dug for sod, the clay helped maintain the integrity of the sod piece making transplanting easier. When perennial peanut is grown on sand and harvested for sod, the sand falls out of the sod piece requiring additional labor to cover the sod with soil when transplanting.

Grain Crops. Rice and soybeans performed well on phosphatic clay. Experimental rice yields were equivalent to yields expected in rice growing regions of Louisiana and Arkansas. Soybean yields were as high as 30 to 40 bushels per acre but were inconsistent. Yields of field corn, grain sorghum, wheat, and triticale were marginal. Best corn yields were observed when planted in early spring. Unfortunately, early spring planting requires the grain be harvested in June or July when normally frequent rains limit field access and increase the risk of total crop loss. The same is true of soybeans and grain sorghum.

Energy and Industrial Crops. Kenaf is a tropical plant, grown for its fiber. It is well-adapted to the hot humid conditions found in central Florida. Kenaf production would fit well with central Florida's weather patterns. Planting and harvest activities take place in the normally dry winter season while few if any field activities would be needed during the wet summer months. Kenaf studies with a number of varieties, on phosphatic clay, resulted in yields averaging around 12 tons of dry matter per acre (Stricker et al., 1998). Although interest in natural fibers is increasing nationally, no market presently exists for kenaf in central Florida.

Sugarcane, energycane, and elephantgrass were planted as potential energy crops on phosphatic clay. These crops were harvested annually for four years, without replanting. Average yields were in the range of 20 to 25 tons of dry matter per acre (approximately 80 to 100 wet-tons per acre). These results indicate that production of these crops could be a major source of renewable energy (Stricker et al., 1993). A processing facility would be needed to convert these crops to energy in the form of methane, ethanol, or electricity through direct combustion. Without an appropriate facility there is no market for the crop. Tree crops including leucaena and *Eucalyptus* were also evaluated on phosphatic clay. Tree crops could be harvested and co-fired with coal in local generating plants, with minor plant modifications. Government subsidies for "closed loop" biomass could make this option economically feasible (Segrest et al., 1998).

Citrus on Phosphatic Clay. A demonstration block of citrus was planted on phosphatic clay in the spring of 1989. Navel oranges on both carrizo citrange and swingle citrumello rootstocks were planted on a two row bed. Trees were not irrigated once they were established. Tree foliage has maintained a dark green color with no visible deficiency symptoms. However, leaf tissue analysis indicated a deficiency of zinc and copper. Internal fruit quality was normal.

Legume Seed Production. Growing seed for both warm-season and cool-season legumes appears to be possible on phosphatic clay soils. Seed yield of cool-season legumes (berseem clover, crimson clover, and red clover) were increased by staging the growth of the plants and by foliar applications of manganese. Manganese levels in plants remained near critical levels for clover, even in treated plots. Seed weight was low and additional work is needed to evaluate the potential for improvement. Greater seed weight is essential because there is a direct correlation between seed weight and seedling vigor. Seed production for tropical legumes (hairy indigo, alyceclover, and desmodium) appeared to be exceptional (Baltensperber et al., 1989).

Marketing and Cost of Production. Being able to successfully grow a crop is only part of the picture. For a crop to be a commercial success, a market must exist or be developed. In addition, there must be a reasonable expectation of profit from growing and selling the crop.

Budgets of estimated production cost for squash, cabbage, and cucumbers on phosphatic clay were compared with reported production costs for squash in Dade Co., cucumbers in southwest Florida, and cabbage in the Hastings area. Conclusions were that total acreage for each crop in Florida is declining while yield per acre of all three crops is increasing, resulting in an increase in total production. This means that in order to increase production on phosphatic clay, acreage in other production areas will have to be reduced or there will be a decline in the price growers receive for the crop.

A study of the market potential for feed grains and alfalfa hay in central Florida was completed

(Rahmani and Degner, 1990). The study identified an existing market for 478,000 tons of alfalfa hay within a 100 mile radius of Polk County. Virtually all of the hay was being shipped from other states. In addition, alfalfa was bringing premium prices in Florida. Unfortunately, it has been determined that growing alfalfa on phosphatic clay is not feasible because of stand loss and difficulties of harvesting alfalfa in a timely manner during the summer months. However, the market could be supplied to some extent by perennial peanut, a tropical forage crop with characteristics similar to alfalfa. Perennial peanut may be better adapted to sandy soils than phosphatic clay. Artificially drying perennial peanut for high quality hay during summer months will enhance its quality and competitiveness with imported alfalfa (Talbot et al., 1994). Feed grain prices were marginal and, with low yields in central Florida, could not compete with traditional grain growing regions. Rice was not included in the study.

Radionuclide Issue

Plants & Soil. Phosphatic clay was found to contain elevated levels of radionuclides, when compared with native unmined soils. The elements of concern, from the uranium decay series, include ^{226}radium, ^{210}polonium, and ^{210}lead. The element of greatest concern was ^{226}Ra. Levels in phosphatic clay averaged 574 Bq kg^{-1} (dry weight basis) compared with unmined land of 30 Bq kg^{-1} (Stricker, et al., 1994). Radionuclide content of soil is important because plants are a link in the food chain. Plants can take up radionuclides through the roots or absorb deposited materials through above ground parts. Radionuclide uptake by plants is influenced by several factors including plant species; soil radionuclide content; and soil characteristics such as texture, pH, and the concentration of other stable elements. For example, legume plants that have a relationship with N-fixing bacteria appear to take up more radionuclides from the soil then other plants. Legumes in general are an order of magnitude higher in absorbing radionuclides than other species such as grasses. Higher soil radionuclide content means more radionuclides are available for plant uptake, other things being equal. Character of the soil such as soil texture influences radionuclide content as well as plant availability. Sandy soils have lower retentive capacity than clay, resulting in lower levels of radionuclides than clay, because of leaching. On the other hand, the low retentive capacity of sandy soils makes radionuclides more available to the plant. Radionuclides are also more available from acidic than alkaline soils. Chemically similar stable elements in soil compete for the same binding sites on plant roots. For example, high Ca and Mg concentrations in soils may reduce ^{226}Ra uptake.

In a study of foods (mainly fruits and vegetables) grown on reclaimed phosphate mined land Guidry et al. (1991) found that foods grown on mined land exhibited higher radionuclide concentrations than foods grown on unmined lands. The higher concentrations would result in higher radiation doses to consumers of these foods. However, the radiation doses would be very low. In general, green leafy vegetables, legumes and root crops were found to have higher concentrations of radionuclides than other crops. The study concluded that restrictions on food production on reclaimed phosphate lands don't appear warranted. There are no standards for radionuclides in foods, however, a normal dietary intake results in a radiation dose of about16 mrem per year in committed effective dose equivalent. The same diet, containing 10% of foods from reclaimed phosphate land, would add only 0.3 mrem more than the individual would receive if food came from sources other than reclaimed phosphate land. Walsh (1991) reported that cancer risks due to radionuclides in food are small and may be considered to be insignificant. The radiation dose from foods is well within normal variation due to background radiation.

Beef & Milk. Presently one of the most common uses for reclaimed phosphatic clay is for grazing beef animals. In addition, it could be feasible to grow forage crops and feed them to dairy animals in the future. To determine if the radionuclides in pasture and forage crops could accumulate in meat or milk, two studies, one with young beef steers, and the second with young dairy heifers were conducted. In the beef study, a group of 60 young beef steers (avg wt. 429 lbs.) were divided into four groups and fed corn silage or alfafa hay grown on phosphatic clay, grazed on reclaimed pasture and the fourth group, (control) or on unmined pasture (Stricker et al., 1994). After approximately 14 months (avg. wt. 820 lbs.) the animals were slaughtered and samples of muscle, kidney and bone analyzed for ^{226}Ra. Radium ^{226} levels in muscle tissues from the reclaimed pasture were significantly higher ($P<0.05$) than muscle tissue from the other three treatments (Table 2). Radium ^{226} levels in kidney tissue from both unmined and reclaimed pasture were higher ($P<0.05$) than from the alfalfa and corn silage treatments. Bone ^{226}Ra levels were higher ($P<0.05$) than both muscle and kidney tissue. Although statistical differences were found among treatments, radionuclide levels were very low and no food safety problems were indicated

In the dairy study, 45 Holstein dairy replacement heifers were divided into three groups. Each group was

Table 2. Radium[226] in tissues from beef animals grown on forages from reclaimed land, and from unmined land

	Muscle		Kidney		Bone	
Treatment	Mean[1]	SD	Mean	SD	Mean	SD
	------------------------Bq kg^{-1} DM------------------------					
Alfalfa hay	0.044[a]	0.033	0.43[a]	0.22	26.22[a]	25.63
Corn silage	0.037[a]	0.041	0.41[a]	0.22	22.53[a]	21.54
Reclaimed pasture	0.081[b]	0.048	0.62[b]	0.18	44.95[a]	32.45
Unmined pasture	0.033[a]	0.030	0.70[b]	0.11	23.41[a]	31.99[a]
Overall mean	0.049[c]		0.54[c]		29.43[d]	

[1] Means with the same letter are not different (P<0.05).
[2] Means within bottom row with the same letter are not different (P<0.05) (Duncan's multiple range test). (from Stricker et al., 1994)

fed either corn silage grown on phosphatic clay, alfalfa silage grown on phosphatic clay, or corn silage grown on native unmined soil (control) into their first lactation. All three elements, ^{226}Ra, ^{210}Po, and ^{210}Pb were examined in this study (Staples et al., 1994). Milk samples were taken on the day of calving, then 15 and 30 days later. The only significant (P<0.05) difference among treatments was with ^{226}Ra. Cows fed both corn silage and alfalfa grown on phosphatic clay produced milk with more ^{226}Ra than milk from cows fed corn silage grown on unmined land (Table 3). No differences were observed with either ^{210}Po, or ^{210}Pb among treatments.

The heifers in this study grew at an acceptable rate, conceived normally, had normal gestation periods, gave high quality colostrum at calving, and produced similar amounts of milk as control heifers. Although milk from heifers fed alfalfa and corn silage from phosphatic clay contained greater concentrations of ^{226}Ra than controls, the values were only slightly above the range reported for milk in the U.S

Another important finding from the dairy study was that forages grown on phosphatic clay appeared to have greater concentrations of molybdenum (Mo) than forages grown on unmined land. Diet concentrations of less than 6 mg kg^{-1} are recommended for cows to prevent molybdenosis. Mo concentrations averaged 6.1 mg kg^{-1} over the entire 14 month period of the study. The ratio of Mo to Copper (Cu) is also an important guideline in predicting molybdenosis or hypocuprosis. A dietary ratio of 1:2 to 1:4 has been suggested as necessary to prevent these disorders. The ratios for alfalfa grown on phosphatic clay averaged 1:1.7 (Staples et al., 1994).

Machine Development and Modification

Rotary Bedder. Building vegetable beds on phosphatic clay presented problems. A number of methods were tried including equipment designed for sand land and a disk hiller in combination with a horizontal shaft rotary tiller. Beds could be built with the various machines but only inefficiently, with numerous passes over the field. To solve this problem a prototype machine, based on machines used on heavy clay soils in Europe, was designed and built (Shaw, 1994 (a)). The machine used a rotor of stepped helicoids proceeded by a rotary tiller on each side. After a number of refinements and modifications, the machine could build a well shaped, fine textured bed in one pass.

Punch Planter. Conventional vegetable planters typically employ a runner or a double disk opener to form furrows in the soil to receive seeds. These types of openers tend to smear the soil and to clog up when used on soils with high clay content, especially when the soil is moist. To solve this problem, a revolving spade planter was designed and fabricated utilizing a vacuum seed meter (Shaw, 1994 (b)). The planter was designed with fifteen spades to space seeds 10 in. apart in the row. The seed

Table 3. Radium[226], ^{210}Pb, and ^{210}Po levels in milk from cows fed corn silage and alfalfa grown on phosphatic clay and corn silage grown on unmined land.

	$^{226}Ra^{1}$	^{210}Pb	^{210}Po
	------------Bq kg^{-1} DM------------		
Corn Silage - Phos. Clay	0.22[a]	0.30[a]	1.38[a]
Alfalfa - Phos. Clay	0.27[a]	0.58[a]	0.94[a]
Corn Silage - Unmined	0.13[b]	0.45[a]	0.92[a]

[1] Means in a column with the same letter are not different ($P<0.05$). (from Staples et al., 1994)

meter was designed for large seeds, which it planted accurately. Small seeds would have to be pelleted to work with the seed meter. The spade wheel performed well in sticky soil and a scraper effectively removed any soil sticking to the spades. No major problems were encountered with sticky soil preventing seeds from dropping.

Cable Powered Drain Plow. To speed up the consolidation and drying of phosphatic clay in the early stages of reclamation, surface drains are needed to remove water from low spots. High flotation tractors have difficulty working on soft clays in the early stages of reclamation. In order to expedite the reclamation process, a non-tractive method of pulling a ditching plow was designed and tested (Shaw, 1995). The drainage equipment consisted of two winch units and a drainage plow attached to the middle of a cable. The system was designed for one winch unit to be located on each side of a clay settling area with a cable stretched between the units. The winch units would pull the drainage plow back and forth across the settling area forming drainage channels. This system could function at any stage of reclamation and could also be used to start shaping the land for macrobeds, while the soil was still fluid. Small scale equipment used to demonstrate this concept was capable of excavating 35 ft^3 per minute over spans of 2000 ft. As a result, it was concluded that a larger system would be very effective for ditching and land forming.

Water Quality

Early in the Mined Lands Agricultural Research/Demonstration Project it was recognized that water quality and nutrient loss due to erosion were concerns as phosphatic clay soils are developed for intensive agriculture. In 1995 the Florida Institute of Phosphate Research approved a two year contract to study water quality from agricultural activities on phosphatic clay soil. Preliminary work included small plot work to calibrate the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model with respect to sediment and runoff predictions. The calibrated model was used to predict runoff and sediment from a second small plot experiment. Water quality measurements including: runoff and sediment amounts, Nitrate-N, ammonium-N, total Kjeldahl N, total P and Soluble reactive P were measured and modeled (Haman et al., 1998). The calibrated GLEAMS model successfully predicted runoff and sediment loading observed in the second small plot experiment. The model also predicted N loading in runoff and sediment, but over-predicted P. Sensitivity analysis showed that the present GLEAMS model does not have appropriate mechanisms for addressing the high mineral P concentrations of phosphatic clay soils. P was strongly correlated with sediment.

A field scale study included two three acre fields. Both fields were on macrobeds with 2% slopes. Flumes and automated water sampling equipment, supplied by IMC-Agrico Co., were installed at the discharge end of each macrobed. A weather station was used to collect rainfall amount, temperature, and wind data related to the fields. One field was planted in bermudagrass and maintained in sod. The second field was clean tilled and kept in a corn-wheat rotation. While numerous precipitation events occurred in both years of the study, most water was retained on site (no runoff). As expected, there were more runoff events from the cornfield. When a runoff event occurred, N forms were below regulatory concern. Both sediment and P from the cornfield were 2 or more than 6 times the concentration found in runoff from the bermudagrass field. When a runoff event occurred, both sediment and total phosphorus (TP) were of environmental concern. Findings related to water quality in the field trial were consistent with the findings of small plot research conducted earlier.

A stilling pond was installed downstream from the two fields. As operated in this study, the stilling pond provided little retention and did nothing for water quality. Retention time was too short to permit natural settling. The suspended clay solids in runoff waters, should they be released, would be of environmental concern. Chemical treatment would likely improve water quality for subsequent discharge. Three compounds were studied: ferric chloride, ferric sulfate, and alum. All compounds were effective in TP removal below 1 ppm using basic chemical techniques. Alum was the most effective coagulant chemical.

Conclusions

Research results show that phosphatic clay soil has potential for intensive agricultural production. However, at this time, no significant commercial agricultural production, other than cattle grazing, is happening on phosphatic clay soil. There are a number of reasons why this situation exists. Once a clay settling area is reclaimed according to the Florida DEP, Bureau of Mine Reclamation standards, it is not suitable for intensive agricultural production. Much of the land is left in a flat-poorly drained condition requiring additional investment in a drainage system. If storm water is to be released into public waters, the turbid-high phosphorus runoff must also be mitigated. Until the past two years, virtually all of the reclaimed land with agricultural potential was owned by phosphate companies. Company policy has been to maintain ownership of all land in a mine until mining is completed. Land is rented on a year to year basis, for cattle grazing, with a provision that the lease may be terminated with thirty days notice. This type of lease is not suitable for someone attempting to grow high value crops. One exception to the one year lease was a ten year closed-end lease granted to a company planning to grow grain sorghum. Unfortunately, the company could not afford to improve drainage or make other land improvements due to the closed end lease. Ten years was not enough time to recover their investment and since the land would be more valuable, they would likely have to pay more to get a new lease on the land. The company didn't make improvements and because of this and other reasons the effort failed.

Research indicated that slightly elevated levels of radionuclides in foods grown on phosphatic clay do not pose a significant health risk to people consuming these foods. However, the risk of adverse public relations for people attempting to grow food crops on this land is likely an impediment to growing food crops. This is one reason why growing biomass and industrial crops has appeal.

Although many crops grow well on phosphatic clay, markets for these crops are already saturated or don't exist at all. Competition from Mexico, because of NAFTA, has reduced the market for Florida vegetables and a number of growers have gone out of business. Markets for landscape trees and sod are also saturated resulting in low returns to those already growing these crops. If a market can be created, biomass and industrial crops could utilize a large acreage of reclaimed land. Efforts are underway with major utility companies to establish a system to co-fire woody biomass with coal and to develop a processing and manufacturing facility for kenaf. In the past two years more than 30,000 acres of mined land containing around 12,000 acres of clay settling area has been sold to private land owners. More land is expected to move to private ownership as more mines are mined out and closed.

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