CROP PRODUCTION ON CLAY TAILINGS FROM PHOSPHATE MINING[1]

by
P. Mislevy, W. G. Blue, and C. E. Roessler[2]

Abstract. Phosphate mining in Florida yields clay and quartz sand tailings as by-products. Clays contain no phytotoxic materials, are high in plant nutrients, and average about 460 g moisture kg^{-1}. Three field experiments were conducted to study forage and grain yields, forage quality, soil and plant nutrient concentrations, and ^{226}Ra contents in crops grown on clay with and without a 50-mm layer of sand tailings. Biomass crops were 5 tall-growing grasses and 2 tall-growing legumes. Grain crops were Zea mays, Sorghum bicolor, Helianthus annuus, and Glycine max in various rotations. Forage crops were 4 grasses grown with N or with 1 of 4 legumes. Dry yields of biomass averaged 140, 59, and 57 Mg ha^{-1} yr^{-1} for Erianthus, Leucaena, and Pennisetum spp., respectively. Crude protein and IVOMD were low in mature, whole-plant samples, except for protein in Leucaena (122 g kg^{-1}). Generally, whole plants contained adequate concentrations of P, 2.05; K, 11.5; Ca, 4.3; Mg, 2.77 g kg^{-1} and Cu, 4.0; Zn, 26; Fe, 68; and Mn, 35 mg kg^{-1}. Plant content of ^{226}Ra (0.23 pCi g^{-1}) was nearly 6 times that from an unmined Spodosol (0.04 pCi g^{-1}). Corn and grain sorghum produced high forage (15.7 and 13.4 Mg ha^{-1}) and grain yields (8.9 and 4.3 Mg ha^{-1}) per harvest, respectively. Concentrations of P, K, Ca, Mg, and Fe in most forages were adequate for cattle diets, while Mn, Cu, and Zn were low. Forage of all grain crops averaged 0.23 pCi g^{-1} ^{226}Ra, which was about 17 times that in the grain (0.0134 pCi g^{-1}) of the same crops. Hemarthria altissima + N, Cynodon nlemfuensis + N and C. nlemfuensis + Medicago sativa averaged 21, 18, and 18 Mg ha^{-1}, respectively. Mineral concentrations in forage ranged from 1.3 to 39 times higher than required for cattle. Forages differed in ^{226}Ra uptake with C. nlemfuensis + N (1.28 pCi g^{-1}) having the highest and Paspalum notatum + N (0.32 pCi g^{-1}) the lowest uptake. Phosphatic clays are a fertile resource that can be used for grass and legume production.

Additional Key Words: reclamation, forage, grain, biomass, radium-226.

Introduction

Phosphate mining in Florida is conducted by strip mining methods. The surface 2 to 15 m of soil, called overburden, is removed to expose the underlying matrix which is an alluvial deposit consisting of equal proportions of phosphate pebble, quartz sand, and phosphatic clay. The phosphate ore is separated from the matrix, yielding 2 by-products phosphatic clay and quartz sand tailings.

Sand tailings are returned hydraulically to mined-out or other areas for storage. Phosphatic clay (slime), consisting of montmorillonite, kaolinite, illite, and

---

[1] Paper presented at the 1991 National Meeting of the American Society of Surface Mining and Reclamation, Durango, Colorado, May 14 to 17, 1991.

[2] P. Mislevy, Professor of Agronomy, Agricultural Research and Education Center, University of Florida, Ona, FL 33865; W. G. Blue, Professor Emeritus, Soil Science Department and C. E. Roessler, Professor, Department Environmental Engineering Science, University of Florida, Gainesville, FL 32611.

Proceedings America Society of Mining and Reclamation, 1991 pp 295-310
DOI: 10.21000/JASMR91010295
https://doi.org/10.21000/JASMR91010295

attapulgite with lesser amounts of other minerals (Hood, 1984; Lamont et al., 1975) is pumped into settling ponds which make up 50% of the mined area (Hood, 1984; Zellars and Williams, 1978). Clear water is decanted with about 90% being recycled. Since mining disturbs the clays from their normal compact arrangement and they become hydrated during the beneficiation process, they require 1.4 units of storage volume for each unit volume of matrix mined (Vondrasek, 1982). Dewatering of phosphatic clay is one of the most difficult problems associated with reclamation. Normally 10 to 15 yr is required before even the surface layer reaches 50% to 60% solid content, a physical condition where man and equipment can work. In fact, after 40 years some slime ponds are no more than 35% solids (Bromwell and Carrier, 1989). Recently several companies have shortened this time, through construction of shallow ditches to expedite removal of surface water.

Mandatory reclamation has placed considerable pressure on the phosphate industry to increase the use of mined lands for agricultural purposes. Because of unique physical and chemical properties of phosphatic clays, improved agricultural crop production has been limited basically to bahiagrass (Paspalum notatum Fluegge) forage production. Recent research studies (Bromwell and Carrier, 1989) have been directed towards unconventional technologies which may lead to the production of alfalfa (Medicago sativa L.), vegetables, and grain crops.

Currently one company in the industry is successfully using alternative technology (sand-clay mix) for phosphatic clay disposal. In the sand-clay mix system, dewatered sand tailings are mixed with thickened clays (15-20% solids) before deposition into a storage area. The sand-clay mix tends to enhance clay consolidation and dewatering and also allow utilization of both droughty, low fertility sand and high moisture holding, fertile clays in an agricultural system. Presently a 2:1 sand-clay ratio mix is being successfully used.

However, there remain approximately 41,000 ha of phosphatic clays without the sand mix in Florida and about 800 to 1200 ha in North Carolina. These phosphatic clays contain no known substances in phytotoxic concentrations. They are low in organic matter (OM) (Bromwell and Carrier, 1989); high in P, K, Ca, and Mg (Zellars and Williams, 1978); and contain marginal concentrations of Mn, Cu, Zn, and Fe. This clay is an acceptable plant growth medium and is inherently more fertile than unmined mineral soils of Florida (Hood, 1984; Zellars and Williams, 1978). The high clay content makes them prone to waterlogging and difficult to cultivate during periods of wet weather (Zellars and Williams, 1978).

Phosphate ore typically contains variable amounts of uranium (U) and its decay products. The concentration of ^{226}Ra, one of the decay products of U, is an important environmental concern for health safety relative to the use of phosphate products and their waste by-products (Guidry et al., 1986; Lindeken, 1980). Radium-226 concentrations (Guidry et al., 1986) on a fresh-weight basis in leafy/cole vegetables, legume/grain crops, garden fruits, and root crops grown on phosphatic clay and other soil debris from phosphate mining were 4.1 and 10.0 pCi kg^{-1} ($P<0.05$) for the unmined and mined lands, respectively.

Phosphatic clays have unique characteristics that are associated with plastic clays. This plasticity and high internal moisture makes them difficult to manage through normal agricultural procedures. Sand tailings, which are a waste product from the phosphate industry, can easily be diverted from deposition or a storage area to the clay surface. Therefore, a reasonable assumption would be that yield and quality of crops can be enhanced and ^{226}Ra can be reduced since sand contains only about 12% to 14% of the concentration found in clay (Roessler et al., 1979). Sand can also improve the physical condition of the clay, making agricultural practices such as seeding, crop management, and harvesting easier.

The objectives of this paper are (1) to determine forage and grain yields, forage quality, plant nutrient and ^{226}Ra concentration in selected biomass, and forage and field (grain) crops and (2) to monitor changes in the levels of extractable nutrients after 4-yr of continuous cropping.

Materials and Methods

The experimental site is located at Bartow, FL (27° 50' N, 81° 55' W) on the surface of 'dry' phosphatic-clay soil (Haplaquents, clayey) (Soil Survey Staff, 1987) averaging 460 g moisture kg^{-1} over the area at a 150-mm depth. This material is approximately 7 to 10 m deep and consists primarily of montmorillonite and attapulgite clays (Hood, 1984; Lamont et al., 1975). It contains 45.4 and 108 g total P and Ca kg^{-1}, respectively, in addition to other elements (Mislevy et al., 1989).

The experimental area was leveled, and parallel ditches 1 m wide by 1 m deep on 32 m centers were constructed to remove rainwater from the surface. The excavated material from ditch construction was cast midway between the parallel ditches to form a bed. The surface was smoothed to form a crown in the middle, paralleling the two ditches, with a maximum crown elevation of about 0.3 m above the top of the ditch (Mislevy et al., 1989).

The 3 studies (biomass, forage, and field crops) were initiated in 1982 and continued over a 4-yr period. The field plot layout was a split-plot, with clay treatments as main plots and crop treatments (biomass, forage, and grain) as subplots with 4 replications. The clay treatments consisted of a phosphatic clay control (no sand layer) and a 50-mm layer of sand tailings applied on the surface of the phosphatic clay, with no mixing. Detailed information on phosphatic clay and sand tailings chemical analyses, biomass and forage crop treatments, cultural practices, harvest dates, etc. were presented in earlier papers (Mislevy et al., 1989;1990). Field crops and their rotations grown on each clay treatment are presented in Table 1. These crops were seeded in mid-March of each year and are called crop 1. Following the harvest of these crops in late June to early July, the crop residue was removed and all treatments were seeded to crop 2 of the rotation (see Table 1).

The only fertilizer applied to corn, sunflower, and grain sorghum was N as ammonium sulfate in a split application (see Table 1). Corn received 100 kg N ha^{-1} when plants were 10 to 15 cm tall and 170 kg ha^{-1} when plants were 45 to 60 cm tall. Nitrogen (N) rates for sunflower and grain sorghum were split in 2 applications of equal amounts, regardless of total N applied (see Table 1). The legume soybean did not receive any fertilizer during the experimental period.

Above ground plants were harvested (0.8 x 3.1 m) for all field crops to a 75-mm stubble to determine forage (grain + stover) dry matter (DM) yield. Forage subsamples were dried at 60°C and ground to pass a 1-mm, stainless steel screen. Samples were analyzed for total N by the procedure described (Gallaher et al., 1976) and for in vitro organic matter digestion (IVOMD) (Moore et al., 1972). Crude protein (CP) was assumed equal to total N x 6.25. Plant tissue preparation for chemical analyses was discussed (Mislevy et al., 1989).

Plants collected from all experiments for ^{226}Ra determinations were similarly dried and ground, (Mislevy et al., 1989; 1990) and above ground plant samples were analyzed for ^{226}Ra by a radon-emanation procedure (Gonzalez, 1984). Radium-226 concentrations were determined in all above ground plant tissue taken in June or July and in tissue taken again from September to November. Soil samples collected from each plot in June 1983, from the 0 to 150-mm depth were analyzed for ^{226}Ra by high-resolution gamma ray spectrometry (Bolch et al., 1977). Values for selected soil and plant samples were compared with values obtained for an unmined Spodosol located at the Agricultural Research and Education Center (AREC) near Ona, Fl.

Field sampling and laboratory procedures used to analyze soil samples for nutrient content are discussed in earlier papers (Mislevy et al., 1989; 1990).

Table 1. Field crop rotations, cultivars and other cultural practices of treatments grown on a dry phosphatic clay 1982-1985.

Field crop rotation	Crop 1[†]	Crop 2[†]	N fertilization[‡]	Plant population (final)
			kg ha^{-1}	Plants ha^{-1} x 10^{3}
Corn - Sunflower	Corn, cv. Jacques 247		280	60[¶]
		Sunflower, cv. Cargill 205	168	185
Sunflower - Grain sorghum	Sunflower		224	185
		Grain sorghum, cv. Northrup King Savanna 5	168	185
Soybean-Grain sorghum	Soybean, cv. Williams 80		[§]	510
		Grain sorghum	168	185
Grain sorghum - soybean	Grain sorghum		224	185
		Soybean, cv. Univ. of Fla V-1	[§]	150

[†] Crop 1 was seeded in Mar. and harvested in late June-July; Crop 2 was seeded in late July and harvested in Nov.

[‡] All N fertilizer was applied in a split application.

[§] No fertilizer was applied to soybeans during the experimental period.

[¶] Row spacing for all crops was 760-mm, except crop-1 soybean, which was 250 mm.

Dry matter yield, CP, and IVOMD in the forage study were complied over harvests and expressed as spring, summer, and fall results (Mislevy et al., 1990). Most other response variables for all 3 experiments, except ^{226}Ra, were pooled over years.

Results and Discussion

Plant Growth Response

Biomass Crops. Total seasonal dry biomass yields pooled over a 2- and 4-yr period were not affected by phosphatic clay treatments (sand vs. no sand). Erianthus produced the highest ($P<0.05$) dry biomass yields, averaging 120 Mg ha^{-1} yr^{-1} over the 2-yr period (1983-1984) and 139 Mg ha^{-1} yr^{-1} over the 4-yr period (1983-1986) (see Table 2). These yields were 2.8 times higher than the second best perennial entry, elephantgrass, and 3.3 times higher than the best annual, forage sorghum, when pooled over 2 yr. This yield gap continued over the 4-yr period with erianthus producing 2.5 times more than elephantgrass and 2.4 times more than the perennial legume leucaena. These 3 perennial crops have produced consistently high yields over a 4-yr period, making them more desirable as biomass entries by reducing yearly establishment costs incurred with annuals.

Table 2. Average oven-dry biomass yields pooled over 2-yr (1983-1984) and 4-yr (1983-1986) periods for 7 entries.

Biomass entry	Average oven-dry biomass 1983-1984 Harv. 1	Harv. 2	Total	1983-1986 Total
	---------------Mg ha^{-1}			----------------
Elephantgrass	43.2 b[*]	----	43.2 b[†]	56.5 b
Alemangrass	16.1 b	9.4 b	31.1 b	----
Sweet sorghum	20.4 b	8.5 b	28.9 b	----
Forage sorghum	23.3 b	13.9 a	37.2 b	----
Leucaena	22.0 b	----	22.0 b	58.5 b
Erianthus	120.1 a	----	120.1 a	139.6 a
Desmodium	30.7 b	----	30.7 b	-----

[*] Means within columns followed by the same letter are not significantly different at the 0.05 level of probability.

[†] Sum of biomass values for Harvest 1 and Harvest 2 for alemangrass, sweet sorghum, and forage sorghum may not equal value for total 1983-1984 because minor amount of biomass was recorded during the third harvest of 1 yr.

Many of the crops in Table 2 were harvested once annually, usually late November to early December. However, alemangrass, sweet sorghum, and forage sorghum were harvested twice each growing season, yielding 30%, 29%, and 37% of the total seasonal yield, respectively, in the second harvest (see Table 2).

Most of the biomass entries established relatively easily on the phosphatic clay. However, the perennial legume desmodium, and perennial grass erianthus, were difficult to establish. Only about 25% of the erianthus stem pieces developed into plants, requiring additional plant material to complete establishment.

Crude protein and digestibility content of above ground biomass material were generally independent of soil treatments during the 1983 and 1984 growing seasons. Crude protein content was highest for the perennial legume leucaena, averaging 122 g kg^{-1} (see Table 3). Desmodium was second highest, averaging 83.0 g CP kg^{-1}. All perennial grasses harvested once or twice per growing season were lower ($P<0.05$) in CP than the legumes, ranging from 26.1 g kg^{-1} for elephantgrass to 36.1 for erianthus following a single harvest. Biomass entries harvested twice per year all contained higher CP content in the second harvest, averaging 45.5 g kg^{-1} compared with 33.5 g kg^{-1} for the first harvest.

Table 3. Crude protein and digestibility of 7 biomass entries averaged over 2 soil treatments and pooled over 1983 and 1984.

Biomass entry	Crude protein Harvest 1	Crude protein Harvest 2	IVOMD Harvest 1	IVOMD Harvest 2
	--------------g kg^{-1}			-----------------
Elephantgrass	26.1 d[*]	----[†]	389.8 c	----
Alemangrass	36.1 c	46.4[‡]	573.2 a	537.4 c
Sweet sorghum	31.7 cd	44.7	565.8 a	595.1 a
Forage sorghum	32.7 d	45.4	483.3 b	553.2 b
Leucaena	122.0 a	----	361.3 d	----
Erianthus	36.1 c	----	269.1 e	----
Desmodium	83.0 b	----	339.9 d	----
Avg.	52.5	45.5	426.1	561.9

[*] Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.

[†] Plants were harvested once per growing season.

[‡] Indicates significant interaction with soil treatments.

Biomass IVOMD was highest ($P<0.05$) for alemangrass and sweet sorghum, averaging 573 and 566 g kg^{-1}, respectively, for harvest 1 (see Table 3). Entries that yielded highest biomass DM (see Table 2) were normally lowest in IVOMD. Harvest 2 values for sorghums were normally higher in IVOMD than values for harvest 1. This would be expected since dry biomass yields for harvest 2 were only half of the initial harvest.

Forage Crops. Total seasonal DM yield of forage crops pooled over 3 yr was not affected by the soil (sand vs. no sand) treatment. Floralta hemarthria + N, Florona stargrass + N, and Florona stargrass + alfalfa produced highest ($P<0.05$) DM yields, averaging 20.8, 18.1, and 17.7 Mg ha^{-1} yr^{-1} over a 3-yr period (see Table 4). The grass + N treatments produced about 28% higher total seasonal DM yield than did the grass + legume combinations. Floralta hemarthria + N and Florona stargrass + N produced nearly 37% more DM than Pensacola bahiagrass + N and Florico stargrass + N. Of all grass-legume combinations tested on the phosphatic clay, the grass-alfalfa mixture produced the highest yield, averaging about 35% higher DM than the same grass grown in association with white clover (WC). Grass-cool season legume combinations grown during the spring season produced far higher yields (+83%) than the same subtropical grasses grown with the addition of N. Total season DM yield averaged over all grass-cool season legume combinations, however, was 18% lower than for all grass + N treatments. Addition of the legumes to the grass provided a less expensive forage treatment because no fertilizer N was applied, and these grass-legume combinations provided needed forage during the drought-stress spring season (Dantzman and Hodges, 1980).

Table 4. Oven-dry forage yields averaged over 3 seasons (1983-1985) for 12 grass-N source treatments.

Grass-N source	Season			Annual total
	Spring†	Summer	Fall	
	--------------Mg ha^{-1}---------------			
Bahia + N‡	1.6 fg*	10.1 c	2.5 d	14.2 c-d
Bahia + WC	3.6 b-d	7.4 e-g	2.0 d	13.0 c-e
Florico + N	1.1 g	9.6 cd	3.4 ab	14.1 cd
Florico + WC	3.4 d	6.3 g	2.7 cd	12.4 de
Florico + Alf	4.0 bc	8.1 ef	2.5 d	14.6 cd
Florico + CD	0.2 h	6.5 g	1.3 e	8.0 e
Floralta + N	3.6 cd	13.9 a	3.4 ab	20.9 a
Floralta + WC	4.0 b	8.5 de	2.5 d	15.0 c
Florona + N	2.0 ef	12.3 b	4.0 a	18.3 b
Florona + WC	2.2 e	7.2 e-g	2.0 d	11.4 e
Florona + RC	4.7 a	7.2 e-g	1.3 e	13.2 c-e
Florona + Alf	4.7 a	9.9 c	3.1 bc	17.7 b

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.

†Spring=sum of Harvests 1 and 2, summer=sum of Harvests 3 through 6, fall=sum of Harvests 7 through 9, annual total - sum of all harvests.

‡N=nitrogen, WC=white clover, Alf=alfalfa, CD=carpon desmodium, and RC=red clover.

Crude protein and IVOMD contents of all grass-N source treatments were independent of soil treatments during the spring and fall seasons and depended on soil treatments during the summer and annual (average over the growing season) period when pooled over the 2-yr (1983-84) growing season.

The grass + legume and grass + N treatments averaged 207 and 112 g CP kg^{-1}, respectively, during the spring season (see Table 5). Crude protein increased 85% during the spring when legumes were seeded with the grass, compared with grass + N. Legumes were also responsible for increasing CP by 29% over N alone during the fall period. Florico stargrass + WC averaged highest ($P<0.05$) CP and IVOMD during the spring and was the highest or among the highest throughout the growing season (see Table 5).

Forage IVOMD during the spring and fall seasons tended to follow the trend of CP with grass + legume treatments (743 and 687 g kg^{-1}) averaging 14% and 8% higher than grass + N (651 and 637 g kg^{-1} respectively).

During the summer and annual periods, grass grown in combination with WC or red clover (RC) yielded lower ($P<0.05$) quality forage when grown on the clay + sand treatment (see Table 6). The application of 50-mm of sand was less favorable for the shallow-rooted WC and RC, resulting in a higher proportion of grass in those treatments. Since these tropical grasses are lower in CP and IVOMD than temperate legumes, forage quality in the mixture is lower, especially during hot summer conditions. Alfalfa did not appear to be affected by the sand amendment. Under deep, well drained soil conditions, alfalfa will develop a major penetrating tap root; but because of the fine texture and high moisture content of the phosphatic clay, no tap root was formed. Lateral roots growing horizontally to the soil surface became the primary root system and were sufficiently intense to supply the plant with adequate nutrients and water regardless of the soil treatment.

Table 5. Crude protein (CP) and digestibility (IVOMD) of 12 grass-N source treatments averaged over harvests by season, and over 2 phosphatic clay treatments, 1983 and 1984.

Grass-N source	Season							
	Spring†		Summer		Fall		Annual	
	CP	IVOMD	CP	IVOMD	CP	IVOMD	CP	IVOMD
	g kg^{-1}							
Bahia + N‡	121 f*	632 i	97§	562	139 de	611 h	114	589
Bahia + WC	238 bc	792 b	204	713	212 a	736 a	215	740
Florico + N	126 f	696 f	107	630	139 de	652 de	120	647
Florico + WC	265 a	829 a	229	754	212 a	739 a	233	769
Florico + Alf	169 d	714 e	148	643	173 c	686 b	159	670
Florico + CD	118 fg	641 i	152	588	143 d	638 ef	145	611
Floralta + N	94 h	663 h	92	639	130 e	663 cd	104	651
Floralta + WC	237 bc	789 b	209	740	190 b	735 a	211	751
Florona + N	108 g	614 j	104	585	145 d	620 gh	118	602
Florona + WC	155 e	682 g	146	652	168 c	665 cd	156	661
Florona + RC	243 b	740 d	146	625	135 de	627 fg	166	654
Florona + Alf	230 c	756 c	187	648	187 b	672 bc	199	683

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.

†Spring = average of harvests 1 and 2, summer = average of harvests 3 through 6, fall = average of harvests 7 through 9, annual = average of all harvests.

‡N=Nitrogen, WC=White clover, Alf=Alfalfa, CD=carpon desmodium, and RC=red clover.

§Means for the summer and annual for CP and IVOMD interacted ($P<0.05$) with phosphatic clay treatments.

Table 6. Crude protein (CP) and digestibility (IVOMD) of 12 grass-N source treatments that interacted with phosphatic clay treatments when averaged over harvests during the summer and annual periods, pooled over 2 yr (1983-1984).

Grass-N source	Sand amendments and F ratios											
	Summer‡						Annual					
	CP			IVOMD			CP			IVOMD		
	Sand	No sand	F ratio	Sand	No sand	F ratio	Sand	No sand	F ratio	Sand	No sand	F ratio
	g kg^{-1}			g kg^{-1}			g kg^{-1}			g kg^{-1}		
Bahia + N§	96 e†	98 de	NS	556 f	567 f	NS	116 e	113 fg	NS	587 h	591 f	NS
Bahia + WC	183 b	224 a	*	685 b	742 b	*	199 b	231 ab	*	719 c	760 b	*
Florico + N	106 e	109 d	NS	622 d	637 d	NS	119 e	121 f	NS	641 f	652 de	NS
Florico + WC	220 a	238 a	*	739 a	768 a	*	227 a	239 a	NS	759 a	778 a	*
Florico + Alf	147 c	148 c	NS	643 c	643 cd	NS	158 c	161 e	NS	671 de	669 cd	NS
Florico + CD	146 c	158 c	NS	594 e	583 ef	NS	142 d	148 e	NS	617 g	606 f	NS
Floralta + N	95 e	89 e	NS	642 c	636 d	NS	106 e	103 g	NS	654 f	648 e	NS
Floralta + WC	190 b	227 a	*	726 a	754 ab	*	199 b	222 b	*	740 b	763 ab	*
Florona + N	109 e	100 de	NS	582 e	589 e	NS	119 e	116 fg	NS	596 h	607 f	NS
Florona + WC	141 cd	152 c	NS	644 c	659 c	NS	151 cd	161 e	NS	657 ef	665 de	NS
Florona + RC	132 d	160 c	*	615 d	635 d	*	157 c	175 d	*	647 f	660 de	NS
Florona + Alf	184 b	190 b	NS	650 c	645 cd	NS	195 b	202 c	NS	682 d	683 c	NS

*Means in a horizontal position are different at the 0.05 level of probability. NS = non significant.

†Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.

‡Summer = average of harvests 3 through 6, Annual = average of all harvests.

§N=nitrogen, WC=white clover, Alf=alfalfa, CD=carpon desmodium, and RC=red clover.

Field Crops. Corn and grain sorghum produced highest ($P<0.05$) oven-dry forage yields, averaging 15.7 and 13.4 Mg ha^{-1}, respectively, for crop 1 over the 4-yr period (see Table 7). Average DM yield for the corn and grain sorghum was about 110% higher than the average for sunflower and soybean. Crop 2, which was planted shortly after the harvest and residue removal of crop 1, ranged from 1.1 to 10.1 Mg DM ha^{-1} for sunflower and grain sorghum, respectively. Grain sorghum was generally quite productive on the phosphatic clay, whether grown as crop 1 or crop 2 of the rotation. Dry matter forage yields for crop 2 interacted with clay treatments (data not shown). Generally, high forage yields were obtained when the grain crops were grown directly on the phosphatic clay. The addition of a 50-mm layer of sand tailings on the clay tended to have a negative effect on forage yields of these annual crops. However, the reduction was only significant for the grain sorghum that followed the sunflower.

Table 7. Average 4-yr (1982-85) oven-dry yields for crops 1 and 2 from each rotation, harvested as forage.

Field crop rotation	Crop 1	Crop 2
Crop 1/Crop 2	----------Mg ha^{-1}-------	
Corn/Sunflower	15.7 a*	1.1†
Sunflower/Grain sorghum	6.0 b	7.2
Soybean/Grain sorghum	7.8 b	10.1
Grain sorghum/Soybean	13.4 a	‡

*Means within the columns followed by the same letter are not significantly different at the 0.05 level of probability.

†Significant interational between phosphatic clay and field crop rotation treatments for crop 2 only.

‡Treatment not harvested.

Grain yields for both crops 1 and 2 of field crop rotations depended on phosphatic clay treatments. Oven-dry grain yields of corn and sorghum were not different ($P>0.05$) between the 2 soil treatments for crop 1 (see Table 8). Sunflower grain yields were reduced by 48% with the application of a 50-mm layer of sand tailings on the surface of the clay. Corn grown with or without a sand layer produced highest grain yields in crop 1, averaging 101% and 116% higher than grain sorghum, respectively. In crop 2, grain yield of sorghum following sunflower was 54% higher ($P<0.05$) from clay than from plants grown with a sand layer (see Table 8). The grain yield of sorghum following soybeans in crop 2 was not different ($P>0.05$) between the sand and no sand treatment. In some cases a sand layer was beneficial, but generally DM yield differences between clay treatments were not significant (Mislevy et al., 1989; 1990). One reason for low forage and grain yields from sunflower may have been due to the fungus Alternaria helianthia (Hansf.) Tubaki & Nishihara which damaged sunflower plants in both crops 1 and 2.

Crude protein and digestibility of corn, sunflower, soybean, and grain sorghum forage for crop 1 were independent of phosphatic clay treatments when averaged over a 3-yr period. Soybeans seeded at a dense population (520,000 plants ha^{-1}) in 250-mm rows, harvested as a forage at the green-pod stage, produced the highest CP content in crop 1, averaging 217 g kg^{-1} (see Table 9). Sunflower forage had the second highest ($P<0.05$) CP, averaging 90 g kg^{-1}, followed by grain sorghum and corn, which averaged 69 and 54 g kg^{-1}, respectively. Crude protein content of sunflower and grain sorghum for crop 2 interacted with phosphatic clay treatments. Sunflowers grown on the phosphatic clay with no sand averaged 118 g CP kg^{-1} ($P<0.05$) as compared with sunflowers grown on the sand treatment which averaged 109 g CP kg^{-1} (data not shown). There were no differences in CP contents of grain sorghum plants grown with or without a sand layer, nor by previous crop.

Digestibility of crop 1 decreased from 736 g kg^{-1} for soybean cut as forage, corn (714), grain sorghum (581), and sunflower (493 g kg^{-1}) (see Table 9). Grain sorghum forage averaged about 19% lower in digestibility than corn, with sunflower averaging about 15% lower than grain sorghum, harvested when plants were physiologically mature. Differences ($P<0.05$) were also obtained in digestibility between grain sorghum (553 g kg^{-1}) and sunflower (528 g kg^{-1}) in crop 2 (see Table 9). However, unlike crop 1, sunflower was only 5% lower in IVOMD than grain sorghum.

Plant Nutrient Concentrations

Biomass Crops

Whole plant nutrient concentrations with the exception of K (11.5 g kg^{-1}) and Mn (35 mg kg^{-1}) were generally independent of soil treatments when pooled over the 1983-84 growing seasons. Concentrations of P, Ca, Mg, Cu, Zn and Fe averaged 2.05, 4.33, 2.77 g kg^{-1} and 4.0, 25.8 and 68.2 mg kg^{-1}, respectively, across entries (see Table 10). Concentrations of major nutrients P (3.07) and K (19.2 g kg^{-1}) (Mislevy et al., 1989) and micronutrients Cu (6.7), Zn (36) and Mn (110 mg kg-1) (Mislevy et al., 1989) were highest ($P<0.05$) in alemangrass tissue when compared with all other biomass crops tested. Tissue concentrations of Ca (3.62) and Mg (3.19 g kg^{-1}), and Fe (75 mg kg^{-1}) were also among the highest for alemangrass. The perennial legumes leucaena and desmodium contained the highest concentrations of Ca (8.89 and 8.62 g kg^{-1}

Table 8. Effect of crop and phosphatic clay treatment interaction on selected grain yields for crop 1 and crop 2.

Field crop rotation	Crop 1		F ratio	Crop 2		F ratio
	Sand	No sand		Sand	No sand	
Crop 1/Crop 2	--------kg ha^{-1}--------------			--------------kg ha^{-1}---------		
Corn/Sunflower	9550	8359	NS			
Sunflower/Grain sorghum	846	1637	*	2551b‡	3933a	*
Soybean/Grain sorghum	----	----		3692a	3920a	NS
Grain sorghum/Soybean	4749	3854	NS			

*Means in a horizontal position different at the 0.05 level of probability. NS= non significant.

†Grain yields should not be compared between crop rotations.

‡Means within a column for grain sorghum crop 2 followed by the same letter are not significantly different at the 0.05 level of probability.

Table 9. Crude protein (CP) and in vitro organic matter digestion (IVOMD) of Crop 1 and Crop 2, for each field crop rotation averaged over 2 phosphatic clay treatments and 3 yr.

Field Crop rotation	Crop 1		Crop 2	
	CP	IVOMD	CP	IVOMD
Crop 1/Crop 2	--g kg^{-1}-----------------------------------			
Corn/Sunflower	54d*	714b	114†	528b
Sunflower/Grain sorghum	90b	493d	63	553a
Sunflower/Grain	217a	736a	59	553a
Grain sorghum/Soybean	69c	581c	---	---

*Means within the columns followed by the same letters are not significnatly different at the 0.05 level of probability.

†Means for CP, Crop 2 interacted with phosphatic clay treatment.

respectively). These concentrations were 3.4 times higher ($P<0.05$) than the average concentration (2.56 g kg^{-1}) in the grasses (see Table 10).
Concentrations of P, K, Ca, Mg, Cu, Zn, Fe, and Mn appear to be adequate in these biomass plants when compared with concentrations found in sorghum-sudangrass (Dotzenko et al., 1966), and other tropical grasses and legumes (Humbert, 1973; Jones, 1979).

Forage Crops

Oven-dry, whole-plant concentrations of K (16.6), Ca (9.3) and Mg (3.8 g kg^{-1}), and Fe (364 mg kg^{-1}) averaged over 9 harvests annually and 3 yr (1983 through 1985) were independent of soil treatments (see Table 11).

Phosphorus (4.0 g kg^{-1}) was the only major nutrient whose concentration depended on soil treatment. Concentrations of the micronutrients Mn (63), Cu (7.7), and Zn (34 mg kg^{-1}) (Mislevy et al., 1990) in whole forage plants was also depended on soil treatment. The application of a 50-mm sand layer decreased the P concentration in bahia + WC but generally increased (with few exceptions) the Mn, Cu, and Zn in bahia + N, and the Mn in Florico + N, and in Florona + RC. Of the 4 subtropical grasses + N tested, Pensacola bahiagrass had the lowest tissue concentration of P and K and the highest concentration of Fe. The P, K, Ca, Mg, Fe, and Mn concentrations in the forage far exceeded the requirements for growing or finishing cattle (Bos spp.). Copper and Zn concentrations in the forage were borderline (Natl. Res. Counc. Comm. on An. Nutr., 1984).

Field Crops

Oven-dry above ground plant concentrations of P (3.4), K (15.2), Ca (7.0) and Mg (4.3 g kg^{-1}), and Mn (32), Cu (6.5), Zn (32), and Fe (102 mg kg^{-1}) averaged over 4 crop rotations and 3 yr for both crop 1 and crop 2 (except K) were independent of clay treatments (see Table 12). Above ground plant K and Cu concentrations were highest in sunflower for crop 1 as were P, K, Ca, Mg, Cu, Zn, and Fe in crop 2. Corn and grain sorghum contained the lowest ($P<0.05$) concentrations of Ca, Mg, Cu, and Zn in crop 1. Plants of above ground grain sorghum also contained low concentrations of minerals in crop 2. Concentrations in grain sorghum were similar

Table 10. Effect of biomass entries on plant mineral concentrations averaged over 2 soil treatments and 1983 and 1984.

Biomass entry	Nutrients in oven-dry whole plants P	 Ca	 Mg	 Cu	 Zn	 Fe
	--------g kg^{-1}--------			--------mg kg^{-1}--------		
Elephantgrass	2.24b*	2.95bc	2.68cd	3.1cd	24cd	53a
Alemangrass	3.07a	3.62b	3.19ab	6.7a	36a	75a
Sweet sorghum	1.92c	1.83d	3.02bc	3.5c	23cd	57a
Forage sorghum	2.22b	2.25cd	3.42a	3.3cd	30b	53a
Leucaena	1.21e	8.89a	2.36de	4.9b	21de	79a
Erianthus	2.09bc	2.17cd	2.12e	2.7d	28bc	83a
Desmodium	1.59d	8.62a	2.63cd	3.8c	18e	77a
Avg.	2.05	4.33	2.77	4.0	26	68

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.

Table 11. Whole-plant mineral concentrations found in forage treatment combinations, averaged over 9 harvests, 2 soil treatments, and pooled over 3 yr (1983-1985).

Grass-N source	Nutrients in oven-dry whole plants K	 Ca	 Mg	 Fe
	----------g kg^{-1}----------			mg kg^{-1}
Bahia + N†	12.5 f*	6.0 f	3.5 e	359 bc
Bahia + WC	15.8 de	12.8 a	4.7 a	638 a
Florico + N	18.0 ab	6.4 f	3.5 e	274 c
Florico + WC	18.3 a	11.6 b	4.2 b	371 bc
Florico + Alf	17.5 a-c	11.8 b	3.5 e	328 bc
Florico + CD	15.7 e	8.2 e	3.8 c	365 bc
Floralta + N	16.6 c-e	5.1 g	3.8 c	303 bc
Floralta + WC	17.3 a-c	10.5 c	4.3 b	401 b
Florona + N	16.7 b-e	6.7 f	3.2 f	270 c
Florona + WC	17.0 b-d	9.8 d	3.7 de	408 b
Florona + RC	16.5 c-e	10.0 cd	3.8 c	328 bc
Florona + Alf	17.3 a-c	12.7 a	3.8 c	328 bc
Avg.	16.6	9.3	3.8	364
Animal req.‡	6.5	1.8-4.7	1.0	50

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.
†N=nitrogen, WC=white clover, Alf=alfalfa, CD=carpon desmodium, and RC=red clover.
‡Amount of nutrients required in diets for beef cattle.

to those in sweet and forage sorghum grown on an earlier phosphatic clay experiment (Mislevy et al., 1989). Nutrient concentrations in these field crops are adequate to meet the requirements for either growing or finishing cattle except for Mn, Cu, and Zn, which may be borderline (Natl. Res. Counc. Comm. on An. Nutr., 1984).

Soil Nutrient Analyses

Biomass, Forage and Field Crops

A pooled-year statistical analysis revealed that only pH and K from the biomass study varied ($P<0.05$) over the 4-yr period (Mislevy et al., 1989). The pH dropped from 7.6 to 7.3 and K decreased by 9 mg kg^{-1}. Soil nutrients and pH did not change ($P>0.05$) over time in the forage or field crop experiments.

Table 12. Effect of field crop averaged over soil treatments (avg. 3 yr) on above ground plant mineral concentrations.

Field crop rotation	Nutrients in oven-dry whole plants							
	P	K	Ca	Mg	Mn	Cu[†]	Zn[†]	Fe
Crop 1/Crop 2	g kg^{-1}				mg kg^{-1}			
	Crop 1							
Corn/Sunflower	2.3 c[*]	6.8 c	2.7 c	2.1 b	29 b	4.3 c	25 c	67 c
Sunflower/Grain sorghum	3.3 ab	21.6 a	12.0 b	6.2 a	22 c	8.3 a	31 a	110 b
Soybean/Grain sorghum	3.7 a	8.4 c	14.0 a	5.9 a	42 a	7.4 b	30 a	150 a
Grain sorghum/Soybean	2.8 b	13.4 b	2.6 c	2.5 b	38 a	4.4 c	28 b	89 bc
Avg.	3.0	12.6	7.8	4.2	33	6.1	29	104
	Crop 2							
Corn/Sunflower	4.7 a	26.0[‡]	13.9 a	7.3 a[†]	31 a	11.5 a	44 a	130 a
Sunflower/Grain sorghum	3.5 b	14.0	2.4 b	2.8 b	33 a	4.7 b	33 b	92 b
Soybean/Grain sorghum	3.0 c	13.0	1.9 b	2.8 b	30 a	4.5 b	29 c	77 b
Grain sorghum/Soybeans[§]	---	----	----	---	--	----	--	---
Avg.	3.7	17.7	6.1	4.3	31	6.9	35	100
Animal req.[¶]	1.8-3.7	6.5	1.8-4.7	1.0	40	8.0	30	50

---

[*] Means within the columns followed by the same letters are not significantly different at the 0.05 level of probability.

[†] Means for Cu and Zn Crop 1 and Mg Crop 2 interacted with years.

[‡] Means for K, Crop 2 interacted with phosphatic clay treatment.

[§] Crop 2 soybeans were generally a failure.

[¶] Concentrations of nutrients required in diet for beef cattle.

Most soil nutrients were affected by the use of the sand amendment. When averaged over 4 yr, soil K (except forage study) and Mg (for all 3 experiments) were higher ($P<0.05$) on those treatments that did not receive the 5-cm sand layer (see Table 13). Chemical analyses of phosphatic clay and the sand (Mislevy et al., 1989) revealed that both K and Mg were high in the clay. Since the sand contained low amounts of both elements, a surface application of sand tended to dilute analyses of clay and sand. This was especially apparent when a 15-cm soil core contained about 5 cm of sand. The remaining elements (P, Ca, Mn, Cu, Zn, and Fe) for biomass, forage, and field crop experiments were all higher ($P<0.05$) on the sand-amended treatment (see Table 13). The P, Ca, and Mg concentrations in the soil were massive; however, Mn, Cu, and Zn may have been marginal to deficient (Kidder and Rhue, 1983).

Biomass entries significantly affected pH and Mehlich I-extractable soil nutrients for P, K, Ca, Mg, Mn, and Zn. However, no consistent pattern was evident between biomass crops and their yields and changes in soil nutrients (see Table 14).

Grass-N source treatments had little effect ($P>0.05$) on Mehlich I-extractable soil P, K, Cu, Zn, and Fe, which averaged 1650, 78, 0.2, 0.9, and 5.2 mg kg^{-1}, respectively. The grass-N source treatment combinations, however, had an effect ($P<0.05$) on Mg, ranging from a high of 1190 mg kg^{-1} in the soil that grew Floralta hemarthria + WC to a low of 1010 mg kg^{-1} in the soil where Floralta hemarthria + N had been grown. A similar pattern developed for bahiagrass. The bahiagrass + N tended to lower the Mg content of the soil more than the bahiagrass + WC (Mislevy et al., 1990).

Grass-N source combinations interacted ($P<0.05$) with soil treatments for both Mehlich I-extractable soil Ca and Mn. The application of sand in almost all cases resulted in higher ($P<0.05$) Ca and Mn values regardless of grass-N source treatments imposed (Mislevy et al., 1990).

Field crop rotation did not affect Mehlich I-extractable soil nutrients which averaged 1601, 86, 4696, 1173, 5.7, 0.22, 0.75, and 5.5 mg kg^{-1} for P, K, Ca, Mg, Mn, Cu, Zn, and Fe, respectively, when pooled over 4 yr.

Radium-226

Biomass Crops

Concentrations of ^{226}Ra found in the top 15 cm of mined phosphatic clay treated with and without a 5-cm sand layer averaged 19.8 and 24.3 pCi g^{-1}, respectively (see Table 15). Analyses of an unmined Spodosol from biomass plots at the Ona AREC averaged 0.24 pCi g^{-1}.

Table 13. Effect of phosphatic clay treatments on Mehlich I-extractable soil nutrients and pH averaged over biomass entries (4 yr), grass-N sources (3 yr) and field crop rotations (4 yr).

Soil treatment	pH (H_2O)	P	K	Ca	Mg	Mn	Cu	Zn	Fe
		mg kg^{-1}							
				Biomass					
Sand	7.4a*	2022a	71b	4708a	906b	7.2a	0.24a	0.97a	9.2a
No sand	7.4a	1074b	94a	4197b	1427a	4.8b	0.18b	0.49b	1.9b
				Grass-N					
Sand	7.3a	2080a	72a	4810a	890b	7.3a	0.21a	1.19a	8.4a
No sand	7.5a	1220b	84a	4370b	1370a	5.3b	0.17b	0.59b	2.0b
				Grain crops					
Sand	7.2a	2100a	74b	4930a	908b	6.8a	0.24a	0.96a	8.9a
No sand	7.2a	1100b	97a	4460b	1435a	4.5b	0.19b	0.53b	2.1b

*Means within columns for each crop followed by the same letter are not significantly different at the 0.05 level of probability.

Table 14. Effect of biomass entries on Mehlich-I-extractable soil nutrients and pH averaged over 2 soil treatments and 4 yr.

Biomass entry	pH(H_2O)	P	Mehlich-I-extractable soil nutrients K	Ca	Mg	Mn	Cu	Zn	Fe
		mg kg^{-1}							
Elephantgrass	7.5b*	1538abc	92a	4532ab	1164abc	6.0b	0.21a	0.76†	6.2a
Alemangrass	7.4b	1524abc	78bcd	4412bc	1171abc	6.3ab	0.21a	0.70	4.9a
Sweet sorghum	7.2c	1704a	73d	4571ab	1072c	6.4a	0.21a	0.76	7.2a
Forage sorghum	7.1c	1650ab	76cd	4642a	1115bc	6.4a	0.21a	0.75	6.2a
Leucaena	7.7a	1458bc	85ab	4385bc	1217ab	5.7c	0.20a	0.69	5.1a
Erianthus	7.5b	1564abc	83abc	4303c	1162abc	5.6c	0.22a	0.73	5.8a
Desmodium	7.6a	1397c	91a	4325c	1263a	5.7c	0.20a	0.70	3.5a
Avg.	7.4	1548	83	4452	1166	6.0	0.21	0.73	5.6

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.
†Indicates significant interaction with soil treatment.

Table 15. Concentrations of ^{226}Ra found in the top 15 cm of soil and in above ground whole biomass plants grown on mined (phosphatic clay) and unmined (spodosol) land, 1983.

Biomass entry	Soil			Plant	
	Mined		Unmined	Mined	Unmined
	No sand	Sand			
	pCi g^{-1}				
Elephantgrass	25.2	20.3	0.21	0.09c*	0.03
Alemangrass	24.5	19.7	----	0.27ab	----
Sweet sorghum	19.7	18.2	0.23	0.25a-c	0.03
Forage sorghum	24.8	22.2	0.30	0.23a-c	0.06
Leucaena	25.1	18.6	----	0.13bc	----
Erianthus	25.3	19.8	0.23	0.24a-c	0.02
Desmodium	25.3	20.0	----	0.37a	----
Avg.	24.3	19.8	0.24	0.23	0.04

*Means within the column followed by the same letters are not significantly different at the 0.028 level of probability.
†Unmined land is located at the Agricultural Research and Education Center, Ona, FL, 80 km southwest of the mined area.

Analyses of plant tissue revealed that the sand layer had no effect on ^{226}Ra, which averaged 0.21 pCi g^{-1} with sand and 0.24 pCi g^{-1} without a 5-cm sand layer. However, differences ($P<0.05$) in concentrations occurred among biomass plants (see Table 15). Elephantgrass and leucaena contained lowest concentrations, averaging 0.09 and 0.13 pCi g^{-1}. On the average, tissue of plants growing on phosphatic clay contained nearly 6 times more ^{226}Ra than plants growing on unmined Spodosols at the AREC, Ona, FL. However, it should be recognized that phosphatic clay soils contain about 100 times (24.3 pCi g^{-1}) more ^{226}Ra than unmined soils (0.24 pCi g^{-1}) (see Table 15). Therefore the plant-soil concentration ratio is smaller (0.010) for the clay than for the unminded soil (0.134).

Forage Crops

Radium-226 in the phosphatic clay averaged 22 pCi g^{-1}. This value is about 80 times higher than the values of 0.27 pCi g^{-1} found in an unmined Spodosol.

Analyses for ^{226}Ra in above ground plant tissue for grass-N source combinations varied significantly ($P<0.05$) between plant treatments for forage harvested in June and September. Averages across grass-N source treatments were 0.70 and 0.73 pCi g^{-1} for mined land in June and September, respectively (see Table 16). Analyses of selected forage plants growing on an unmined Spodosol averaged 0.14 pCi g^{-1} ^{226}Ra. These values are about 1/5 the ^{226}Ra concentration found in the same plant species when grown on the phosphatic clay with or without a sand layer.

These data indicate a differential uptake of ^{226}Ra between forage plants (see Table 16). Bahiagrass + N had the lowest concentration, averaging 0.32 and 0.24 pCi g^{-1} for forage harvested in June and September, respectively. Florona stargrass + N and Florico stargrass + N contained the highest concentrations of ^{226}Ra, averaging 1.28 and 1.00 pCi g^{-1}, respectively, for forage harvested in June. These values were about 4 and 3.1 times higher than those for Pensacola bahiagrass.

These forages contain about 5 times more ^{226}Ra than found in forage grown on an unmined Spodosol. However, the increment of radiaton dose to humans consuming beef and milk from animals fed these forages would be less than 1.0 mrem yr^{-1} (Roessler and Wood, 1987). The National Council on Radiation Protection and Measurements has adopted 1 mrem yr^{-1} as the annual effective dose equivalent corresponding to the Negligible Individual. Risk Level [i.e., the level of excess risk from any individual source or practice below which further effort to reduce radiation exposure to the individual is unwarranted (Natl. Counc. Rad. Prot. and Measur., 1987a)]. The human dose increment attributable to these forages is a small fraction of the average annual effective dose equivalents to the U.S. population of approximately 100 mrem yr^{-1} from natural radiation sources exclusive of radon daughters in the lung and 300 mrem yr^{-1} including the lung dose from radon daughters (Natl. Counc. Rad. Prot. and Measur., 1987b).

Field Crops

Concentrations of ^{226}Ra in forage (except crop 2), soil, and forage-soil and grain-soil ratios were independent of soil treatments. Corn harvested for forage from crop 1 contained 19% and 13% lower ($P<0.05$) concentrations of ^{226}Ra than sunflower and grain sorghum forage respectively (see Table 17). Radium-226 concentration in grain sorghum forage

Table 16. Radium-226 concentration in the soil and in whole forage crop plants grown on mined (phosphatic clay) and unmined (spodosol) land in June and September, 1983.

Grass-N source	Soil		Plant		
	Mined	Unmined†	Mined		Unmined
			June	Sept	June
	pCi g^{-1}				
Bahia + N‡	22a*	0.23	0.32d	0.24f	0.03
Bahia + WC	22a	----	0.57c	0.51de	----
Florico + N	22a	0.28	1.00b	0.73cd	0.16
Florico + WC	23a	----	0.43cd	0.54de	----
Florico + Alf	20a	----	0.80b	1.15b	----
Florico + CD	24a	----	0.93b	0.91bc	----
Floralta + N	21a	0.35	0.56c	0.53de	0.045
Floralta + WC	22a	----	0.54cd	0.38de	----
Florona + N	21a	0.21	1.28a	0.51de	0.33
Florona + WC	22a	----	0.99b	1.46a	----
Florona + RC	20a	----	0.44cd	0.91bc	----
Florona + Alf	24a	----	0.48cd	0.93bc	----
Avg.	22	0.27	0.70	0.73	0.14

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.
†Unmined land is located at the Agricultural Research and Education Center, Ona, FL, 80 km southwest of the mined area.
‡N=nitrogen, WC=white clover, Alf=alfalfa, CD=carpon desmodium, and RC=red clover.

Table 17. Radium-226 concentrations in forage, grain, soil, and ratios between concentrations in plants and soils, averaged over 2 phosphatic clay treatments, 1983.

Field crop rotation	Soil	Plant	Plant/ soil ratio	Grain	Grain/ soil ratio
	pCi g^{-1}			pCi g^{-1}	
Crop 1					
Corn	18.4a*	0.051b	0.003b	0.0104a	0.0006a
Sunflower	19.9a	0.266a	0.014a	0.0464a	0.0023a
Soybean	19.2a	-----	-----	------	------
Grain sorghum	21.5a	0.379a	0.018a	0.0076a	0.0004a
Avg.	19.8	0.232	0.012	0.0214	0.0011
Crop 2					
Sunflower	20.7a	0.353a	0.017a	------	------
Grain sorghum	20.5a	0.205b	0.010a	0.010†	0.0005b
Grain sorghum	22.5a	0.220b	0.010a	0.017	0.0008a
Soybean	21.3a	0.155b	0.007a		
Avg.	21.3	0.233	0.011	0.014	0.00065

*Means within columns followed by the same letters are not significantly different at the 0.05 level of probability.
†Indicates significant interaction with phosphatic clay treatments.

averaged over crop 1 and crop 2 was 0.27 pCi g^{-1}, which was similar to the concentration in forage sorghum and sweet sorghum biomass grown on a phosphatic clay (see Table 15) (Mislevy et al., 1989). The ^{226}Ra concentration in the soil ranged from 18.4 to 21.5 pCi g^{-1}, resulting in a forage-soil ratio of 0.003 to 0.018 pCi g^{-1} for corn and grain sorghum, respectively, harvested in July for crop 1 of the rotation (see Table 17). There was no difference (P>0.05) in concentrations of ^{226}Ra in the grain of corn, sunflower, and grain sorghum, which averaged 20%, 17%, and 2% of the concentrationsfound in their respective forage for crop 1. The ^{226}Ra concentrations in forage, grain, and soil in crop 2 were similar to concentrations following the harvest of crop 1 (see Table 17). There was an interaction for ^{226}Ra concentration in grain from grain sorghum of crop 2. Grain sorghum grown after sunflower averaged 0.009 and 0.0105 pCi g^{-1} for the sand and no-sand soil treatments, respectively. However, concentration of ^{226}Ra in grain from grain sorghum grown after soybeans was higher ($P<0.05$) (0.023 pCi g^{-1}) when grown on the no-sand treatment compared with the sand treatment (0.0115 pCi g^{-1}).

`Any paper below with links are on the bottom page.`

Literature Cited

Bolch, W. E., E. D. Whitney, R. M. Chhatre, and C. E. Roessler. 1977. Uranium and radium concentrations in Florida phosphate fractions by GeLi spectrometry. p. 400-414. In: Proc. Health Physics Soc. 10th Mid-year Topical Symp., Natural Radioactivity in Man's Environment, Saratoga Springs, NY. Oct. 1976. Rensselaer Polytechnic Inst., Troy, New York.

Bromwell and Carrier, Inc. 1989. Production of high-value cash crops on mixtures of sand tailing and waste phosphatic clays. Florida Institute of Phosphate Research, Bartow, FL. Publication No. 03-075-080.

Dantzman, C. L., and E. M. Hodges. 1980. Weather at Ona, Florida for the 36-year period 1942-1978. Florida Agric. Exp. Stn. Circ. S-270.

Dotzenko, A. D., N. E. Humburg, G. O. Hinze, and W. H. Leonard. 1966. Effects of stage of maturity on the compositions of various sorghum silages. Colorado Agric. Exp. Stn. Tech. Bull. 87.

Gallaher, R. N., C. O. Weldon, and F. C. Boswell. 1976. Semiautomated procedure for total nitrogen in plant and soil samples. Soil Sci. Soc. Am. J. 40:887-889.

Gonzalez, D. A. 1984. Radium-226 by radon emanation at the University of Florida. M.S. thesis. Univ. of Florida, Gainesville, FL.

Guidry, J. J., W. E. Bolch, C. E. Roessler, J. T. McClave, and J. R. Moon. 1986. Radioactivity in foods grown on Florida phosphate lands. Publ. 05-015-038. Florida Inst. of Phosphate Res., Bartow, FL.

Hood, H. 1984. Phosphate mining in Florida, a source book. Florida Defenders of the Environ. and Environ. Serv. Ctr. Florida Def. of the Environ., Gainesville, FL.

Humbert, R. P. 1973. Plant analysis as an aid in fertilizing sugar crops: Part II. Sugarcane. p. 289-298. In L.M. Walsh and J. D. Beaton (ed.) Soil testing and plant analysis. SSSA, Madison, WI.

Jones, R. J. 1979. The value of Leucaena leucocephala as a feed for ruminants in the tropics. World Anim. Rev. 31:13-23.

Kidder, G., and R. D. Rhue. 1983. Interpretation of soil tests. Notes in Soil science. Florida Coop. Ext. Serv., Univ. of Florida, Gainesville.

Lamont, W. E., J. T. McLendon, L. W. Clements, Jr., and I. L. Feld. 1975. Characterization studies of Florida phosphate slimes. U.S. Bureau of Mines RI 8089. U.S. Dep. of Interior, Washington, DC.

Lindeken, C. L. 1980. Radiological considerations of phosphogypsum utilization in agriculture. p. 459-480. In D. P. Borris and P. W. Boody (ed.) Phosphogypsum: Proceedings of the International Symposium on Phosphogypsum. Vol. II. Florida Institute of Phosphate Research. Bartow, FL.

Mislevy, P., W. G. Blue, and C. E. Roessler. 1989. Productivity of clay tailings from phosphate mining: I. Biomass Crops. J. Environ. Qual. 18:95-100.

Mislevy, P., W. G. Blue, and C. E. Roessler. 1990. Productivity of clay tailings from phosphate mining: II. Forage crops. J. Environ. Qual. 19:694-700.

Moore, J. E., G. O. Mott, D. G. Dunham, and R. W. Omer. 1972. Large capacity in vitro OM digestion procedure. J. Anim. Sci. 35(1):232 (abstract).

National Council on Radiation Protection and Measurements. 1987a. Recommendations on limits for exposure to ionizing radiation. Rep. 91. NCRP, Bethesda, MD.

National Council on Radiation Protection and Measurements. 1987b. Ionizing radiation exposure of the population of the United States. Rep. 93. NCRP, Bethesda, MD.

National Research Council, Committee on Animal Nutrition. 1984. Nutrient requirements for beef cattle. 6th ed. Natl. Acad. of Sciences, Washington, D.C.

Roessler, C. E., F. A. Smith, W. E. Bolch, and R. J. Prince. 1979. Uranium and Radium 226 in Florida phosphate materials. Health Phys., 37:269-277.

Roessler, C. E., and J. G. Wood, Jr. 1987. Radionuclide uptake by forages, phase II - assessment of radium-226 transfer to animal products and radiation dose to humans. Final Rep. Int. Mineral and Chemcial Corp., Bartow, FL.

Soil Survey Staff. 1987. Classification and correlation of soils of Polk County, Florida. USDA-SCS, South Natl. Tech. Center, Fort Worth, TX.

Vondrasek, A. F. 1982. Traditional land reclamation and waste clay storage methods. p. 43-54. In S. W. Clark (ed.) Phosphatic Clay Workshop. Florida Institute of Phosphate Research Publ. No. 02-020-012. Bartow, FL.

Zellars, M. E., and J. M. Williams. 1978. Evaluation of the phosphate deposits of Florida using the mineral availability system. Final Rep. Contract No. JO 377000. U.S. Dep. of Interior, Bureau of Mines, Pittsburgh, PA.

Gallaher, R. N., C. 0. Weldon, and F. C. Boswell. 1976. Semiautomated procedure for total nitrogen in plant and soil samples. Soil Sci. Soc. Am. J. 40:887 -889
http://dx.doi.org/10.2136/sssaj1976.03615995004000060026x

Jones, R. J. 1979. The value of Leucaena leucocephala as a feed for ruminants in the tropics. World Anim. Rev. 31:13-23.

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

Mislevy, P., W. G. Blue, and C. E. Roessler. 1990. Productivity of clay tailings from phosphate mining: II. Forage crops. J. Environ. Qua!. 19:694-700.
http://dx.doi.org/10.2134/jeq1990.00472425001900040011x

Roessler, C. E., F. A Smith, W. E. Bolch, and R. J. Prince. 1979. Uranium and Radium 226 in Florida phosphate materials. Health Phys., 37:269-277.
http://dx.doi.org/10.1097/00004032-197909000-00001