Forage Production and Quality as Influenced by Amended Quartz Sand-Tailings following Phosphate Mining[1/]

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ABSTRACT

Quartz-sand tailings is a waste product from the Florida phosphate mining industry. Individual tailings disposal areas may occupy 20 to 60 ha and support no vegetation. A split plot field experiment was conducted on a sand tailings deposit to study the effect of various amendments on yield, quality, and mineral concentrations of 'Callie' bermudagrass (*Cynodon dactylon* var. *aridus* Harlan et de Wet) and 'Siratro' [*Macroptilium atropurpureum* (DC) Urb]. The two species were established on nine treatments: one sand-tailings control (SC); three with air-dried phosphatic clay (PC) at 110, 225, and 340 Mg ha^{-1}; and three with overburden (OB) at 448, 1,120, and 1,800 Mg ha^{-1}. All PC and OB treatment rates contained air-dried sewage sludge (SS) at 45 Mg ha^{-1} and were all roto-tilled to a 20 to 25 cm depth. There were two additional treatments of OB at 1800 Mg ha^{-1} without SS, with and without roto-tilling into sand tailings. Callie established slower ($P<0.05$) on SC and OB, than on treatments containing SS and/or PC. However, after the root system developed, yields were similar on all sand-tailings treatments. Crude protein and *in vitro* organic matter digestion for Callie and Siratro did not differ between soil treatments, but Siratro was generally superior to Callie in forage quality. Forage concentrations of P, K, Ca, Mg, Mn, and Zn were adequate in both species for good cattle growth on all treatments. However, Cu tended to be low in Siratro for plant and cattle growth. Once root systems were well established, good yields of quality forage with suitable mineral concentrations were produced on regularly fertilized, quartz-sand tailings.

Additional Index Words: Siratro, *Macroptilium atropurpureum*, Callie bermudagrass, *Cynodon dactylon* var. *aridus*, Reclamation.

Forage Production and Quality as Influenced by Amended

Quartz Sand-Tailings following Phosphate Mining

P. Mislevy and W. G. Blue

Phosphate mining in Florida produces phosphatic clays (PC) and quartz-sand tailings as waste products of the industry. Both waste products are moved hydraulically from the beneficiation plant (where phosphate particles are separated by a series of washing, screening and flotation processes) to mined out or storage areas. The sand tailings amount to about 90 million Mg ha^{-1} annually and contain no phytotoxic substances (1), but are low in several nutrients, organic matter, and water retention capacity, making revegetation a problem (1,2). Hortenstine and Rothwell (3) reported that the addition of municipal compost and N, P, and K, respectively, increased yields ($P<0.05$) of sorghum [Sorghum bicolor (L.) Moench] and oats (Avena sativa L.), but highest yields were low when compared with well-fertilized Florida soils.

Studies conducted by Mislevy and Blue (4,5) indicated 'Siratro' [Macroptilium atropurpureum (DC) Urb] and 'Callie' bermudagrass (Cynodon dactylon var. aridus Harlan et de Wet) produced high yields of good quality forage when high amendment rates [PC, sewage sludge (SS) and top soil] were applied to the sand. However, information is lacking regarding plant growth when amendment rates were reduced and/or replaced with overburden (OB) (sand, silt and clay mixture found above the phosphorite ore zone).

The purpose of this research was to study the effects of low rates of PC, OB with SS and OB without additional clay or organic matter, on growth, quality and mineral concentrations of forage plants.

MATERIALS AND METHODS

The investigation was conducted during the growing seasons of 1978 through 1980 on sand tailings located about 10 m above the natural soil surface. Characteristics of quartz-sand tailings, OB and SS are presented in Table 1 (6). Quartz-sand tailings contained about 4.2 dag kg^{-1} total P along with other elements. The field plot layout was a split-plot with amended sand-tailings (Table 2) as main plots (2.5 by 6.2 m) and plant species (Callie bermudagrass and Siratro) as subplots (1.2 by 6.2 m).

Prior to the establishment of those sand-tailings treatments which received overburden (5 through 9), a 5-, 10-, or 15-cm depth of sand tailings was removed to accommodate the amendments, so all treatments were at the same elevation. Dolomitic limestone was applied on all treatments at 2.24 Mg ha^{-1}. All amendments were mixed into the sand tailings to a depth of 20 to 25 cm, except treatment 9 which was non-rototilled.

Both Callie bermudagrass and Siratro were planted on separate plots on each amended sand-tailings treatment. The bermudagrass was vegetatively planted from rooted crowns and Siratro from seed at 5.6 kg ha^{-1} in May 1977. Both grass and legume was planted on 0.6 m centers. Fertilizers were applied at a rate of 25 kg P ha^{-1}; 95 kg K ha^{-1}; and a fritted micronutrient mix F 503$^{(R)}$ at the following elemental rate: Fe, 8; Zn, 3.1; Mn, 3.4; Cu, 1.3; B, 1.3; and Mo, 0.1 kg ha^{-1} on both species 15 days after planting to encourage establishment. In addition, Callie bermudagrass received 112 kg N ha^{-1} in two applications. Maintenance fertilizer during 1978 to 1980 was 20 kg P ha^{-1} and 75 kg K ha^{-1} in March; and 15 kg P ha^{-1} and 55 kg K ha^{-1} in June and September. In addition, nitrogen as urea was applied at 56 kg ha^{-1} after each harvest throughout the experimental period on Callie only. Beginning in early May, Callie bermudagrass was harvested every 30 days to a 7.5-cm stubble height.

There were six harvests in 1978, and seven harvests in 1979 and five harvests in 1980. Siratro was harvested on a 60-day schedule to a 10-cm stubble, starting in June totaling three harvests per year. Irrigation was applied only in 1977 to encourage establishment.

Harvested forage was dried at 60 C for dry matter (DM) calculations and ground to pass a 1-mm stainless steel screen. Samples were analyzed for *in vitro* organic matter digestion (IVOMD) (7) and total N (8). Nitrogen (dag kg^{-1}) was multiplied by 6.25 to obtain crude protein (CP). Samples were dry-ashed at 450 C, dissolved in HCL, and heated to dryness to dehydrate silica; they were redissolved in HCL, filtered, and made to volume for determination of P and other elements by standard analytical procedures.

Soil pH was determined in a 1:2 soil/water ratio in 1N KCl. Soil organic matter (OM) was determined by Walkley-Black method as modified by Walkley (9). Extractable elements were determined by shaking 5 g of soil with 20 ml of double-acid extractant (0.05 N HCl + 0.025 N H_2SO_4) for 5 minutes followed by filtration. Phosphorus in filtrates was determined by the ascorbic acid method, K by flame spectrophotometry, and Ca and Mg by atomic absorption spectrophotometry.

Callie and Siratro forage harvested in June, August, and October of 1978 and 1979 was analyzed for IVOMD, N, and minerals, then combined over years. Forage mineral concentrations were determined for each species at each of the above three harvest dates and combined over years (1978 and 1979). Soil nutrients were monitored at the end of the 1978 and 1979 growing seasons through soil tests, and reported for pH and double-acid extractable nutrients.

RESULTS AND DISCUSSION

Plant Yield Response

Total seasonal DM yields of Callie bermudagrass in 1978 were dependent on amended sand-tailings treatments. Highest yields were obtained from treatments containing SS, which increased yields during the first year by an average of 4.3 Mg ha^{-1} (Table 3). These results appear to follow earlier data reported by Mislevy and Blue (4) comparing the performance of tropical grasses grown on amended sand-tailings.

The addition of small amounts of SS (45 Mg ha^{-1}) appeared to aid in rapid development of the grass-root system, possibly because of the high OM content, which slowly released plant nutrients (Table 1). This high OM may have also increased the water-holding capacity, since water retention on sand-tailings is about 2.2% water by weight at 0.10 atm (4).

The amendment of sand-tailings with PC also resulted in yield increases, especially during the first and second year after establishment (Table 3). Phosphatic clays, like OM, aid in water and nutrient holding capacities.

Dry matter yields for Callie bermudagrass the second year after establishment averaged 15.9 Mg ha^{-1} (Table 3) with no differences ($P>0.05$) between soil treatments. This same pattern continued in 1980, the third year after establishment, even though average yields were reduced by 29% from the previous year, possibly due to a 40% reduction in rainfall during the months June thru October of 1980.

The tropical legume Siratro, unlike Callie bermudagrass, did not appear to respond to additional SS and OM. Yields over all amended sand-tailings treatments averaged 3.1, 2.9, and 1.1 Mg ha^{-1}, in 1978, 1979 and 1980, respectively. However, no significant difference was observed in Siratro yields between amended sand-tailings treatments during any of the 3 years tested. It was observed that treatments receiving SS contained considerably more broadleaf weeds when compared with the sand check and OB treatments. Similar results were obtained in an earlier experiment (5) when Siratro was grown on several amended sand tailings treatments.

These data indicate the addition of both SS and PC to sand tailings result in both improved establishment and high initial yields of only Callie bermudagrass. The PC and SS resulted in only a temporary (1 year) yield increase. Observations during the second and third years indicated that root systems in all amended sand-tailings treatments became deeper and occupied more soil volume. These more extensive root systems were better able to exploit the soil for available moisture and nutrients.

Forage Quality

Both digestibility and CP of Callie and Siratro forage were independent of amended sand-tailings treatments during 1978 and 1979. Siratro was generally higher ($P < 0.05$) in IVOMD and CP when harvested in June and August, however, the quality of the October forage was generally higher ($P < 0.05$) for Callie bermudagrass (Table 4). This reversal in forage quality for Callie and Siratro between June and October was probably due to a severe infestation of "leaf blight" (Rhizoctonia solani Kuhn) on Siratro. This disease effects Siratro foliage in mid-summer resulting in leaf necrosis and defoliation, consequently, forage quality was reduced. The loss of IVOMD and CP could possibly be reduced if Siratro was clipped more often. Clipping Siratro on a 60-day cycle allowed disease built up which caused leaf death and ultimately leaf drop.

Grazing Siratro with minimum pressure would also prevent a severe fungus buildup. This would encourage high quality forage, and allow enough photosynthetic area to remain for vigorous plant growth.

Plant and Soil Mineral Status

Mineral concentration of Callie bermudagrass varied ($P<0.05$) among amended sand-tailings treatments when averaged over three harvests and 2 years (Table 5). Concentrations of P ranged from 0.35 to 0.41 dag kg^{-1} for the OB 1800, NR, and sand check treatments, respectively, with an overall average of 0.39 dag kg^{-1}. All forage contained about twice the P required in the diet of growing and finishing cattle (10). The low P value found in forage grown on the OB treatment (OB 1800, NR) may have been a reflection of not-mixing this material with the sand tailings that contained high P (4.2 dag total P kg^{-1}).

The K concentration in this forage averaged 1.42 dag kg^{-1} and ranged from 1.32 to 1.58 dag kg^{-1} ($P<0.05$). The concentrations of K in sand-tailings treatments were border-line for good animal performance (10). Since all amended sand-tailings treatments contained a high concentration of sand and the cation exchange of this material was low [CEC=0.8 cmol (+) .kg^{-1}] much of the applied K was probably leached. The data indicated that concentration of K in Callie bermudagrass during 1978 averaged 1.29 dag kg^{-1} but increased to 1.73 dag kg^{-1} in 1979. This would indicate that as the plant root system developed more soil volume was contacted; consequently, forage plants contained a high concentration of K.

Calcium and Mg concentrations in forage from different amended sand-tailings treatments ranged from 0.50 to 0.59 dag kg^{-1} and 0.25 to 0.30 dag kg^{-1}, respectively (Table 5). Average Ca and Mg concentrations in the bermudagrass forage were 0.55 and 0.28 dag kg^{-1}, respectively. The Ca level appeared more than adequate for the diet of growing and finishing cattle; however, the Mg concentration is below that required by growing and finishing cattle but adequate (0.18 dag kg^{-1}) for lactating cows (10).

All micronutrient concentrations (Mn, Zn and Cu) analyzed in the forage were adequate for growing and finishing cattle (Table 5). Differences ($P<0.05$) did exist between sand-tailings treatments for Mn, Zn, and Cu. The Mn concentration was the lowest in forage grown on the sand check (15 mg kg^{-1}) or those treatments containing low amounts of clay in the amended treatments. The Zn and Cu forage concentration was lowest when grown on the amended treatments containing OB without SS. Data in Table 1 showed that SS contained relatively high concentrations of Zn and Cu which may have made a contribution to the forage.

Concentrations of minerals in Siratro followed a similar pattern to Callie bermudagrass with the exception of Ca, Mg, and Mn which were 53% higher, 111% higher, and 26% lower, respectively in Siratro than in Callie (Table 6). Phosphorus and Ca concentrations in Siratro was more than double these required by growing and finishing cattle (10). All other minerals were in adequate concentrations for cattle.

Double-acid-extractable soil nutrients and pH were monitored at the end of the first (1978) and second (1979) harvest seasons. Soil extractable nutrients were remarkably similar from amended treatments for Callie bermudagrass and Siratro, therefore, values were combined for both crops. Differences ($P<0.05$) between sand-tailings treatments were obtained for pH, P, K, Ca and Mg during both 1978 and 1979 (Table 7). In 1978, pH of amended soil treatments ranged from 6.2 to 7.2, with an average of 6.6. This value dropped about 0.2 units after the second harvest year. Generally, treatments containing OB (pH 6.0) were 0.6 to 0.8 units lower in pH than treatments without OB. Consequently, as the rate of OB increased, pH decreased. Extractable P, Ca and Mg were 5088, 9306 and 153 kg ha^{-1}, respectively, when averaged over amended soil treatments and years (Table 7). Even though this P was not all available to plants, the P and Ca values are exceedingly high when compared with extractable nutrients found in well fertilized Ona (sandy, siliceous, hyperthermic, Typic Haplaquod) or Pomona (sandy, siliceous, hyperthermic, Ultic Haplaquod) fine sand located in southern Florida (11). The extractable K averaged 74 kg ha^{-1} after the first harvest year, but increased to 132 kg ha^{-1} in 1979. The concentration of K in soil appeared to be related to the amended sand-tailings treatments; generally increasing as PC and OB content increased, as a consequence of reduced K leaching. The major sources of K responsible for the increase was fertilizer and SS.

These data indicate that adequate yields of good quality forage can be produced on well fertilized quartz-sand tailings. The addition of SS, PC, or OB as amendments to sand tailings were beneficial on forage yield and forage mineral concentrations in the first year. As the crop root system expanded and exploited additional soil volume, Callie bermudagrass and Siratro produced good yields with respectable CP, IVOMD, and adequate mineral concentration on the unamended sand tailings or sand tailings + OB without additional SS or PC. Therefore if reduced yields the first year after establishment can be accepted, no amendments of PC or SS are necessary on sand tailings. However, it may be desirable to apply the same amount of potassium fertilizer in 4 applications rather than 3 and continued the application of N after each harvest.

Literature Cited

1. Zellars, M. E., and J. M. Williams. 1978. Evaluation of the phosphate deposits of Florida using the mineral availability system. Final Report. U.S. Dep. of Interior, Bureau of Mines, Pittsburgh, Pa. Contract no. JO 377000. 196 pp.

2. Farmer, E. E., and W. G. Blue. 1978. Reclamation of lands mined for phosphate. p. 585-608. In F. W. Shaller and P. Sutton (ed.) Reclamation of drastically disturbed lands. Am. Soc. of Agron., Madison, Wis.

3. Hortenstine, C. C., and D. F. Rothwell. 1972. Use of municipal compost in reclamation of phosphate-mining sand tailings. J. Environ. Qual. 1:415-418. https://doi.org/10.2134/jeq1972.00472425000100040018x

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

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

6. Calhoun, F. G., V. W. Carlisle, R. E. Caldwell, L. W. Zelazny, L. C. Hammond, and H. L. Breland. 1974. Characterization data for selected Florida soils. Soil Sci. Res. Rep. no. 74-1. Soil Sci. Dep. Univ. of Florida Soil Characterization Lab., and Soil Conservation Service, USDA. University of Florida, Gainesville.

7. 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. Abstr. no. 261.

8. Gallaher, R. N., C. O. Weldon, and F. C. Boswell. 1976. Semi-automated procedure for total nitrogen in plant and soil samples. Soil Sci. Soc. Am. Proc. 40:887-889.
https://doi.org/10.2136/sssaj1976.03615995004000060026x

9. Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils. Soil Sci. 63:251-264. https://doi.org/10.1097/00010694-194704000-00001

10. National Research Council, Committee on Animal Nutrition. 1976. Nutrient requirements for beef cattle. No. 4, 5th ed. Natl. Academy of Sciences, Washington, D.C. 56 pp.

11. Mislevy, P., C. L. Dantzman, J. W. Prevatt, A. J. Overman, G. M. J. Horton, and F. A. Johnson. 1982. Forage production and utilization from a south Florida multicropping system. Univ. of Fla. Bull. 830. 39 pp.

Table 1
Characteristics of sand tailings and amendment materials used in the study.

Material	pH (H_2O)	Double-acid extractable P	K	Ca	Mg	Na	Mn	Zn	Cu	Fe	OM	Soil separates Sand	Silt	Clay	Texture†
		mg kg^{-1}									dag kg^{-1}				
Sand tailings	7.0	2,450	12	4,840	76	72	4.4	3.8	0.4	48	0.27	97.8	1.4	0.8	S
Overburden	6.0	390	6	930	41	15	0.9	0.3	0.1	20	0.17	84.3	4.2	11.6	LS
Sewage sludge	7.3	125	593	3,170	513	552	12.8	26.0	1.0	22	12.0	----	---	----	--

†LS = loomy sand; S = sand.

Table 2

Amendment treatments and rates of amendments added to each sand-tailings treatment.

Sand tailings treatment	Phosphatic clay	Over-burden	Sewage sludge
	Amendment		
	Mg/ha		
1	0	0	0
2	110	0	45
3	225	0	45
4	340	0 ‡	45
5	0	450 (5 cm)	45
6	0	1100 (10 cm)	45
7	0	1800 (15 cm)	45
8	0	1800 (15 cm)	0
9	0 (NR) †	1800 (15 cm)	0

†NR was not rototilled.

‡Depth of overburden rate applied.

Table 3

Total seasonal dry matter yield of Callie bermudagrass and Siratro as affected by amended sand-tailings treatments over a 3-year period, 1978-1980.

Amended sand-tailings treatments†	Callie 1978	Callie 1979	Callie 1980	$\bar{x}$	Siratro 1978	Siratro 1979	Siratro 1980	$\bar{x}$
Mg ha^{-1}	Mg ha^{-1}							
Sand check	10.2 d*	15.1 a	11.4 a	12.2	2.8 a	2.8 a	2.0 a	2.5
PC 110 + SS 45	14.7 ab	15.8 a	11.7 a	14.0	2.9 a	1.7 a	0.4 a	1.6
PC 225 + SS 45	15.9 ab	16.8 a	12.4 a	14.9	3.0 a	2.7 a	0.9 a	2.2
PC 340 + SS 45	16.5 a	17.4 a	11.1 a	15.0	3.2 a	3.5 a	0.6 a	2.4
OB 450 + SS 45	15.1 ab	16.5 a	11.5 a	14.3	3.0 a	2.0 a	0.4 a	1.8
OB 1100 + SS 45	14.6 ab	15.9 a	10.4 a	13.6	2.6 a	3.7 a	1.0 a	2.4
OB 1800 + SS 45	13.5 bc	15.4 a	10.9 a	13.2	2.6 a	3.1 a	1.0 a	2.2
OB 1800,	10.5 d	15.0 a	11.7 a	12.4	3.6 a	2.3 a	1.5 a	2.4
OB 1800, NR	11.6 cd	15.3 a	10.7 a	12.5	3.8 a	4.7 a	1.8 a	3.4
Avg.	13.6	15.9	11.3	13.6	3.1	2.9	1.1	2.3

*Means within a column followed by the same letters are not significantly different at the 0.05 level of probability according to Duncan's Multiple Range Test.

†PC = phosphatic clay; SS = sewage sludge; OB = overburden and NR = not rototilled.

Table 4

Percentage *In vitro* organic matter digestion (IVOMD) and crude protein (CP) of Callie bermudagrass and Siratro harvested three selected months and combined over 2 years, 1978 and 1979.

Plant entry	Harvest June	August	October
	---dag kg^{-1}---		
		IVOMD	
Callie	52.2 b*	54.3 a	59.4 a
Siratro	61.6 a	53.0 a	53.0 b
		CP	
Callie	9.5 b	10.1 b	13.8 a
Siratro	17.5 a	13.0 a	11.3 b

*Means within a column for each variable followed by the same letter are not significantly different at the 0.05 level of probability according to Duncan's Multiple Range Test.

Table 5

Effect of amended sand-tailings treatments on mineral concentrations in Callie bermudagrass averaged over 1978 and 1979.

Amended sand-tailings treatments †	Forage minerals P	K	Ca	Mg	Mn	Zn	Cu
Mg ha^{-1}	---dag kg^{-1}---				---mg kg^{-1}---		
Sand check	0.41	1.37	0.59	0.30	15	32	5.9
PC 110 + SS 45	0.39	1.39	0.55	0.29	17	35	5.5
PC 225 + SS 45	0.39	1.41	0.58	0.28	19	35	5.7
PC 340 + SS 45	0.39	1.38	0.59	0.29	22	36	5.8
OB 450 + SS 45	0.40	1.32	0.56	0.30	22	37	5.6
OB 1100 + SS 45	0.39	1.40	0.53	0.28	25	36	5.5
OB 1800 + SS 45	0.39	1.37	0.51	0.29	24	37	5.2
OB 1800,	0.38	1.52	0.50	0.27	34	28	4.7
OB 1800, NR	0.35	1.58	0.50	0.25	30	26	4.8
Avg.	0.39	1.42	0.55	0.28	23	34	5.4
LSD (0.05)	0.02	0.12	0.04	NS	5	4	0.5
Animal requirements ‡	0.20	0.5-0.8	0.30	0.4-1.0	10-20	20-30	4.0

† PC = phosphatic clay; SS = sewage sludge; OB = overburden and NR = not rototilled.

‡ For growing and finishing steers.

Table 6

Effect of amended sand-tailings treatments on mineral concentrations in Siratro averaged over 1978 and 1979.

Amended sand-tailings treatments†	Forage minerals						
	P	K	Ca	Mg	Mn	Zn	Cu
Mg ha^{-1}	---------dag kg^{-1}			--------	----mg kg^{-1}		----
Sand check	0.40	1.43	0.88	0.60	15	49	5.2
PC 110 + SS 45	0.44	1.55	0.84	0.56	16	45	5.7
PC 225 + SS 45	0.44	1.55	0.83	0.53	15	47	5.6
PC 340 + SS 45	0.43	1.51	0.88	0.59	16	47	5.7
OB 450 + SS 45	0.42	1.34	0.85	0.59	16	49	5.4
OB 1100 + SS 45	0.40	1.46	0.77	0.57	17	50	4.9
OB 1800 + SS 45	0.43	1.54	0.79	0.52	18	44	4.6
OB 1800,	0.40	1.50	0.83	0.56	21	46	4.3
OB 1800, NR	0.40	1.39	0.86	0.60	23	46	4.6
Avg.	0.42	1.47	0.84	0.57	17	47	5.1
LSD (0.05)	0.02	0.17	0.08	NS	3	NS	0.9
Animal requirements‡	0.20	0.5-0.8	0.30	0.4-1.0	10-20	20-30	4.0

† PC = phosphatic clay; SS = sewage sludge; OB = overburden and NR = not rototilled.

‡ For growing and finishing steers.

Table 7

Effect of amended sand-tailings treatments on pH and double-acid extractable nutrients following uniform fertilization and cropping.

Amended sand-tailings treatments†	pH (H_2O)	Double-acid extractable nutrients P	K	Ca	Mg
Mg ha^{-1}		-----------	kg ha^{-1}	-----------	
			1978		
Sand check	7.0 a	5,020 bc	49 d	10,640 b	105 c
PC 110 + SS 45	7.0 a	5,350 ab	60 cd	11,160 ab	139 bc
PC 225 + SS 45	7.2 a	5,710 a	72 c	11,870 a	190 a
PC 340 + SS 45	7.2 a	5,690 a	74 c	11,980 a	197 a
OB 450 + SS 45	6.5 b	4,410 c-e	65 cd	8,915 c	174 ab
OB 1100 + SS 45	6.4 b	4,705 cd	72 c	8,890 c	190 a
OB 1800 + SS 45	6.3 b	4,120 d-f	78 bc	8,400 cd	188 a
OB 1800,	6.3 b	3,965 ef	94 ab	7,795 de	195 a
OB 1800, NR	6.2 b	3,630 f	105 a	7,060 e	217 a
Avg.	6.6	4,733	74	9,634	177
			1979		
Sand check	6.7 a	5,760 ab	74 b	10,190 bc	81 b
PC 110 + SS 45	6.8 a	5,730 b	99 b	12,190 ab	114 b
PC 225 + SS 45	6.6 ab	5,710 b	110 b	13,710 a	114 b
PC 340 + SS 45	6.8 a	6,205 a	112 b	13,485 ab	139 ab
OB 450 + SS 45	6.0 c	5,310 c	110 b	8,780 c	105 b
OB 1100 + SS 45	6.5 a-c	5,200 c	164 a	8,690 c	137 ab
OB 1800 + SS 45	6.3 a-c	4,910 d	193 a	8,270 c	172 a
OB 1800,	6.0 c	5,200 c	152 a	8,290 c	114 b
OB 1800, NR	6.1 bc	4,970 d	179 a	8,110 c	186 a
Avg.	6.4	5,443	132	8,978	129

† PC = phosphatic clay; SS = sewage sludge; OB = overburden and NR = not rototilled.