Calcareous Oolitic Limestone Rockland Soils of the Bahamas: Some Physical, Chemical, and Fertility Characteristics

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Abstract

Andros is considered the island in the Bahamas archipelago with the greatest potential for agriculture. However, very little has been published about the physical, chemical, and fertility characteristics of the soil although some areas in North Andros have been farmed intensively by commercial offshore farmers from the USA over the past 90 years. Having mainly pine vegetation, the land in the central part of North and Central Andros seems to be occupied, mainly by the immature aluminous lateritic rockland soils belonging to the San Andros soil series and varying in color from gray to reddish brown. This book chapter presents physical, chemical, and fertility information on some of the soils of North and Central Andros.

Keywords

Alkaline · Andros · Bahamas · Chemical · Oolitic limestone soil · Rockland soil

34.1 Introduction

Generally Bahamian soils are thin and discontinuous, mostly lack potassium and nitrogen, and therefore, exhibit low fertility (Foos and Bain 1995) but pockets of clay are also found throughout the landscape. The soils in Andros are developed from oolitic limestone, and oolitic soils are derived from dissolved calcium carbonate, which precipitate out as ooliths (Currie et al. 2019). Soils in Andros are usually sandy and poorly developed (Sealey 1985). The soil mainly exhibits low organic

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matter content and the pH is dominantly alkaline ranging from 7 to 8 as a result of being derived from limestone weathering (Currie et al. 2019; Henry 1974; Patterson and Stevenson 1977). The soils are young and reflective of the geologically young age of limestone parent material (Currie et al. 2019). The young soil exhibit dominance of stones and sand, and the smaller sized particles such as clay are lesser. The sandy soils commonly occur on unconsolidated carbonate sands and are composed of unaltered carbonate mineral and organic material (Foos and Bain 1995). The rockland landscapes are often rocky and flat and commonly have soft limestone substrate that is suitable for farming (Smith and Vankat 1992).

34.2 Soil Sampling

Composite soil samples were collected from farms and from the forests around the Bahamas Agriculture Research and Training Development Project (BARTAD) Area, the San Andros area, the Nicoll's Town area, and the Stanyard Creek area. The areas in Andros from where the soil samples were collected are given in Table 34.1. As indicated, both virgin forest and farm soils were sampled. The samples were air-dried, passed through a 2 mm sieve, and stored in metal containers and plastic bags prior to analysis (Fig. 34.1).

Table 34.1 Soil sampling areas in Andros

Soil #	Location
1	From around San Andros Airport—Farm soil—Didymus Smith
2	From around San Andros Airport—Forest soil
3	From BARC area—Light gray forest soil
4	From BARC pilot test farm—Wilfred Mackey
5	From BARC area—Forest soil—Near Wilfred Mackey
6	From BARC pilot test farm—Enoch Marshall
7	From BARC agronomy field 3-12A eastern Part
8	From BARC area—Forest soil near agronomy field 3-12A
9	From pothole behind North Andros high school
10	From Stanyard Creek—Light gray farm soil—H. Frazier
11	From Stanyard Creek—Light gray woodland soil
12	From Stanyard Creek—Gray farm soil—H. Frazier
13	From broadleaf Forest near Heastie's farm
14	From pot in which citrus grew—Soil came from Heastie's farm
15	From BARC agronomy field 3-12A legume fertility Trial
16	From BARC area—Reddish brown forest soil
17	From BARC pilot test farm—Ernest Ebanks
18	From Nicoll's town—Farm lot soil—Nemiah Wilson
19	From Nicoll's town—Beach ridge brown sand
20	From Nicol's town—Broadleaf, yellowish brown forest soil
21	From San Andros Airport area—Farm soil—Wendell Gaitor

Fig. 34.1 Map of the Andros Bahamas, the site where soils were collected

34.3 Soil Analysis

34.3.1 Physical Properties

Particle size analysis was performed using the hydrometer method as described in Alabama A&M University International Soils Bulletin #2 (Taylor et al. 2010a).

34.3.1.1 Soil Classification: Color and Texture

Color and texture classification of soils are provided in Table 34.2. The soils which developed from calcareous rock formed during the Pleistocene era and under pine vegetation have a variety of colors (Table 34.2). The three basic soil colors, however, are gray, brown, and red. Various gradations of these can be encountered in pockets

Table 34.2 Color and textural classification of the soils

Soil #	Soil color	% Sand	% Silt	% Clay	Soil texture
1	Grayish brown	55	29	16	Sandy loam
2	Grayish brown	47.7	24.5	27.8	Sandy clay loam
3	Light gray	54	27	19	Sandy loam
4	Light brown	58	24	18	Sandy loam
5	Light brown	53.3	24.9	21.8	Sandy clay loam
6	Brownish gray	48	31	21	Loam
7	Brownish gray	48	31	21	Loam
8	Yellowish brown	47.8	27.6	24.6	Sandy clay loam
9	Brownish red	4	24	72	Clay
10	Light gray	85	10	5	Loamy sand
11	Light gray	82	10	8	Loamy sand
12	Gray	82	13	5	Loamy sand
13	Dark gray	83	10	7	Loamy sand
14	Dark brown	83	11	6	Loamy sand
15	Brownish gray	55.3	26.3	18.4	Sandy loam
16	Reddish brown	25.7	44.1	30.2	Clay loam
17	Light gray	51.9	29.9	19.1	Sandy loam
18	Dark brown	64.4	25.8	9.8	Sandy loam
19	Brown	80.1	13.1	6.8	Loamy sand
20	Yellowish brown	19.5	29.5	51.0	Clay
21	Reddish brown	53.0	34.5	12.5	Sandy loam

and large basins in the pine forest. The brownish gray seems to be more widespread in North Andros being found, like the other soils, between and within the loose soft limestone rocks. The coastal sandy soils occupying the beach dunes are also used for agriculture in areas such as Nicoll's Town and Stanyard Creek. These soils may be light gray or brown. The predominant texture of the soils used in this study was sandy loam with all the coastal beach dune soils being loamy sands. There were a few sandy clay loams, one clay loam, and two clays (Table 34.2). The dominance of sand and less clay particle percentage is reflective of a young soil. The low clay content is known to limit soil water holding capacity (Currie et al. 2019).

34.3.2 Chemical Properties

The following chemical properties were measured using procedures outlined in the Florida A&M University International Soil Bulletin #1 (Taylor et al. 2017).

- Sodium bicarbonate extractable phosphorus (P)
- Langmuir P adsorption maximum
- Soil pH
- Electrical conductivity

- Exchangeable bases [calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na)]
- Cation exchange capacity (CEC)

34.3.2.1 Soil Phosphorus

The inorganic P in the Bahamian calcareous soil is dominantly fixed by calcium (Ca), whereby 55.7–99.9% was reported to be in the Ca-P fraction (Taylor and Woods 1981). Therefore, these soils will require heavy P fertilizer applications to adequately supply P to crops.

Soil P values given in Table 34.3 indicate that all the farm soils except samples No. 15 and 21 had either normal or high levels of available P measured by the sodium bicarbonate method. All the forest soils had low levels of available P. This indicates that newly cleared land would require heavy applications of P fertilizers or fertilizers containing P to attain sufficiency. Also, the frequent or long-term additions of P to these Rockland soils will result in a buildup of residual P and high fertility level. Previous study using sequential fractionation data illustrated that Ca and Mg

Table 34.3 Sodium bicarbonate extractable phosphorus (P) and Langmuir adsorption maximum

Soil #	0.5 M $NaHC0_3$-P level (range)[a] (mg/kg)	P adsorption maximum	
		mg/100 g	lbs/acre
1	133.6 (H)	42.5	850.0
2	13.2 (L)	60.0	1200.0
3	15.2 (L)	50.0	1000.0
4	110.4 (H)	–[b]	–[b]
5	10.4 (L)	40.0	800.0
6	66.4 (N)	47.6	952.0
7	68.4 (N)	49.0	980.0
8	12.0 (L)	66.6	1332.0
9	12.0 (L)	56.0	1120.0
10	38.4 (N)	59.0	1180.0
11	16.8 (L)	34.5	690.0
12	52.0 (N)	34.5	690.0
13	15.6 (L)	66.6	1332.0
14	148.0 (H)	32.3	646.0
15	33.0 (L)	44.0	880.0
16	10.8 (L)	100.0	2000.0
17	100.0 (H)	50.0	1000.0
18	36.0 (N)	60.0	1200.0
19	–[c]	–[c]	–[c]
20	14.8 (L)	50.0	1000.0
21	15.0 (L)	50.0	1000.0

[a](L) = low, (N) = normal, (H) = high
[b]Does not fit a Langmuir adsorption
[c]No measurement made
[d]mg/kg × 2 = lbs./acre

associated P accounted for proportionally more P in the agricultural soils; however, this fraction was below the detectable limit in non-agricultural soils. This suggests that repeated heavy application of phosphate fertilizer could have resulted in the formation of stable, crystalline calcium phosphate minerals in the agricultural calcareous soils (Zhang et al. 2014). It is reported that phosphate reacts with calcium carbonate in soil whereby it is fixed by calcium carbonate through precipitation and adsorption (Fixen et al. 1983; Zhou and Li 2001). Wandruszka (2006) further indicated that the role of calcium carbonate in P retention by calcareous soil is significant in the presence of relatively high P concentration, while the noncarbonate exhibit a more important role at lower P concentrations.

It is well documented that in calcareous soils, applied P fertilizers are adsorbed to the soil surfaces and are very slowly released to the soil solution. The rate of release can be too slow to replenish the soil solution with an adequate amount of P. The result for many crops may be P insufficiency and finally deficiency. However, it is possible to experimentally determine the maximum amount of P a given soil will adsorb per unit weight and adjust the quantity to pounds per acre. This is done by using the Langmuir adsorption equation (Olsen and Watanabe 1957) and calculating the absorption maximum. Woodruff and Kamprath (1965) reported that of the five soils they studied, the two with the highest adsorption maximum gave the highest yield for millet at ¼ the adsorption maximum and two with a lower adsorption maximum gave the highest yield at ½ the adsorption maximum, while the other with the lowest adsorption maximum gave the highest yield at the adsorption maximum. They concluded that soils with a high P adsorption maximum apparently are able to supply sufficient P for growth at a lower saturation than the soils with a low P adsorption maximum. The adsorption maxima of the soils in our study are generally higher than those of the soil in their study. Therefore, the assumption will be made that if the soils contain or are supplied with enough P to occupy ¼ the adsorption maxima, then P sufficiency can be acquired. The calculations to determine the quantity of P necessary to attain sufficiency are given in an earlier report (Taylor et al. 2010b).

34.3.2.2 Soil pH

Soil pH measurements were made in 0.01 M $CaCl_2$ following the procedure outlined in Florida A&M University International Soil Bulletin #1—Rev. 2 (Taylor et al. 2017). As indicated in Table 34.4, the pH of all the soils was in the slightly alkaline range except the red soil which had a pH of 6.6 (slightly acid) and is the only Bahamian soil the authors have measured which had a slightly acid soil reaction. This is good from a plant nutrition standpoint (Nelson 2003), but this red clay soil only occupied a very small area (a wide and deep pothole). The red aluminous lateritic soils of the Bahamas usually cover small areas and in the natural state may be slightly acid in reaction but would be expected to become neutral to slightly alkaline after cultivation due to release of calcium from the broken limestone rocks.

Table 34.4 pH, electrical conductivity (EC), exchangeable bases, and CEC of the soils

Soil	pH	EC[a] (mmhos/cm)	meq/100 g of soil (range[b]) Ca	Mg	K	Na	CEC[c]	Level
1	7.4	1.1	15.6 (H)	1.4 (H)	0.47 (N)	ND[d]	17.5	(H)
2	7.4	0.27	18.8 H)	0.56 (N)	0.15 (L)	0.07 (L)	19.6	(H)
3	7.5	0.70	19.4 (H)	1.1 (H)	0.33 (N)	ND	20.8	(H)
4	7.5	0.75	16.3 (H)	2.0 (H)	0.33 (N)	ND	18.6	(H)
5	7.5	0.40	24.5 (VH)	0.53 (N)	0.15 (L)	ND	25.2	(H)
6	7.5	1.1	15.4 (H)	1.2 (N)	0.70 (N)	ND	17.3	(H)
7	7.5	0.5	14.8 (H)	1.2 (N)	0.30 (N)	0.52 (N)	16.8	(H)
8	7.5	2.2	26.8 (VH)	3.3 (H)	0.48 (N)	2.55 (VH)	33.1	(VH)
9	6.6	0.50	18.0 (H)	1.4 (N)	0.62 (N)	ND	20.1	(H)
10	7.4	1.1	10.1 (H)	1.2 (N)	0.08 (VL)	ND	11.4	(N)
11	7.5	0.8	12.8 (H)	1.5 (N)	0.02 (VL)	ND	14.4	(N)
12	7.6	1.8	11.4 (H)	1.3 (N)	0.13 (L)	ND	12.8	(N)
13	7.5	0.54	20.3 (H)	0.77 (N)	0.06 (VL)	0.13 (L)	21.2	(H)
14	7.4	1.1	16.9 (N)	1.6 (N)	0.70 (N)	1.2 (H)	20.4	(H)
15	7.6	0.57	17.1 (H)	1.4 (N)	0.23 (N)	ND	18.7	(H)
16	7.1	0.73	20.1 (H)	0.33 (L)	0.26 (N)	ND	20.7	(H)
17	7.6	1.4	16.0 (H)	2.2 (H)	0.55 (N)	0.75	19.5	(H)
18	7.7	3.5	48.7 (VH)	7.1 (VH)	1.3 (H)	0.30 (N)	57.4	(VH)
19	7.6	1.7	15.4 (H)	2.1 (H)	0.21 (L)	ND	17.7	(H)
20	7.4	0.92	28.0 (VH)	2.4 (H)	0.61 (N)	ND	30.9	(VH)
21	7.5	0.84	16.0 (H)	1.1 (N)	0.23 (L)	ND	17.2	(H)

[a]EC = Electrical conductivity
[b](L) = low range; (N) = normal range; (H) = high range; V = very high range. The ranges are based on the small exchange approach to soil testing developed by Dr. Dale E. Baker, Department of Agronomy, The Pennsylvania State University
[c]CEC = Cation exchange capacity is a measure of the soils total capacity to hold positively charge nutrients
[d]Not detected

34.3.2.3 Electrical Conductivity

The electrical conductivity procedure used is outlined in Florida A&M University International Soil Bulletin #1—Rev. 2 (Taylor et al. 2017).

The electrical conductivity (EC) measurements of the saturated paste extracts of these soils indicate that only one soil (No. 18) would be a salinity hazard (Table 34.4).

34.3.2.4 Exchangeable Bases

Exchangeable bases were measured using the ammonium acetate extraction (pH 9) method (Taylor et al. 2017).

Levels of exchangeable bases (Ca, Mg, K, Na) are presented in Table 34.4. Most of the calcium values were high, with 4 of the 21 being very high. Generally, the exchangeable magnesium values were within the normal range with 7 in the high range and 1 in the very high range. Of the virgin forest soils, only one was within the low range. This could be interpreted to mean that newly cleared land should have adequate levels of magnesium for crop production. However, fertilizer additions of this nutrient may still be necessary after several croppings due to crop removal.

Most of the exchangeable potassium values were within the normal range. Three of the 21 values were very low and another five was low. Values for the virgin forest soils were all low. This strongly suggests that newly cropped land would have to be heavily fertilized with potassium containing fertilizers to have successful crop production.

The data also shows that the soils have the capacity to accumulate potassium for future crop production having been previously fertilized with this element since the farm soils generally had higher values than the adjacent virgin soils. Calculations for the amount of potassium to be added to reach sufficiency using exchangeable potassium values were presented in Alabama A&M International Soils Bulletin #3 (Taylor et al. 2010b).

Most of the soils have no exchangeable sodium with just one having a very high sodium value. It is very difficult to explain why some virgin soils have low levels of sodium, while most have no sodium. Sodium is not one of the essential plant nutrients but its presence in the soil in large quantities can cause structural problems and can also be an indicator of salt built-up (Vance et al. 2008; Warrence et al. 2003).

The cation exchange capacity (CEC) of the soils was determined by summation of Ca, Mg, K, Na as outlined in Florida A&M University International Soil Bulletin #1—Rev. 2 (Taylor et al. 2017).

34.3.2.5 Cation Exchange Capacity (CEC)

The cation exchange capacity (CEC) measurements were all in the normal to high range with two being in the very high range and most being in the high range. Based on the soil texture and the perceived low organic matter levels in the soils, these values were higher than expected. However, the type of clay minerals and the organic matter levels were not determined; therefore, one can only speculate. The problem of measuring accurate CEC levels in the Bahamian calcareous rockland soils was briefly discussed in Alabama A&M International Soils Bulletin #3 (Taylor et al. 2010b). Further research is needed to elucidate this problem so that one can with confidence measure and interpret CEC values and use them to aid crop production. The other question of the high exchangeable calcium was also discussed. More research is needed to also answer this question.

34.4 Conclusion

Andros soils are dominantly sandy in texture and slightly alkaline in pH. The alkalinity is a result of soil development from oolitic limestone. Therefore, the alkalinity could be a challenge to crop production unless the crops are adapted to content alkalinity. The sandy soils with low clay content are reflective of a young soil, the low clay content has potential to negatively affect water holding capacity. Forest noncultivated soils exhibited low P concentration compared to agricultural soils illustrating the influence of P fertilizer addition to availability of P. The soils exhibit high calcium concentration and normal potassium concentration. The CEC was normal to high; however, more studies are required on organic matter level and clay mineral content in order to understand CEC dynamics.

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