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Comparative Analysis of Soil Health in Backyard Farms on Multiple Islands of The Bahamas

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Abstract

Food insecurity is a major concern in The Bahamas due to our inadequate food and agricultural infrastructure and heavy reliance on imports. To mitigate this threat, the Bahamian government has been encouraging homeowners to engage in backyard farming. However, the success of backyard farming relies on the presence of healthy soils. In this study, we conducted a comparative analysis of soil health in backyard farms across several islands in The Bahamas. Our analysis focused on key indicators such as nutrient availability, pH, salinity, water-holding capacity, and organic carbon. Our results revealed that none of the 38 soil samples analysed fell within the optimal range for all of the selected indicators. Our results suggested that soil treated with synthetic fertilizer did not exhibit higher nutrient availability compared to naturally fertilized or unfertilized samples. Additionally, through correlation analysis, we found a positive relationship between organic carbon and water-holding capacity. Conversely, negative correlations were observed between pH and nitrogen, as well as organic carbon and pH. These correlations imply that optimizing pH levels and enhancing water holding capacity may play a crucial role in improving soil health in The Bahamas, with particular attention to increasing organic carbon content.

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Introduction

Soil is one of the most important natural resources essential for human and ecological health. It provides numerous ecological services that are essential for sustaining agricultural-based economies, ensuring food security, and mitigating climate change (Lehmann et al., 2020). The most obvious connection between soil health and societal stability is agriculture. Without healthy soil, the agricultural sector would face significant obstacles, potentially leading to global food shortages and economic difficulties. However, soil is much more than a medium for plant growth. Healthy soils are crucial in mitigating global warming and climate change. Particularly, soil acts as a sink, effectively removing harmful greenhouse gases from the atmosphere (Tahat et al., 2020). Moreover, soil health holds great importance in conserving diverse and sustainable ecosystems (Cardoso et al., 2013). It also contributes to the resilience of these ecosystems in the face of natural disasters such as hurricanes (Lugo, 2008).

Food insecurity poses a significant concern in The Bahamas, with Karpyn et al. (2021) reporting that 21% of individuals in the country have experienced some form of food insecurity. This issue arises due to The Bahamas having a relatively weak agricultural sector, leading to the reliance on food imports, which accounts for the majority of its food supply (Poitier, 2022; Thomas, 2017). To address this risk, the Bahamian government has actively encouraged homeowners to engage in backyard farming, as it is expected to reduce the high food import rate and mitigate the impact of high food prices (Yu, 2017). While backyard farming has been shown to enhance food security and sustainability in other jurisdictions, its success has been heavily linked to soil health (Jiao et al., 2019). However, there is currently a lack of comprehensive information on the soil health status in The Bahamas, highlighting the urgent need to assess the condition of soils in backyard farms across the archipelago.

Soil health encompasses various chemical, biological, and physical factors that influence its ability to support microbial life and agriculture (Arias et al., 2005; Lehmann et al., 2020). A key indicator of soil health is soil organic carbon. Soil organic carbon significantly impacts soil water retention, nutrient storage and availability, aggregate stability, and pH (Stott, 2019; Weil & Magdoff, 2004). In The Bahamas, soil organic carbon levels are generally low due to the prevalence of calcium carbonate rocks (Kindler & Hearty, 1997). Another important indicator is nutrient availability, which encompasses essential nutrients required for plant growth (Binkley & Vitousek, 1989). While specific nutrient requirements may vary slightly among plants, nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, zinc, manganese, copper, boron, molybdenum, and chlorine are necessary for plant growth and productivity (Uchida, 2000). Among these, nitrogen, phosphorus, and potassium (NPK) are commonly deficient and targeted by NPK fertilizers to enhance their availability (Moebius-Clune et al., 2016). According to the Food and Agriculture Organization of the United Nations, The Bahamas used a total of 238.2 kg of fertilizer per hectare of arable land in 2020, which was higher than the global average of 180.1 kg per hectare of arable land (2020). Soil pH is also a significant soil health indicator that can influence nutrient availability and explain nutrient deficiencies (Alam et al., 1999; Moebius-Clune et al., 2016). In The Bahamas, the soils are generally alkaline due to limestone content, which may affect nutrient availability. High soil pH has been shown to significantly reduce the availability of phosphorus, zinc, iron, and manganese (Moebius-Clune et al., 2016). Salinity, the presence of soluble salts in soil, is another important indicator as high salinity can lead to soil degradation and negatively impact plant growth and productivity (Hardie & Doyle, 2012; Machado & Serralheiro, 2017). Given the island geography of The Bahamas, there is an elevated risk of high salinity, particularly during storm surges caused by hurricanes (Paldor & Michael, 2021; Provin & Pitt, 2001).

Therefore, this study aimed to assess the soil health of backyard farms across The Bahamas, comparing the collected data with recommended values from reputable sources such as the Cornell Assessment of Soil Health (CASH; Moebius-Clune et al., 2016). Priority was given to indicators directly related to agricultural endeavours and those that mitigate common threats to Bahamian soil quality, including the effects of hurricanes. The study hypothesized that soil samples from the Family Islands would exhibit better health compared to samples from New Providence, considering the higher urbanization and population density in the latter, which can contribute to reducing soil quality (Ghanem, 2018; Yao et al., 2022). Additionally, it was hypothesized that soil fertilized with synthetic fertilizers would demonstrate higher nutrient availability compared to samples fertilized with natural fertilizers or unfertilized samples. Synthetic fertilizers are designed to provide readily available nutrients, while natural fertilizers require time for decomposition before nutrient release into the soil (Sabry, 2015; Stewart, 2023).

Methodology

Sampling Sites

The sites selected in this study were backyard small plots of privately owned land used for small-scale commercial farming or subsistence farming. Sites in New Providence were more accessible due to the researchers residing in New Providence and the facilities for testing samples being in New Providence. Therefore, samples from Family Islands were shipped to New Providence for testing. Sites were chosen based on convenience and availability; backyard farmers in New Providence who were willing to give access for sample collection, and backyard farmers on Family Islands who were willing to collect and ship soil to New Providence were included in the study. Table 1 shows the location of sampling sites in New Providence, as accurate location data was available for these sites.

Samples were taken from seven sites on New Providence and one site on each Family Island, resulting in 13 total sampling sites. The number of samples per site is shown in Table 1. Backyard farmers provided information regarding the types of fertilizers used in the soil, if any. This information was used to classify soil samples as synthetically fertilized, naturally fertilized, or unfertilized.

Table 1 *Samples Taken at Each Site.*

Sampling Site	Number of Samples
Andros	1
Berry Islands	1
Eleuthera	2
Exuma	10
Grand Bahama	2
New Providence Site 1	1
New Providence Site 2	2
New Providence Site 3	6
New Providence Site 4	2
New Providence Site 5	1
New Providence Site 6	1
New Providence Site 7	8
Ragged Island	1

Soil Sampling

Soil samples were collected from a depth of 0-6 in (0-15 cm) using a shovel, following the method described by Stott (2019). To preserve the integrity of the samples, they were placed in sealable Ziploc bags, plastic bags, or containers until they could be analysed in the laboratory. To ensure accuracy and reliability, each sample underwent multiple tests. The indicator value for a particular site was calculated as the average of all the samples obtained from that site.

Soil Type/Texture

Soil type can help predict or explain values regarding several of the soil health indicators, such as soil organic carbon and soil water holding capacity. While aggregation tests can be done to confirm the exact ratio of soil particles and their sizes, for this study a simpler method was chosen, as soil texture was not intended to be a focal point. The ribbon test was used to determine the broad type of soil (clay, sand, silt). To conduct the ribbon test, a ball of soil was formed in the hand using soil and water. A ribbon was then made by rolling the ball into an elongated shape. Sandy soils do not form a ribbon, and silty soils form a ribbon < 1 in (2.5 cm) in length. Ribbons > 1-2 in (2.5-5 cm) are comprised mostly of clay (Whiting et al., 2014). Two ribbon tests were conducted for each site, with additional tests carried out in certain cases to confirm the findings. Only two tests were necessary for the soil samples from each site as they were usually consistent with each other.

Soil Nutrient Tests

Soil nutrient availability is one of the most important aspects of soil fertility, so these tests comprised a significant part of the methodology. These tests were completed using a Lamotte soil test kit. This kit was preferred, as it is one of the most accurate commercially available soil testing kits. A study in 2007 showed that it was 94% correct compared to laboratory test results (Faber et al.). To complete these tests, a general soil extraction solution was created. To do this, 14 mL of universal extracting solution was placed in a test tube, and eight level 0.5 g spoons of soil were added. This mixture was then capped and shaken for one min (samples with high carbonate content were swirled for 30 s before shaking to allow excess gases to escape). After shaking, the solution was filtered using filter paper, and the filtrate was used for future tests. All tests were carried out in triplicate to ensure accuracy and reliability.

To test for nitrate nitrogen, 1 mL of general soil extract was added to a spot plate using a pipette. Then, 10 drops of nitrate reagent 1 and 0.5 g of nitrate reagent 2 were added to the extract. These components were then mixed and allowed to sit for five min. After five min, the colour of the mixture was compared to the nitrate nitrogen colour chart to determine the nitrate nitrogen availability. Results were measured in pounds per acre and converted to mg/kg.

To test for nitrite nitrogen, five drops of general soil extract were added to a spot plate using a pipette. Then, one drop of nitrite reagent 1 and one drop of nitrite reagent 2 were added and mixed with a stirring rod. Then three drops of nitrite reagent 3 were added and mixed, after which the mixture was left to sit for one min. The colour was then compared to the nitrite nitrogen colour chart, and the results were measured in ppm (1 ppm is equal to 1 mg/kg).

To test for potassium, a soil extract was added to a test tube. One potassium B tablet was added and shaken until dissolved in the extract. Potassium reagent C was then added by allowing it to drain down the side of the tube into the extract. The solution was mixed before potassium was determined in the soil. An empty test tube (potash tube B) was then placed on the potassium reading plate, and the mixture of extract and reagents was added to it using a pipette. This was done until the black line on the reading plate was no longer visible. The amount of the liquid corresponded to the level of potassium available, in pounds per acre, which was converted to mg/kg.

To test for phosphorus, 15 mL of general soil extract was placed in a test tube using a pipette. Then, six drops of phosphorus reagent were added to the solution using a different pipette, and this was capped and shaken. Then, one phosphorus test tablet was added to the solution, and it was capped and shaken until the tablet dissolved. The colour of the solution was compared to the phosphorus colour chart to determine the phosphorus availability. Results were measured in pounds per acre and converted to mg/kg.

Soil pH was also measured using the Lamotte test kit. To complete this test, soil and distilled water were added to a test tube. Then, five drops of soil flocculating solution were added, and the mixture was shaken and left to settle. After settling, 1 mL of the solution was added to a spot plate. Two drops of duplex pH indicator were added to the sample to indicate its pH range. The range of the pH correlated to a more specific indicator. Then, two drops of this indicator were added to 1 mL of the sample in a spot plate to indicate the specific pH.

Soil salinity was measured using a portable meter. Soil samples were sieved to remove any large debris such as rocks or roots. A soil slurry was created by mixing one part of soil into two parts of distilled water, or a ratio of 1:2, with 20 g of soil and 40 mL of distilled water. The meter was then placed in the slurry and a reading was determined. Soil salinity was recorded as total dissolved solids (TDS) and measured in ppm or mg/l.

Soil Water Holding Capacity

To test soil water holding capacity, soil samples were first weighed; 25 g of the soil extract was used for each sample, which was then placed in funnels with filter paper. Then, the soil was saturated with water. The ratio of soil to water was 1:2 (25 g of soil to 50 mL of water). The water was allowed to drain out of the soil, and the amount of water was recorded once it stopped. The water collected was subtracted from the original 50 ml, and the difference was the amount of water retained in the soil. This method is similar to the Sustainable Intensification Assessment Framework method of testing soil water holding capacity (SI Toolkit, n.d.), but due to available resources, it was altered. The equation for finding the percentage of water retained is shown below:

$$\% \, SWHC = \left[\frac{Vo - Vc}{\mathrm{Vo}}\right] \times 100$$

where Vo is the original water volume and Vc is the volume collected after drainage (SI Toolkit, n.d.).

Soil organic carbon was measured using loss on ignition (LOI). To complete this test, a drying oven and an ignition oven were used. To prepare for drying, soil samples were sieved to remove any rocks, plant matter, or other objects. The samples were dried at 105 °C for 24-72 hr to remove the moisture. For each sample, 15 g of dried soil was used. The dry soil was placed in the ignition oven and left at 500 °C for three hr. This removed organic carbon, and what remained was weighed. The equation for finding the percentage of organic carbon in soil samples is shown below:

$$\% \, SOC = \frac{\left[\frac{Mo - Mf}{Mo}\right] \times 100}{1.724}$$

where LOI is the percentage of mass lost on ignition, Mo is the original mass of the sample, and Mf is the final mass of the sample after ignition. This method was altered slightly due to available resources (Allen et al,, 1974; Chmura et al., 2003).

Data Analysis

This data was represented graphically using bar graphs created in Excel, which was also used to complete the calculations for mean and standard error. A two-sample *t*-test assuming unequal variance, and a single factor analysis of variance (ANOVA) were conducted to test the hypotheses. An alpha level of 5% and $p < .05$ were considered statistically significant. Correlation analysis using Pearson's correlation was used to find the correlation between groups of two indicators, using organic carbon, pH, and salinity as independent variables and the other indicators as dependent variables. Pearson's correlation analysis was used to show the strength and nature of the relationship by providing a correlation coefficient between -1 and 1. Negative values show an indirect relationship and positive values show a direct relationship, and the closer the value is to an absolute value of 1 the stronger the relationship. Meanwhile, the closer the value is to 0 the weaker the relationship (Sedgwick, 2012).

Results and Discussion

Indicator results

Optimal values for four of the eight indicators are taken directly from the CASH framework (Moebius-Clune et al., 2016). Optimal values for phosphorus are between 3.5 and 21.5 mg/kg, potassium values are ≥ 74.5 mg/kg, and the pH is between 6.4 and 7.3. Organic carbon was assessed on a more-is-better trend, but any value above 6% was considered optimal (Moebius-Clune et al., 2016). In the CASH framework, nitrogen is not assessed at all due to its volatility; nitrogen values in soil are very dynamic and can change drastically. Additionally, salinity was not assessed directly, and water-holding capacity was assessed using a methodology that this study was unable to utilize. According to the Australian Department of Environment and Resource Management, the optimal value for nitrate nitrogen is between 10 and 50 mg/kg (Pattison et al., 2010), and due to nitrite nitrogen being either inaccessible or toxic to plants, it will be assessed on a less-is-better scale (Oke, 1966).

Similarly, salinity, although it can be tolerated, is a form of soil degradation (Machado & Serralheiro, 2017; Sahab et al., 2021), so it was assessed on a less-is-better scale. Salinity lowers the osmotic potential in groundwater, making it more difficult for plants to retrieve the water necessary to function (Moebius-Clune et al., 2016). Therefore, higher salinity is generally less healthy for soils and contributes to lower soil fertility. Lastly, water-holding capacity was assessed on a more-is-better scale. Although the methodology is different from CASH, the principle is that higher water-holding capacity is indicative of healthier soil (Moebius-Clune et al., 2016).

Five of the eight indicators in this study had defined optimal ranges (nitrate nitrogen, phosphorus, potassium, pH, and organic carbon), and three did not (nitrite nitrogen, salinity, water holding capacity). Of the 38 samples, one was within the optimal range for three of the five indicators, 18 were within the optimal range for two of the five indicators, eight were optimal in one of the five indicators, and 11 were optimal in none of the five indicators.

In Table 2, soil samples were grouped by the site they were taken from. The average value of all samples collected is represented by the blue line on each graph in Figure 1. There was only one sampling site for each Family Island, so, for brevity, each site is referred by island name. However, this does not imply that the value taken is representative of the entire island. As shown in Table 2, the sites with the highest nitrate nitrogen were Andros with 75 mg/kg and New Providence Site 1 with 66 mg/kg, and these exceeded the optimal value. The sites with the lowest nitrate nitrogen were New Providence Site 5 with 8.3 mg/kg and Grand Bahama with 9.2 mg/kg, and these were below the optimal value. All other sites were within the optimal range. These results showed a high level of variation that is consistent with the observed volatility of nitrogen values in soil (Moebius-Clune et al., 2016).

Table 2 *Average Indicator Values at each Site.*

Site	Nitrate Nitrogen (mg/kg)	Nitrite Nitrogen (mg/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)	pH	SWHC (%)	TDS (mg/kg)	Organic Carbon (%)
Exuma	22.5 ± 3.55	-	61.46 ± 3.35	-	8.25 ± 0.02	23.4 ± 0.68	95.4 ± 5.47	3.5 ± 0.06
NP Site 1	66.67 ± 8.33	3.67 ± 1.33	37.5	123.34 ± 26.67	7	34.67 ± 0.67	160.67 ± 3.93	20.9 ± 1.16
NP Site 2	38.33 ± 11.88	1.67 ± 0.67	81.25 ± 9.77	38.75 ± 8.7	8	31 ± 2.63	66.17 ± 3.48	9.4 ± 3.49
NP Site 3	38.06 ± 5.92	1.78 ± 0.38	91.67 ± 3.84	-	8	30.78 ± 2.39	82.83 ± 7.01	9.6 ± 1.9
NP Site 4	40 ± 11.18	1	46.88 ± 2.55	-	8	31 ± 1.98	91.17 ± 7.9	5.9 ± 0.16
NP Site 5	8.34 ± 1.66	1	62.5 ± 10.21	-	8 ± 0.02	30.67 ± 0.67	67.67 ± 0.88	11.8 ± 0.19
NP Site 6	30 ± 10	-	31.25 ± 5.1	-	8.07 ± 0.07	29.33 ± 0.67	120.33 ± 7.26	15.1
NP Site 7	55 ± 5.23	-	64.84 ± 4.91	35.31 ± 6.29	8.12 ± 0.03	30.08 ± 0.63	193.08 ± 15.25	5 ± 0.11
Andros	75	2.33 ± 1.33	50	-	8	35 ± 1	326.33 ± 3.93	5.
Ragged Island	38.34 ± 18.33	4 ± 3	75	-	8.13 ± 0.07	27 ± 1	247.67 ± 6.12	3.7 ± 0.19
Grand Bahama	9.17 ± 0.83	-	31.25 ± 6.25	-	8.23 ± 0.03	27 ± 1.29	63.5 ± 2.49	5.5 ± 0.4
Eleuthera	43.33 ± 4.22	4.00 ± 1.74	43.75 ± 3.61	-	7.53 ± 0.21	44. ± 0.82	88.83 ± 8.38	14.4 ± 0.4
Berry Islands	35 ± 20.21	-	37.5	-	8.13 ± 0.07	17 ± 2.45	71.33 ± 3.18	4.1 ± 0.58
Optimal Range	10–50 mg/kg	N/A	3.5–21.5 mg/kg	≥ 74.5 mg/kg	6.3–7.4	N/A	N/A	6%

Note: - indicates a value below the detection limit of the test, ± standard error.

The values for the first nutrient, nitrite nitrogen, are shown in Table 2. New Providence Site 1 (3.67 mg/kg), Ragged Island (4 mg/kg), and Eleuthera (4 mg/kg) had the highest nitrite nitrogen levels. New Providence Site 6 (0.5 mg/kg) and Grand Bahama (0.5 mg/kg) had the lowest nitrite nitrogen levels. As nitrite nitrogen is unusable to plants and can be toxic to some plant species (Spann & Schumann, 2010); less of it is optimal for soil health. It is worth noting that several sites had similar levels of nitrate and nitrite nitrogen.

Phosphorus values are shown in Table 2. All the sites exceeded the optimal range, but the two sites closest to it were New Providence Site 6 and Grand Bahama (both 31.25 mg/kg). Although it may be assumed that adding the maximum amount of nutrients or fertilizers to soil would be optimal for its health, excess nutrients can cause adverse environmental effects such as eutrophication (Dodds & Smith, 2016). Eutrophication is the accumulation of nutrients in bodies of water, such as lakes or ponds, and it can cause further negative phenomena such as algal blooms (Glibert et al., 2005). The nutrients that contribute most to eutrophication are nitrogen and phosphorus (Dodds & Smith, 2016); thus, it is important to avoid over-application of fertilizers. Besides the island of San Salvador, most islands of The Bahamas have very few bodies of standing water that could be affected by eutrophication (Park et al., 2009). However, as groundwater makes up a significant portion of the Bahamian drinking water supply (Welsh & Bowleg, 2022), Bahamian backyard farmers should still be conscious of any potential forms of groundwater contamination and avoid over-fertilization.

The last nutrient test in this study is potassium, the results of which are shown in Table 2. The detection limit of the potassium test was 50 mg/kg, and only five samples exceeded that limit. However, as a precipitate was formed in all the tests, the test was not negative, and potassium was not completely absent. The site with the highest level of potassium was New Providence Site 1 with 123.3 mg/kg. This was the only site that was above the minimal optimal value of 74.55 mg/kg.

Table 2 also shows the pH levels of the various sites. There was very little variation between the pH levels recorded across the various sites. The alkalinity of the samples correlates with, and is consistent with the known properties of limestone soil in The Bahamas (Yu, 2017), as most samples are between 8.0 and 8.4 pH. The two outliers are New Providence Site 1, which had a significantly lower pH of 7 and is the only site within the optimal range, and Eleuthera, which had a pH of 7.5. These outliers may be explained by the high level of organic carbon at each site. New Providence Site 1 (20.9%) and Eleuthera (14.4%) both showed high levels of organic carbon. Organic carbon has been shown to optimize soil pH (Moebius-Clune et al., 2016) and is a likely contributor to why low pH was observed at these sites; although, other factors are likely also involved. Soil water holding capacity was also recorded in Table 2. The highest percentage of water holding was Eleuthera (44%), followed by Andros (35%) and New Providence Site 1 (34.7%). The lowest recorded percentage was the Berry Islands at 17%.

Salinity, shown in Table 2, was measured using total dissolved solids (TDS) measured in ppm. Andros had the highest salinity with 326 ppm, followed by Ragged Island with 247 ppm, and New Providence Site 7 with 190 ppm. The lowest salinity levels were New Providence Site 2 (66.2 ppm), Site 5 (67.6 ppm), and Grand Bahama (63.5 ppm). Different crops have different tolerances for salinity, so the effects of high salinity can vary based on specific crop choices (Moebius-Clune et al., 2016).

Lastly, organic carbon content, measured by loss on ignition, is shown in Table 2. The highest was New Providence Site 1, with a percentage of 20.9% organic carbon, followed by New Providence Site 6 with 15.1%, and Eleuthera with 14.4%. The lowest organic carbon percentages were Exuma (3.5%), Ragged Islands (3.17), and Berry Islands (4.1%).

Hypothesis testing

The two hypotheses were tested using statistical tests to determine the variance between the data collected. The first predicted that New Providence samples would be less healthy than Family Island samples. There were 21 samples taken from New Providence and 17 samples taken from the various Family Islands. A *t*-test (unequal variance) was used to test the mean values of the samples when separated into New Providence and Family Island groups. The results are shown in Table 3. An alpha level of 5% or 0.05 was used, and if the $p > .05$, it was concluded that no statistical difference was present. Meanwhile, if $p < .05$, then there was a statistical difference (Greenland et al., 2016). The test was conducted for every indicator used, excluding potassium and nitrite nitrogen, which had multiple samples below the detection limit. Three indicators showed a statistical difference between New Providence and Family Island samples. These indicators were nitrate nitrogen, phosphorus, and organic carbon. For nitrate nitrogen ($p = .01$), the New Providence mean value (44.3 mg/kg) was higher than the Family Islands' mean value (28.1 mg/kg). Similarly, for organic carbon, New Providence samples (14.4%) had a higher mean value than Family Island samples (8.9%). For phosphorus, mean values for both New Providence and Family Island samples were above the optimal range (69.4 and 54.5 mg/kg). For all other indicators, the test showed no statistical difference ($p > .05$), and the numerical differences can be disregarded. Using this information, the first hypothesis can be rejected. Although this does not show that New Providence had the healthiest samples of all the islands, when grouped against the Family Islands collectively, New Providence samples were, on average, just as healthy or healthier.

Table 3 *Two-tailed t-test Assuming Unequal Variance.*

Location	Nitrate Nitrogen (mg/kg)	Phosphorus (mg/kg)	pH	TDS (mg/l)	SWHC (%)	Organic Carbon (%)
New Providence Samples	44.3 ± 3.7	69.3 ± 4.9	8 ± 0.05	128.8 ± 16.5	30.7 ± 1.6	14.44 ± 1.3
Family Island Samples	28.1 ± 4.9	54.5 ± 3.9	8.1 ± 0,07	112 ± 17.5	26.8 ± 1.9	8.9 ± 0.9
t stat	2.64	2.38	-1.5	0.7	1.56	2.05
p	.013	.023	.143	.489	.127	.048

Note: p values are significant at $p \leq .05$, ± standard error.

To test the second hypothesis, a single-factor ANOVA was used. The sites, separated by fertilizer usage, are shown in Table 4. It was predicted that due to synthetic fertilizers providing nutrients in an accessible form (Sabry, 2015; Stewart, 2023), samples fertilized using synthetic fertilizers would have higher nutrient availability than naturally fertilized or unfertilized samples. A variety of natural and synthetic fertilizers were used, as fertilizers are intended to have a significant effect on nutrient availability.

Two of the four nutrient categories were analysed: nitrate nitrogen and phosphorus. Nitrite nitrogen was excluded as it is inaccessible to plants, so it is usually absent from synthetic fertilizers, entirely. Potassium was also excluded due to low detection levels. Out of the samples collected, eleven were fertilized using synthetic fertilizer, and they were from Exuma and New Providence Site 5. Another 11 samples were fertilized using natural fertilizers, and they were taken from New Providence Site 1, Site 2, Site 7, and Grand Bahama. Lastly, 15 samples were unfertilized, and they were taken from New Providence Site 2, Site 3, Site 4, Site 6, Grand Bahama, Eleuthera, Ragged Island, and the Berry Islands. Specific fertilizer data was not available for the sample taken from Andros, so it was excluded from this section of the study.

Table 4 *Sites and Samples Categorized by Fertilizer Type.*

NPK Fertilized	Natural Fertilizer	Unfertilized
Exuma (Manure, Miracle Grow)	New Providence Site 7 (Manure)	New Providence Site 4
New Providence Site 5 (Manure, Osmocote Smart Release Plant Food)	New Providence Site 1 (Manure)	New Providence Site 6
	Grand Bahama Sample 1 (Black Kow Composted Manure)	Berry Islands
	New Providence Site 2 Sample 2 (Milorganite, Epsom salt)	Grand Bahama Sample 2
		Eleuthera
		New Providence Site 2 Sample 1
		New Providence Site 3 (Aragonite)
		Ragged Island

The results of the ANOVA tests are compiled in Table 5. For nitrate nitrogen (p = .0004), synthetic fertilized samples had the lowest mean value (21.2 mg/kg), followed by unfertilized samples (36.1 mg/kg), and naturally fertilized samples had the highest mean value (50.8 mg/kg). The second hypothesis can also be rejected, as the test showed no statistical difference ($p > .05$) for one of the two nutrients, and for nitrate nitrogen, synthetically fertilized samples had the lowest mean value. Due to the uncertainty regarding specific fertilizer content, application ratios, application frequency, and crop rotations, further investigation would offer a more effective conclusion on the efficacy of using natural and synthetic fertilizers in Bahamian soil. Additionally, there were more sampling sites tested that used natural fertilizers (four) or that were unfertilized (eight) compared to sites fertilized using synthetic fertilizer (two), and there may have been other factors specific to these sites that resulted in low nutrient values. However, it can still be suggested that natural fertilizers may be as effective as synthetic fertilizers for providing nutrients to Bahamian backyard farms and should not be ignored as a viable possibility without further investigation.

Table 5 *Single-Factor ANOVA.*

Category	Nitrate Nitrogen (mg/kg)	Phosphorus (mg/kg)
Synthetically Fertilized Samples	21.2 ± 5.02	61.6 ± 3.57
Naturally Fertilized Samples	50.8 ± 5.91	66.5 ± 5.61
Unfertilized Samples	36.1 ± 2.9	65 ± 6.73
p	.0004	.17

Note: p values are significant at $p \leq .05$, ± standard error.

Correlation Analysis

Figure 1shows a correlation matrix of all the indicators used in this study.

Correlation analysis was used to investigate the effect of certain variables on others, and to do so, organic carbon, pH, and salinity were designated as independent variables, due to the prevalent effect they can have on other indicators. These designations were only used to separate the factors while discussing their correlation, as no aspect of soil health is completely independent or dependent.

Organic carbon correlation results are shown in Table S1 of the Supplementary Data. Organic carbon was found to have a very weak positive correlation with nitrate nitrogen (0.22) and phosphorus (0.05). These values are not statistically significant, so further study is necessary to make definitive statements about the connection between organic carbon and nutrient availability in Bahamian soil. Conversely, pH, shown in Table S2, was found to have a negative correlation with nitrate nitrogen (-0.41). Lastly, salinity, shown in Supplementary data file Table S3, was found to have a positive correlation with nitrate nitrogen (0.51) and no significant correlation with any other indicators.

In this study, pH had a negative correlation with nitrate nitrogen availability; however, the range of pH in this study was quite limited, so further study with a wider range of pH across samples would offer more information on this relationship in Bahamian soil. Additionally, the interactions between nutrient testing apparatus and nutrients in the soil and plant roots and nutrients in the soil are different, so the effects of pH on plant nutrient uptake could not be observed using the apparatus available for this study. Similarly, salinity did not show a significant negative correlation with any nutrients but rather a positive correlation with nitrate nitrogen was observed. Further studies into the importance of soil salinity would benefit Bahamian agriculture as salinity, especially in areas heavily affected by saltwater intrusion, may have significant effects on nutrient availability in Bahamian soils.

A notable finding was that two independent variables also had influences on each other, further displaying the interconnectivity of soil health indicators. Specifically, organic carbon and pH were found to have a correlation of -0.6, which is a significant negative correlation. This is consistent with research, as increasing organic carbon percentages in soil has been found to optimize soil pH (Moebius-Clune et al., 2016). This can be expressly relevant to Bahamian agriculture, as Bahamian soil is generally alkaline and above the optimal pH range (Yu, 2017).

Figure 1 *Correlation Matrix of Indicators Used in this Study*

	Nitrate Nitrogen	Nitrite Nitrogen	Phosphorus	pH	SWHC	Salinity (TDS)
Nitrate Nitrogen	1					
Nitrite Nitrogen	0.3	1				
Phosphorus	0.2	0.06	1			
pH	-0.41*	-0.74**	0.11	1		
SWHC	0.33*	0.19	0.05	-0.45**	1	
Salinity (TDS)	0.51**	0.11	-0.04	-0.03	0.1	1

Note: * and ** are significant at the $p \leq .05$ and $p \leq .01$ level respectively.

Soil Texture

Soil texture was another notable aspect of this study, and the textures of samples taken from the various sites are shown in Table S4 of the Supplementary data file. A connection was observed between soil texture and organic carbon results. Sandy samples, such as those taken from the Berry Islands (4.1%), Ragged Islands (3.7%), and Exuma (3.5%), had low organic carbon, and the samples with the highest organic carbon were mainly comprised of either silt in New Providence Site 1 (20.9%) and Site 6 (15.15) or clay in Eleuthera (14.4%). Similarly, the sites that had the highest water-holding capacity were mostly clay in Eleuthera (44%) or silt in New Providence Site 1 (34.67%); however, Andros (35%) showed a high percentage despite being sandy. Pearson's correlation analysis showed a coefficient of 0.76 between organic carbon and soil water holding capacity, the highest of any coefficient in the study. This is significant for Bahamian soil, given the possible negative effects of hurricanes and flooding as climate change persists (Curell, 2011; Lugo, 2008). Increasing organic carbon in soil can potentially lead to the improvement of soil water-holding capacity (Moebius-Clune et al., 2016), and this would improve the ability of Bahamian backyard farms to weather some of the negative ecological effects of tropical storms and hurricanes.

Conclusion

For The Bahamas to develop its agricultural industry and achieve food security, it is necessary to investigate and improve Bahamian soil health. This study investigated soil health in backyard farms across The Bahamas by analysing soil nutrient availability, pH, water-holding capacity, salinity, and organic carbon. The samples tested in this study were mostly within the optimal range for nitrogen but showed excess phosphorus and very low potassium availability. The pH of the samples was above the optimal range, which is typical for limestone soil found in The Bahamas, and high pH negatively correlated with nitrate nitrogen. Additionally, organic carbon was above the optimal range in samples, and high organic carbon correlated with lower pH and higher water holding capacity. These correlations suggest that increasing organic carbon may be instrumental in optimizing Bahamian soil health. Future studies should expand the scope by including commercial farms as well as backyard farms and increasing the sample size to make more definitive conclusions. Indicators, such as microbial activity, should be investigated as they contribute heavily to nutrient availability as well as wet aggregate stability, which is essential for withstanding disruption and erosion from hurricanes. Soil health is a complex problem that The Bahamas must address as it progresses toward food security, and studies that investigate Bahamian soil health are the first step to achieving that goal.

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