Haiti Soil Fertility Analysis and Crop Interpretations for Principal Crops in the Five WINNER Watershed Zones of Intervention

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Abstract

Subsistence farming and environmental degradation dominate the landscape in Haiti and there is little accurate soil-fertility research available to growers. The Watershed Initiative for National Natural Environmental Resources (WINNER) project focuses on improving living conditions by spurring sustainable economic growth and protecting environmental resources in five major watershed regions of Haiti: Gonaives, Archaie/Cabaret, Cul-de-Sac, Kenscoff, and Mirebalais/Saut D'eau. This report focuses on the soil-test data development, soil-test interpretations, and crop-specific fertilization recommendations calibrated for the Mehlich-3 (M-3) extractant. Fifteen hundred soil samples were analyzed for physical and chemical properties by researchers at the University of Florida. There is currently no M-3 calibrated crop response data in Haiti, therefore the soil fertility results were compared to crop-specific soil index values for crops growing in similar soils in areas with similar climate. Nitrogen was the limiting factor for crop growth most often. Phosphorus was deficient at 62% of sites. The dominant fertilizer formulation in Haiti is 12-12-20, yet soil-test results show that only 4% of soils sampled required K fertilization. Soil reports containing soil-test values with interpretations were generated. Tables, useful for improved fertilization rates based on these interpretations for a total of 24 commonly grown Haitian crops were compiled from the literature. This project provides tools for growers to increase yields beyond subsistence farming levels and the flexibility to grow additional types of crops. Future research will focus on the development of calibrated M-3 crop interpretations that are specific to the various climate and site conditions in Haiti in order to achieve the most efficient nutrient/crop management strategies.

INTRODUCTION

Haiti's Socio-Economic Background

According to 2010 United States Central Intelligence Agency (US-CIA), data 9.7 million Haitians live within the borders of the 27,750 km^2 country, which is an area slightly smaller than the state of Maryland (with a population of 5.8 million) (MD SDC, 2010). While the median age is twenty one, 38% of the population is ≤ 15 years of age. In contrast, only 3.4% of the Haitian population is ≥ 65 and 51% is ≤ 20 (US-CIA, 2011). Forty seven percent of the population of Haiti lives in urban areas according to recent data (US-CIA, 2011); however, the city of Port-au-Prince has received an influx of rural refugees after the magnitude 7.1 January, 2010 earthquake. As of early 2011, more than one million people are still living in tent cities in the aftermath of the devastation.

Haiti is the poorest country in the Western hemisphere; 76% of Haitians live in poverty on less than two dollars (US) per day, while 56% live in abject poverty on less than one dollar per day (Sletten, 2004). Many Haitians do not consume enough calories on a daily basis and, nearly 60 percent of children younger than five suffering from diseases of malnutrition (Avery, 2010). These poverty conditions are exacerbated by the high cost of imported food, which accounts for a large percentage of all food available in Haiti. To partially correct this condition and to stimulate entrepreneurialism, local food production is a laudable goal. To that end, there is a need for an overhaul of the current agriculture system and municipal infrastructures to sufficiently feed and improve living conditions for Haiti's population.

When governed by French rule, Haiti was referred to as “The Pearl of the Antilles”. In fact, economists estimated that Haiti provided as much as 50% of the gross national product of France during the mid-eighteenth century. Raw materials such as sugar, coffee, lumber, cocoa, tobacco, cotton, and indigo dye from Haiti were imported to France and refined, packaged, and sold across Europe. Today agriculture provides one-fourth of the country’s annual economic output (Corbet, 1999); 1.3 million hectares are devoted to agriculture production (United Nations Convention to Combat Desertification, 2006). Two-thirds of the population rely on the agriculture industry for jobs, mainly subsistence or self-sufficiency farming. A total of 11.5% of land is covered with permanent crops, while 28% of land is classified as arable (US-CIA, 2011).

Climate

Haiti’s climate ranges from tropical to semi arid with an average rainfall of more than 127 cm in the capital city to trace amounts in arid regions. The tropical weather pattern creates two rainy seasons from April to June and August to mid-November. These rainy seasons are often followed by periods of drought; hurricanes and flash-flooding are common. Storm waters wash the productive top-soil, raw sewage, and urban pollutants into surface waters; these pollutants then make their way into the nation’s waterways. Flood waters carve into the hillsides and carry sediment down slope.

According to the National Data Climatic Center the distribution of soil suborders, range of soil pH, fine-textured soils, and average precipitation amounts (93 cm/yr) in Oklahoma are comparable to some regions in Haiti. Florida has similar climate, sandy soil textures, and tropical rainfall patterns (rainy season followed by periods of drought) as other regions in Haiti.

Florida has an average precipitation of 138.7 cm/yr, similar to areas in Port Au Prince/Cul-de-Sac watershed (Fiondella, 2010).

Watershed Initiative for Natural National Environmental Resources (WINNER) Project

The capital city of Port-au-Prince is located in the Cul-de-Sac plain. This plain contains some of Haiti's most productive agriculture lands. The Cul-de-Sac watershed is characterized by steep hillsides that were once covered with tree canopies and perennial crops like shade-grown coffee. Land within the Cul-de-Sac watershed has been intensely managed for sugar cane; the trees have been harvested and annual crops now cover the hillsides. The transition from forested to intensive agriculture increased the potential for runoff and subsequent soil erosion. As a result, both major rivers in the region have experienced stream bank erosion and sedimentation. In addition, ground water levels have fallen due to increased urban withdrawals and groundwater salt intrusion is becoming common. The challenges faced in the Cul-de-Sac watershed typify many of the challenges faced in many of the watersheds of Haiti (USAID/WINNER).

The Haitian Watershed Initiative for National Natural Environmental Resources (WINNER) project is a joint venture with Chemonics, contracted by the United States Agency International Development (USAID), the University of Florida Institute of Food and Agriculture Science (UF-IFAS), Ch2M Hill, Research Planning Inc. and Caudill Web. The overall goal of the project is to improve living conditions by spurring sustainable economic growth and protecting environmental resources in five major watershed regions of Haiti: Gonaives, Archaie/Cabaret, Cul-de-Sac, Kenscoff, and Mirebalais/St. D'eau (Figure 1), are the focus of an international effort to improve environmental and social conditions, in part, through increasing agricultural productivity in a sustainable manner. All of the watersheds, excluding Gonaives, are geographically connected.

Improving the livelihood of Haitians within these targeted regions can be achieved, in part, through the use of appropriate soil-testing methods to predict positive crop responses to added nutrients. A calibrated soil-test is a soil extraction procedure resulting in a soil-test value that can be correlated with a positive crop response to fertilization. The calibration process involves replicated field trials including a wide range of soil, water regimes, and climatic conditions, and is crop-specific (Savoy, 2009). Initial soil-test calibrations and interpretations for specific crops in Haiti must be based on established calibrations and interpretations from other locations with similar soil properties, because, to date, no calibration work has been done within Haiti. Developing base-line soil fertility analysis and implementing more efficient growing practices (such as proper fertilization rates) can increase crop yields and food availability. Additionally, increased grower education through the local extension service can help reduce and ameliorate environmental degradation from years of subsistence farming.

Soil Quality Issues

Haiti's expanding population and scarcity of arable lands combined with intensive exploitation of steep slopes with minimal crop inputs gives rise to increasing erosion rates and poor crop yields (Isaac, 2006). According to the United Nations Convention to Combat Desertification (UNCCD), Haiti's topography includes approximately 63% of land with a slope greater than 20%, while only 29% of land has slopes less than 10%. The United States

Department of Agriculture Natural Resource Conservation Service (USDA NRCS) classifies soils on slopes of 8% and greater as highly-erodible lands and, therefore, are not naturally suited for agriculture without significant inputs. The UNCCD estimates that less than 20% of the 1.3 million hectares of cultivated lands are able to sustain agriculture activities, but the area farmed in Haiti is six times greater than the estimated area suitable for crop production. Farming of unsuitable lands has lead to significant land degradation as a result of deforestation, desertification, soil erosion, flooding, and improper land management.

Deforestation, the natural terrain, land use change, and years of farming have left the land highly susceptible to soil erosion and possible further land degradation. Eighty years ago, 60% of the country was covered with forest, whereas today forested areas cover less than 2% of land. Tree plantings and understory growth have had little time to establish before being harvested and turned into fuel wood or charcoal – the main source of energy for more than 70% of the population. Typical ecosystem services are disrupted since there is little plant litter available for soil nutrient cycling or organic matter production. Additionally, forest land use changes to agriculture and urbanization exacerbate erosion because natural sediment buffers and soil-stabilizing plant material are removed (UNCCD, 2006).

Soil Characteristics in the Zones of Intervention

Haiti's topography and geologic history have created a wide-range of climatic and soil conditions within a relatively small geographic area (Isaac, 2006). Based on NRCS soil maps of Haiti (Figure 2), there are large areas of Inceptisols and Entisols with pockets of Aridisols, Alfisols, or Ultisols with udic or ustic soil moisture regimes in the five watershed regions (USDA-

NRCS, 2010A). The soils have formed over basalt or limestone parent material (Isaac, 2006). Entisols are characterized by a lack of horizon development; they are commonly formed in floodplains and steep slopes where the rate of erosion exceeds the rate of soil development (Brady and Weil, 2008). Entisols tend to have an ochric or anthropic (man-made) epipedon; many are sandy or very shallow (USDA-NRCS, 2010B). Inceptisols can have the beginnings of diagnostic horizon development (B horizon), but still lack any well-defined characteristics of any other soil order. Inceptisols form in humid and sub-humid regions that have altered horizons that have lost bases or iron and aluminum but retain some weatherable minerals (USDA-NRCS, 2010 C). Given Haiti's topography, climate, and anthropogenic activities, soils are generally poorly developed because they are prone to erosion. These young, recently deposited soils have little chance to develop in situ before eroding further down slope.

Soil-Test Methods for Haiti

Previous soil research performed in Haiti used soil nutrient extraction procedures (Bray 1 and Olsen) that were developed for mildly acidic soils of the Mid-western United States. However, soil pH in Haiti ranges from acidic to alkaline (calcareous). The commonly used Bray 1 and Olsen soil-tests for P should not be expected to work across the broad range of soil pH and suborders in Haiti. The Bray 1 extractant often produces erroneously low P values in calcareous soils, while the Olsen test is reliable on neutral and alkaline soils but inaccurate on acid soils less than pH 5.0 (Mallarino, 2000).

Researchers involved with the WINNER project determined that the Mehlich-3 (M-3) soil-test was well suited to the variations in soil conditions common in Haiti. The M-3 soil-test was designed to extract multiple elements in a wide range of mineralogy and pH, from less than 6.0 to greater than 7.4. Researchers at Iowa State University determined that P soil-test results for M-3 and Bray 1 are similar in acid and neutral soils, but the M-3 extractant performs better in high pH and calcareous soils (Mallarino, 2000). The M-3 extractant has been the focus of considerable research with selected crops and therefore, both calibration and crop interpretation information can be found in the literature. Since Haiti has no soil-test calibration or interpretation information based on soil-testing using the M-3 extractant, we must rely on values found in the literature.

The M-3 extractant releases the extractable forms of macronutrients P, K, Ca, Mg, Na, as well as the micronutrients Cu, Zn, Fe, and Mn from the soil matrix. The extraction solution is composed of acetic acid (CH_3COOH), ammonium nitrate (NH_4NO_3), nitric acid (HNO_3), ammonium fluoride (NH_4F), and ethylenediaminetetraacetic acid (EDTA). Acetic acid buffers the reagents to pH 2.5, preventing Ca from precipitating as calcium fluoride. Ammonium nitrate and NH_4F facilitate the extraction of basic cations; NH_4F also extracts Fe and Al phosphates. Nitric acid aids in the extraction of Ca phosphate as well as the other macro- and micronutrient cations. The acid EDTA chelates micronutrients and works with acetic acid to prevent precipitation of calcium fluoride (North Carolina Department of Agriculture and Consumer Services, 2007).

The M-3 test is an efficient method for soil nutrient determination since one extractant can be used to determine multiple nutrient values such as P and cations simultaneously, saving time and money. Another desirable trait of M-3 is that the results are not affected by storing samples for several months, which was important to this project since it was nearly two months from the time of soil sampling until the samples arrived in Miami for analysis (Zhang, 2010). Additionally, several states have done calibration studies linking the M-3 extractant to crop responses to added nutrients. Therefore, soil-test results can be used as a predictive tool for future crop response before any fertilizer is applied to agriculture fields. Oklahoma State University (OSU) has done extensive work with M- 3 soil-test interpretations and corresponding fertilizer recommendations for 18 of the 24 principal culture crops in Haiti (Table 1).

Crop Interpretations

The macronutrients N, P, and K are the three most commonly deficient vegetable crop nutrients. The starting point for efficient vegetable crop fertilization and nutrient management is estimating the plant-available residual soil fertility (Brandenberger, 2009). For the WINNER project, interpretations and fertilizer recommendations were developed from the literature since no field calibration trials and corresponding crop response research existed in Haiti.

Nitrogen Recommendations for Vegetable Crops

When comparing OSU and UF-IFAS N application recommendations, seven crops had different recommendations (in kg/ha): corn, eggplant, lettuce, okra, peppers, spinach, and tomatoes. For all seven crops the UF-IFAS N recommendations were greater than the OSU recommendations. Corn, eggplant, pepper, and tomato required double the amount of N according to UF-IFAS Vegetable Production Guide. The differences in N application rates can be attributed to the increased nutrient holding capacity of the finer textured soils of Oklahoma (less required N) and a greater incidence of leaching rainfall in Florida (greater N required).

The soil analysis database and corresponding grower reports are designed to account for a broad range of variables (e.g. climate, mineralogy, fertility levels); therefore, both OSU and UF-IFAS N recommendations have been provided to make the fertilizer rate determinations. In depth, local calibration trials will need to be developed to determine the most efficient application rates for N. The OSU and UF-IFAS rates should be used until crop yield research trials are performed in Haiti.

Objectives of the Fertility Recommendation Project

The objectives for this portion of the comprehensive WINNER Project included: 1) creating a soil-analysis database of farm sites within the 5 watershed regions (Zones of Intervention), 2) providing crop-specific fertilizer rate recommendations for N, P, and K, and 3) creating a grower report containing the results of the research conducted on their farms. The WINNER research team has developed a database and report system containing soil nutrient values, physical properties, and M-3 crop interpretations for the principal crops grown on the farm sites within the five watersheds. These data can be utilized by growers, land owners, and extension agents to improve crop efficiencies and overall yields. This report focuses on the processes of data development, soil-test interpretations, and crop-specific fertilization recommendations.

Materials and Methods

Crop Interpretations

The UF-IFAS Vegetable Production Guide was utilized to provide N recommendations for all crops and N, P, and K recommendations for leeks. For the crops with no M-3 interpretations available in the literature (i.e., banana, cassava, papaya, sugarcane, wetland rice), agriculture specialists working in the Caribbean basin were consulted to make N, P, and K recommendations (R. Yudin, Personal Communication). Oklahoma State University calibrated soil-test index crop interpretations were utilized for 18 other principal crops (Brandenberger, 2009; Zhang, 2009). The OSU soil-test index is expressed as pounds of the extracted nutrient per acre (Zhang, 2009), but the OSU soil-test index was converted to parts per million (ppm) using the formula: lb/acre = ppm × 2. All fertilizer recommendations were provided in kg/ha/year (Appendix A). Micronutrient soil-interpretations were not available for most crops; therefore, micronutrient fertilizer recommendations were not generated for this portion of the project.

The on-site investigators recorded grower information, geo-spatial data, investigator names, and a detailed cropping history (see Appendix B: Grower Metadata Sheet). Five types of crop culture categories were developed. Precedent culture was defined as the crop harvested immediately before soil sampling. Crops growing at the time of soil sampling were recorded as current culture. The principal culture was defined as the primary crop by dollar value grown on the farm; fertility recommendations for the 24 principal crops (see Table 1) recorded by investigators were developed as a result of the soil fertility analysis. Secondary culture crops were lesser value crops associated with the principal crop. Crops that the grower planned to sow in future rotations were recorded as future culture (F. Sergile, Personal Communication).

The USDA's National Institute of Food and Agriculture (NIFA) worked with WINNER to determine soil sampling locations in conjunction with 1,500 Haitian growers. The WINNER project, led by Dr. F. Sergile (UF International Programs) and Dr. J Louissaint (University of Port-au-Prince), was in charge of training the crew leaders who conducted the on-site soil sampling. The original training program was planned for implementation in Port-au-Prince by Dr. D. Shannon (Auburn University), Dr. E. Hanlon (UF-IFAS), and Dr. F. Sergile; however, this planned training event was interrupted by the January 2010 earthquake. As a result, a Power Point presentation describing field soil sampling procedures was developed to help train the crew leaders in an effort to ensure that all samples were taken in the same manner. In March 2010, the soil samples were collected from farm sites across the five watersheds included in the study.

Soil Sampling Process

Detailed soil characterizations were not recorded for the samples included in this study. Soil fertility analysis results were limited to the A or Ap horizon, the zone of plant root nutrient uptake. In the absence of bucket augers, shovels were used to excavate soil to a 15 cm depth (Figure 3). A 2.5 cm section of soil was lifted out with the shovel and then the sides were cut away with a knife. After removal of any debris, the sample was placed in a bucket; multiple samples were taken from each farm site and hand-mixed in the bucket. From the mixed soil, a 0.5 kg sample was removed and transferred to a labeled soil sample bag. The same label was added to the individual meta-data form, linking the soil sample and the meta-data. The soil sampling crews met with the growers on-site to discuss and complete the metadata sheet. Tools were cleaned between each sample location and knives were rinsed with rubbing alcohol to reduce the potential for cross-sample contamination; water was not used to clean the sampling tools to prevent possible nutrient contamination (Hanlon, 2010).

Each of the 1,500 soil samples was placed inside a one gallon zip seal bag, sealed and placed inside another zip seal bag and sealed. Multiple samples were then wrapped in a black trash bag and packaged inside a cardboard box. The unique soil ID labels were transcribed on each soil sample bag before being packed and shipped from Haiti. Six hundred and ninety kilograms of soil were loaded into a shipping container and sent by freighter to Miami in May 2010.

Soil-Test Procedures

Before the soil samples were shipped to Florida, researchers developed sample handling, preparation, and laboratory processes to maintain high quality control standards. Once in Miami, the soils, still in unopened sample bags, were treated with gamma energy electromagnetic radiation to sterilize the soil and kill any pathogens. There was no corresponding rise in temperature or chemical residue left behind from this process (Food Technology Services Inc, 2011).

There were no facilities available in Haiti to properly dry the soil samples before packing and shipment. Once the irradiated samples were delivered to the University of Florida Tropical Research and Extension Center (TREC), the sample bags were opened and air-dried in a plastic-enclosed hot house, where daytime temperatures reached approximately 37.8^{o} C. The dried samples were then ground by mortar and pestle and analyzed. The unique soil ID label of each soil sample was recorded and used throughout all preparation and laboratory processes.

Soil texture determinations, as well as a variety of soil chemical properties including pH, total N, EC, and total and organic C were analyzed at TREC. Soil pH and EC (1:2 soil to deionized water ratio) were determined by standard methods of UF-IFAS Extension Soil Testing Laboratory (Mylavarapu, 2009). Total soil N was analyzed using a CNS analyzer (Vario Max Elementar, Hanau, Germany) (Y. Li, Personal Communication). Soil samples were also prepared for nutrient analysis with the M-3 extractant at TREC. Scientists at TREC soil laboratory mixed 4 g of ground soil with 40 mL of M-3 extractant solution, which is double the amount of soil and extractant used in the traditional M-3 extraction procedure. This process complies with the original M-3 procedure, preserving the soil/extractant ratio, while allowing for sufficient solution for all laboratory analysis (Savoy, 2009). The filtrate was stored at 4^{o} C until it was shipped to the University of Florida Analytical Research Lab in Gainesville, FL for analysis. Extractable P, K, Ca, Mg, Zn, Mn, Cu, Fe, and Mo were determined by Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES) (Mylavarapu, 2009).

Computer Programs

Geographic Information System (GIS) map layers were developed from the interpolation of the soil analysis results for pH, N, P, and K. Multiple Microsoft programs were utilized to develop the final report and crop recommendations. The original metadata forms were transcribed into Microsoft Excel as were the soil chemical analysis results; Excel was also utilized to create a table for individual crop fertilizer rates according to soil test results (recorded in kg/ha). Microsoft Access was used to verify Form ID labels assigned in Haiti and Soil ID labels assigned in the laboratory. After verification and removal of mismatched forms and soil labels, Access was used to merge the matching label information into individual records (rows); the merged data was transferred back to Excel. A soil test report form was developed in Microsoft Word and Microsoft Mail Merge was used to link the Excel formatted grower information, sample information, and soil sample results into individual Microsoft Word printable reports. These individual reports were verified for data-transfer accuracy. These reports are the end result of this portion of the WINNER project.

An Excel table with the primary crop interpretations was included with each report file sent to WINNER (see Appendix B: Primary Crop Interpretations). The OSU crop fertilizer recommendations can be looked up on the table and be entered either by hand or by computer on the report form containing the soil test analysis results. There was a blank text box on each grower's report for additional notes and recommendations to further assist the growers.

Challenges and Sample Problems

The original timetable for the soil fertility analysis was January 2010; the goal was to have analysis results and crop interpretations completed in time for the spring planting rotation in May. The catastrophic earthquake made this goal impossible to achieve. The project was stalled due to lack of facilities, manpower, and logistical issues. A separate group of people facilitated the training of the crew leaders on GPS recording and sampling procedures than was originally planned in the Scope of Work.

Approximately one-third of the samples had erroneous data that was removed from this data set and archived; the reasons for the discrepancies include improper recording of metadata and improper soil labeling procedures in Haiti. The GPS readings were taken in multiple coordinate systems that created transcription errors when developing a GIS data layer of the 1,500 sample locations. In addition, some of the GPS recordings were invalid – in some cases the coordinates did not match any location in Haiti; the soil sample records that were unable to be matched to a specific site location were excluded from the study. From an initial 1,500 locations, 1,157 samples were able to be matched with their location information and were moved on to the soil test phase.

In some cases, the Form ID label (from the field) and the Soil ID label (from the soil laboratory) could not be paired; either the Form ID or the Soil ID did not exist in the dataset. Other label matching issues arose including: two or more samples contained the same Soil ID label or the Form label could not be found among the Soil ID labels. Out of 1,157 samples, 1,047 had verifiable matching label data (Form ID label matched Soil ID label) and were carried forward for crop interpretation analysis (Appendix C**:** Final Grower Report).

RESULTS AND DISCUSSION

When comparing soil-test results between sample sites and watersheds, it is important to note that the results varied for multiple reasons. The date and rate of the last fertilization were not known and varied between sites. It is likely that some of the locations were fertilized just before sampling, thus creating higher soil-test fertility measurements than would naturally occur. Also, depending on the type of crop grown, some sites may have received more fertilizer throughout the year. The density of sample sites was likely a function of the size of the watershed or the fact that more agriculture occurs in one region compared to another.

Table 1 displays the distribution of the principal crops among the 1,047 farm sites that were subjected to crop interpretation analysis; banana, bean, corn, sorghum, and sweet potato were the five most commonly grown crops (by farm-gate value). These 24 crops occur within all crop culture classifications (precedent, current, secondary, future).

As expected, most soils sampled (840) had an alkaline pH ranging from 7.1-8.2, while 45 had a neutral pH (7.0) and 117 had an acidic pH ranging from 4.5 – 6.9 (Table 2). The EC measurements were less than 1 dS/m for all samples; these values are consistent with highly-leached conditions in well-drained soils.

Nitrogen

Nitrogen was the limiting nutrient for most soils (Q. Wang, Personal Communication). Geographic Information Systems (GIS) map layers for Mirebalais and Cul-de-Sac watersheds were developed from the soil fertility analysis results by GIS specialists affiliated with the WINNER project. Figures 4 and 5 illustrate soil N content ranging from low (<10 ppm) to excessive (>30 ppm) for the Cul-de-Sac, Kenscoff, and Mirebalais/St. D'eau watersheds. When considering final N recommendation rates, the research team assigned the higher N fertilizer rates from the UF-IFAS' Vegetable Production Guide to the 234 sites with textures similar to Florida soils (sand, loamy sand, and sandy loam). The finer-textured soils that were similar to Oklahoma soils were assigned the N fertilizer rates developed by OSU (Table 2).

Phosphorus

For the five watershed regions, approximately 26% of soils (270 of 1047) had sufficient M-3 P concentrations ($\geq$ 32 mg/kg) while 19% of samples (202 of 1047) had M-3 P that were below method detection limits (Figure 6). Phosphorus fertilizer applications would be recommended for 62% of soil samples (Table 2).

Potassium

According to M-3 soil-test results, only 4.3% of soil samples (45/1047) were deficient in K (Figure 7). The rest of the samples had K concentrations greater than 125 mg/kg (excessive levels). This finding can be attributed to centuries of fertilization creating K build-up in soils. Due to fertilizer availability, the dominant fertilizer formulation currently used in Haiti is 12-12-20 (Wang, Personal Communication), which illustrates that Haitians are not following an efficient nutrient management program to increase crop yields or improve soil fertility (Table 2).

Grower Report

More than a year has passed since the original sampling and growers have undoubtedly changed crops with the seasons. For this reason we designed a flexible report format that can be utilized for a variety of crops through multiple growing seasons based on research-based soil-test interpretations and local crop expert recommendations (Appendix C). The individual grower reports with the resulting M-3 soil-test results and crop-specific fertilizer recommendations have room for additional comments by local extension agents and other specialists to further improve yields and land management practices. The resulting report system can aid in future funded soil research and contribute to a modern, competitive Haitian agriculture industry that utilizes the most current trends in research and development to help feed the nation and reduce land degradation.

The authors see a continued use of the resulting soil interpretations and specific crop recommendations in future crop rotations at each of the 1,047 sites; a soil-test needs to be done every two to three years in most cropping situations so that the soil analysis data from the initial test can be used for subsequent crops. There is value in creating individual reports containing grower information and soil-test data because it allows the grower the opportunity to grow any of the twenty-four specified crops for which soil-test interpretations and fertilizer recommendations were developed in this project. The report template should be distributed among local professional crop specialists so they can communicate with the growers from each of these soil-sample sites. Once the growers have identified the crops they plan to grow in future rotations, the most current soil test data and crop interpretations can be used to increase crop yields and vigor while conserving environmental resources. An increased yield translates to additional income or food for the growers; assisting Haitian growers to exceed subsistence farming levels provides an opportunity for economic and social development while making the entire food production process more sustainable with attendant environmental benefits.

CONCLUSIONS

This project resulted in the creation of a soil-analysis database within the 5 watershed regions (Gonaives, Archaie/Cabaret, Cul-de-Sac, Kenscoff, and Mirebalais/St. D'eau), crop-specific fertilizer recommendation rates for N, P, and K and corresponding grower reports summarizing the research results. The calibration information supplied by OSU, UF-IFAS, and Caribbean agriculture specialists should be used to improve fertility and crop yields of Haitian soils until on-site calibrated crop response trials are conducted. Through the results of the soil-test analysis, researchers discovered that there is a need to change the dominant fertilizer formulation currently used in Haiti. In future funded research efforts, Haiti needs a valid soil testing program to include M-3 calibrations and crop interpretations; site-specific calibration of soil-test research can lead to crop and fertilizer replicated research specific to the unique regions of Haiti. The results of the soil fertility analysis project and corresponding crop interpretations are the initial steps in a comprehensive nutrient and land management program that will increase crop yields and food availability at a local level, improve local economic output, and ultimately help assuage environmental degradation.

FIGURES AND TABLES

Figure 1. Five watersheds (Gonaives, Cabaret, Cul-de-Sac, Kenscoff, and Mirebalais) targeted for detailed soil fertility testing as part of the Watershed Initiative for Natural National Environmental Resources (WINNER) project.

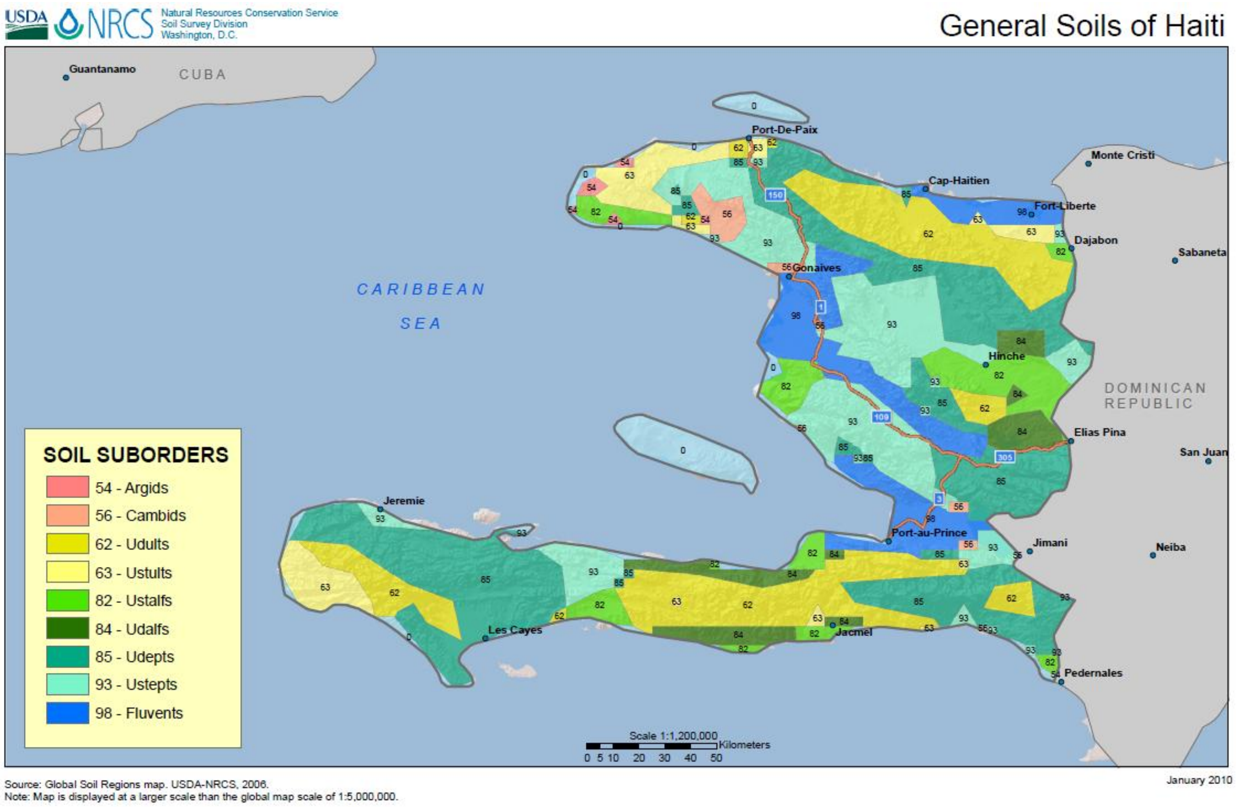

Figure 2. Distribution of dominant soil suborders within Haiti (USDA-NRCS, 2010A).

A.  B.  C. 

Figure 3. Detailed soil sampling procedure used for soil fertility as part of the Watershed Initiative for Natural National Environmental Resources (WINNER) project. Soils were excavated to a depth of 15 cm to create a slab face (A), soils were remove the soil with the blade of a shovel and the sides were cut away with a knife (B);. A 2.5-cm soil sample core was collected (C).

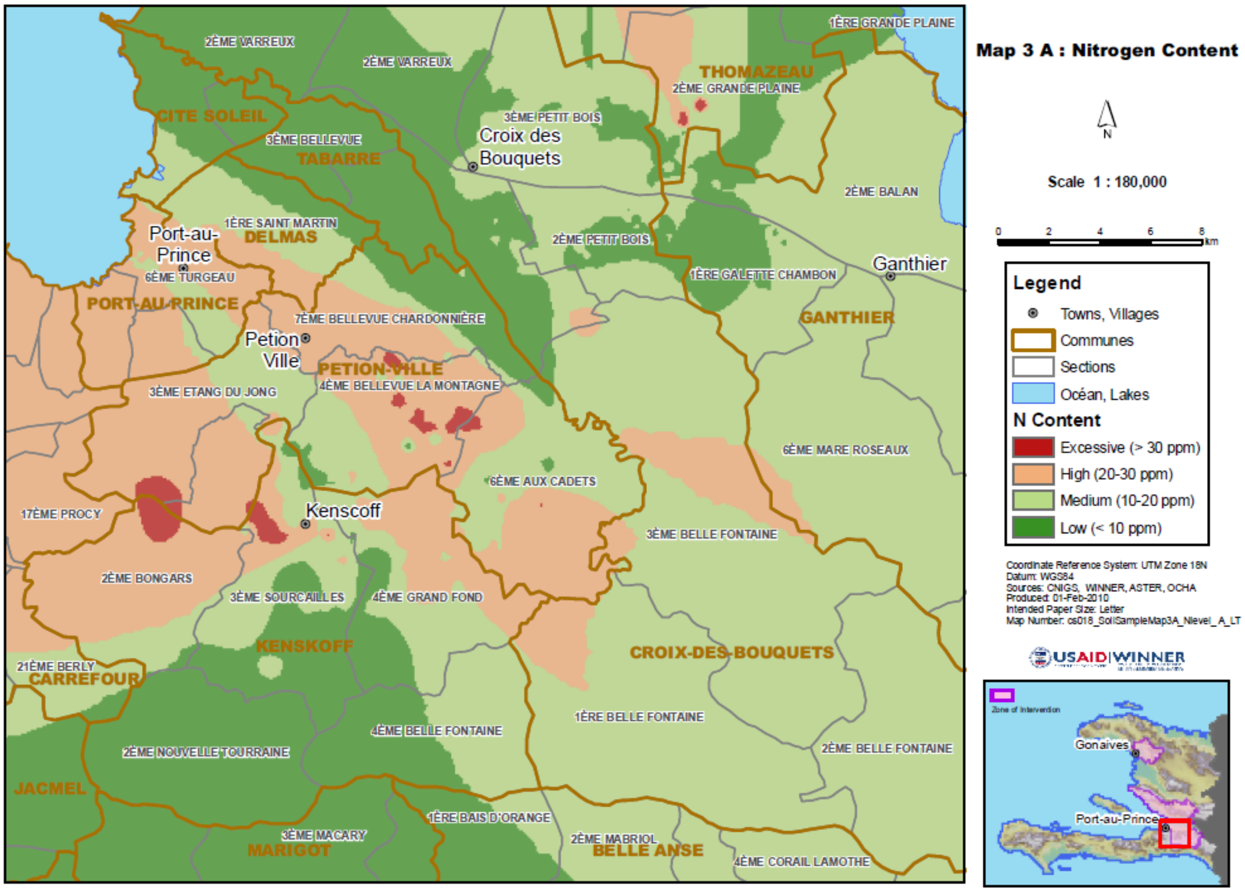

Figure 4: GIS interpolated map of soil nitrogen content from low (><10 ppm) to excessive (>30 ppm) derived from soil nutrient analysis results for the Cul-de-Sac and Kenscoff Watersheds as part of the Watershed Initiative for National Natural Environmental Resources (WINNER) project.

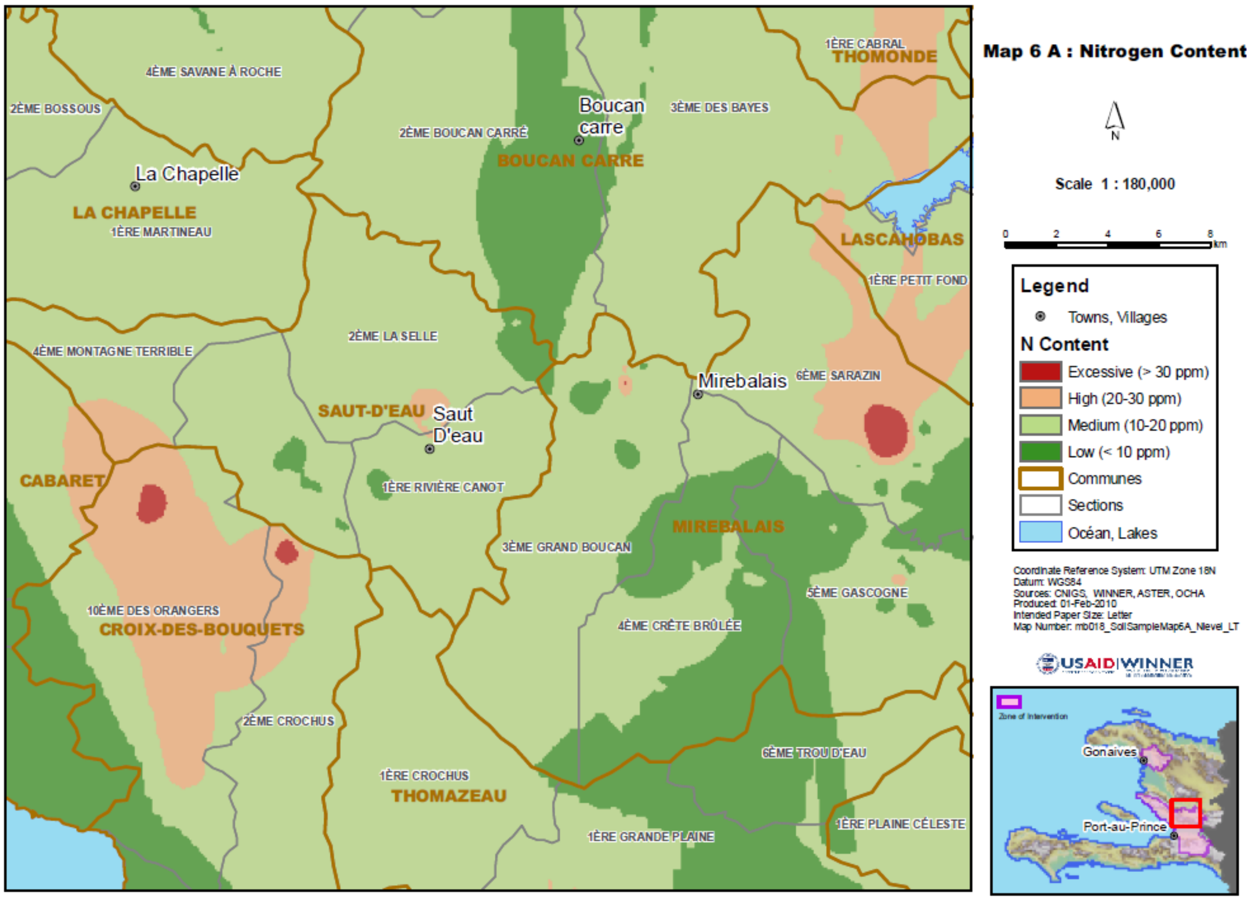

Figure 5: GIS interpolated map of soil nitrogen content from low (<10 ppm) to excessive (>30 ppm) derived from soil nutrient analysis results for the Mirebalais/St.D'eau watershed as part of the Watershed Initiative for National Natural Environmental Resources (WINNER) project.

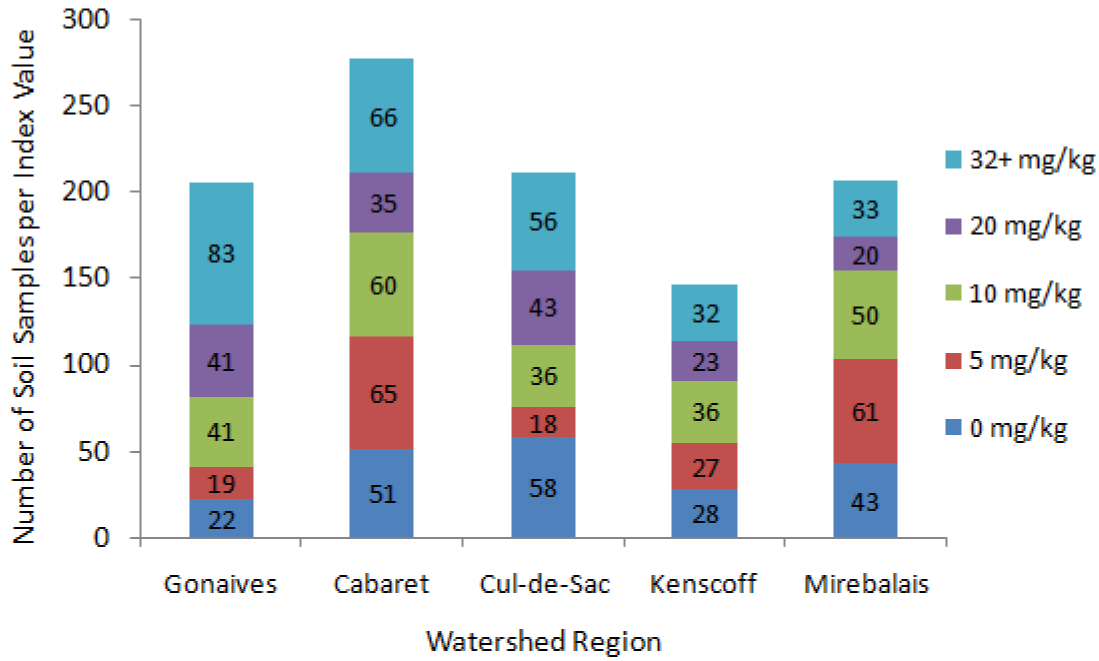

Figure 6: Mehlich-3 P soil-test values and ranges of 1,047 soil samples from Haiti listed by watershed region in the Watershed Initiative for National Natural Environmental Resources (WINNER) project.

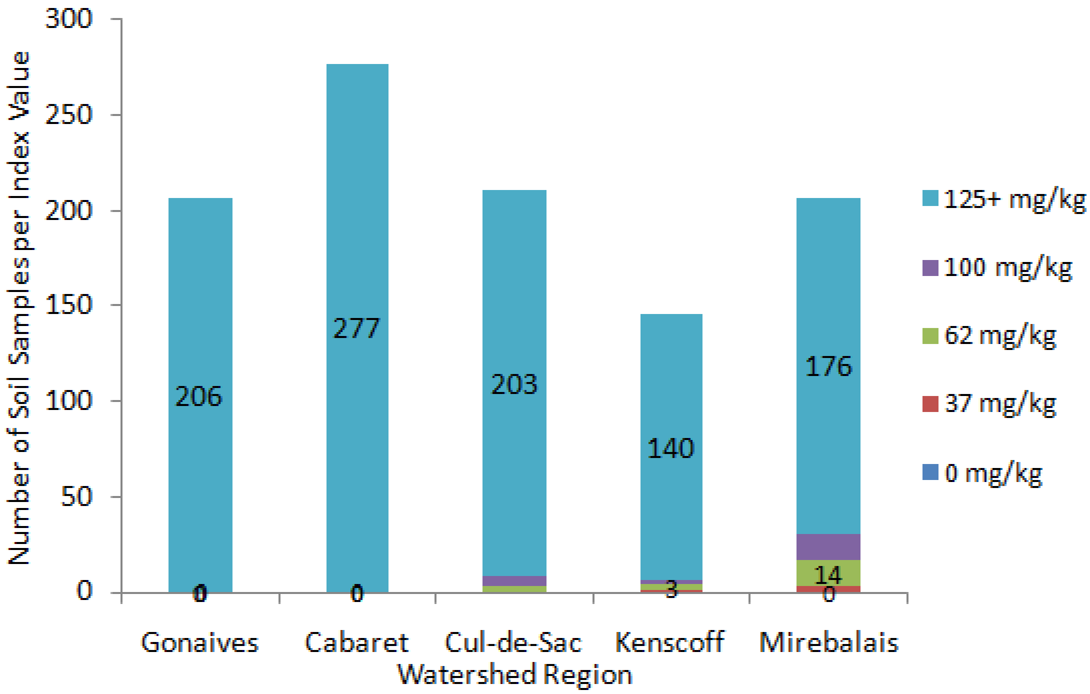

Figure 7: Mehlich-3 K soil-test values and ranges of 1,047 soil samples from Haiti listed by watershed region in the Watershed Initiative for National Natural Environmental Resources (WINNER) project.

TABLE 1. Principal crops and their distribution among 1,047 farm sites targeted for soil fertility testing as part of the Watershed Initiative for Natural National Environmental Resources (WINNER) project in Haiti.

Principal Crop		Number of Soil Samples Collected
Common Name	Scientific Name	
Banana	*Musa spp.*	356
Bean (red, black)	*Phaseolus vulgaris*	339
Corn	*Zea mays*	187
Sorghum	*Sorghum bicolor*	117
Sweet Potato	*Ipomoea batatas*	52
Water melon	*Citrulus lanatus*	52
Leek	*Allium ampeloprasum*	48
Potato	*Solanum tuberosum*	46
Lettuce	*Lactuca sativa*	42
Cabbage	*Brassica oleraceae*	40
Okra	*Abelmoschus esculentus*	30
Carrot	*Daucus carota ssp. sativa*	29
Sugar beet	*Beta vulgaris*	24
Rice	*Oryza sativa*	22
Cassava	*Manihot esculenta*	21
Spinach	*Spinacia oleracea*	21
Tomato	*Lycopersicon esculentum*	20
Pepper	*Capsicum spp.*	18
Eggplant	*Solanum melongena*	13
Sugar cane	*Saccharum officinarum*	11
Onion	*Allium spp.*	7
Yam	Dioscorea spp.	6
Peanut	*Arachis hypogaea*	3
Papaya	*Carica papaya*	2

TABLE 2. Statiscal analysis of soil-test results for 1,047 soil samples from the Watershed Initiative for National Natural Environmental Resources (WINNER) soil fertility project. The mean and median for pH, EC, N, P, and K for all soil samples and for the 5 individual watersheds in the Zones of Intervention.

Soil Nutrient		All Soil Samples	Cabaret	Cul-de-Sac	Gonaives	Kenscoff	Mirebalais
pH	mean	7.3	7.4	7.5	7.6	6.6	7.3
	median	7.4	7.4	7.5	7.7	7.1	7.3
EC	mean	430.4	400.1	429.5	630.1	374.4	312.9
us/cm	median	341.9	327.2	364.9	371.3	361.4	287.1
N	mean	0.124	0.098	0.109	0.1	0.179	0.161
mg/kg	median	0.103	0.092	0.092	0.092	0.163	0.125
P	mean	25.7	22.8	24.5	37.1	24.8	20.0
mg/kg	median	15.3	18.3	18.2	26.4	14.6	9.5
K	mean	506.4	592.4	444.3	706.8	431.4	308.5
mg/kg	median	415.7	502.9	350.2	672.2	374.9	248.9

APPENDICES

APPENDIX A: Principal Crop Interpretations Table

Appendix A. Mehlich-3 crop fertilizer interpretations for 24 principal (primary) crops as part of the Watershed Initiative for National Natural Environmental Resources (WINNER) project in Haiti. Reported in kg/ha.

		Banana	Bean	Cabbage (gabbage)	Carrot	Cassava (Manioc)	Corn	Egg Plant	Leek
N	OSU	45-90	67	156	156	45-90	98	89	107
kg/ha	UF			196	196		179	179	168
P	**0**	65-135	46	58	58	35-60	31	58	46
kg P/ha	**5**		38	48	48		23	48	38
	10		31	38	38		15	38	38
	20		17	21	21		8	21	0
	32+		0	0	0		0	0	0
K	**0**	132-270	89	111	111	65-135	89	111	89
kg K/ha	**37**		74	93	93		59	93	74
	62		59	74	74		44	74	74
	100		30	37	37		30	37	0
	125+		0	0	0		0	0	0

Appendix A continued. Mehlich-3 crop fertilizer interpretations for 24 principal crops in Haiti.

		Lettuce	Okra (gombo)	Onion	Papaya	Peanut	Pepper	Potato	Rice
N	OSU	107	71	134	65-90	13	89	179	20-110
kg/ha	UF	134	107	168			179	224	

P	**0**	58	58	58	140-170	31	58	46	50-100
kg P/ha	**5**	48	48	48		23	48	38	
	10	38	38	38		15	38	31	
	20	21	21	21		8	21	17	
	32+	0	0	0		0	0	0	

K	**0**	111	111	111	100-140	59	148	222	35-60
kg K/ha	**37**	93	93	93		44	115	185	
	62	74	74	74		30	89	148	
	100	37	37	37		22	37	74	
	125+	0	0	0		0	0	0	

Appendix A continued. Mehlich -3 crop fertilizer interpretations for 24 principal crops in Haiti.

		Sorghum	Spinach	Sugar beet	Sugar cane	Sweet potato	Tomato	Water melon	Yam (Ignam)
N	OSU	76	107	107	50-110	54	89	134	54
kg/ha	UF		80			67	179	168	
P	**0**	23	58	46	35-65	46	58	58	46
kg P/ha	**5**	19	48	38		38	48	48	38
	10	15	38	31		31	38	38	31
	20	8	21	17		17	21	19	17
	32+	0	0	0		0	0	0	0
K	**0**	74	111	89	90-135	89	167	111	89
kg K/ha	**37**	56	93	74		74	122	93	74
	62	37	74	59		59	89	74	59
	100	22	37	30		30	37	37	30
	125+	0	0	0		0	0	0	0

Sources: Oklahoma Cooperative Extension Service (OSU) PSS-2225 OSU Zhang, H. et al Soil Test Interpretations .

http://osufacts.okstate.edu/docushare/dsweb/Get/Document-1490/PSS-2225web.pdf

HLA-6036Soil Test Interpretations for Vegetable Crops Brandenberger, L. et al

http://osufacts.okstate.edu/docushare/dsweb/Get/Document-6620/HLA-6036web.pdf

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http://edis.ifas.ufl.edu/topic_hs_vegetable_production_guide_for_florida _(sp170)

Tropical fruits - Yudin, Richard. ryudin@ufl.edu

APPENDIX B: Grower Metadata Sheet

Numéro de l'échantillon	**Date**
Cultivateur	
Proprietaire	
Rendement : haut ( ) ; bas ( ) *Cochez la case correspondante*	
Localité ________________________________ ; **Section communale** ____________________ **Commune** ____________________________________ ; **Altitude** ___________________________ **Coordonnées: Latitude**______________________________ ; **Longitude** _______________________	
Culture actuelle/précedente -- Culture(s) principale(s) *(Indiquez les cultures principales)* **Cultures secondaires** *(Indiquez les cultures secondaires)*	
Culture planifiée *(Inscrivez toutes les cultures planifiees)* **- Culture(s) principale(s)** *(Indiquez les cultures principales)* **Cultures secondaires** *(Indiquez les cultures secondaires)*	
Commentaires	
Nom de l'enquêteur : _________________________ ; **Approuvé(e) par :** _____________________	

APPENDIX C: Final Grower Report

WATERSHED INITIATIVE FOR NATIONAL NATURAL ENVIRONMENTAL RESOURCES (WINNER)

Soil Analysis Results

Farmer: ETIENNE Hylisse   Geographical Sector: Cabaret   Sampling Date: 13/03/2010

Locality/Communale/Commune: Sous rigole (Thoman), 1st Boucassin, Arcahaie

Altitude/Latitude/Longitude: 188Ft 57,30 m 18° 47.020’ 072° 28.888’

Soil Test Results and Recommendations

Soil ID: CA0001   **pH: 7.3**   **EC: 265**   **Soil Texture: Sandy Clay**

Soil Nutrient Levels:

Total N	P	K	Ca	Mg	Zn	Mn	Cu	Fe	B	Mo
%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
0.055	25	364	5826	689	4.6	166.16	4.41	51.13	3.35	

Principal Crop Nutrient Needs:

Crop	N	P	K
	kg/ha	kg/ha	kg/ha

Additional Recommendations:

Sources: N, P, K- Oklahoma Cooperative Extension Service (OSU) PSS-2225 OSU Zhang, H. et al Soil Test Interpretations . http://osufacts.okstate.edu/docushare/dsweb/Get/Document-1490/PSS-2225web.pdf
HLA-6036Soil Test Interpretations for Vegetable Crops Brandenberger, L. et al http://osufacts.okstate.edu/docushare/dsweb/Get/Document-6620/HLA-6036web.pdf
Nitrogen –University of Florida Vegetable Production Guide. Olson,S.M. ed http://edis.ifas.ufl.edu/topic_hs_vegetable_production_guide_for_florida _(sp170)
Tropical fruits - Yudin, Richard. ryudin@ufl.edu

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