ABSTRACT

VILA RUIZ, CRISTINA PILAR. Assessment of the Potential for Vegetable Gardens in Elementary Schools Across a Tropical Urban Watershed in Puerto Rico. (Under the direction of Ted Shear, Elvia Meléndez-Ackerman, Mario Flores Mangual, and Sarah Warren)

School gardens provide environmental services and social benefits that can have a wide impact in communities and cities, while preparing future generations for more sustainable ways of living. However, in order for a school to create and sustain a vegetable garden, key social factors and adequate soil conditions must be in place. This project evaluated both social factors and soil conditions in the Rio Piedras watershed of San Juan, Puerto Rico. By conducting a survey of school principals, we identified the social factors that are considered opportunities and constraints to establishing and sustaining a school garden. By analyzing soils from the schoolyards, we determined the nutrient content, pH, CEC, organic matter, conductivity, texture, bulk density, and heavy metals (Cd, Cr, Pb) of soils sampled from the most suitable locations for vegetable gardens. A total of 20 school were visited within the Rio Piedras watershed. Eleven schools lacked success in sustaining a garden, while 7 schools had gardens at the time of the visit. The reason for garden failure included invasive species, disappearance of government initiatives, and lack of continuity by teachers or parents. Results from the survey reveal factors that will help in implementing and sustaining long-term vegetable gardens: (a) engagement of stakeholders, (b) sponsorship, (c) gardening skills and logistics, and (d) curriculum integration. Certain social conditions around the school gardens need to be improved to ensure the support and success of the gardens. Data on soil properties indicated that the soils are alkaline and that they have high Na, bulk density, mostly clayey or sandy texture, low CEC, low nutrient availability but heavy metal concentrations that are below U.S. EPA toxic standards. Not all soil physical and chemical soil properties are suitable to sustain vegetable gardens, so they will need to be managed. Results emphasize the need to study the potential of urban garden success ensuing a social-ecological perspective. It is hoped that the findings of this study will provide useful information that can inform the development of vegetable gardens and overall soil management at elementary schools in the Rio Piedras watershed.
Assessment of the potential for vegetable gardens in elementary schools across a tropical urban watershed in Puerto Rico

by
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BIOGRAPHY

Cristina P. Vila Ruiz was born and raised in San Juan, Puerto Rico. In 2012, Cristina graduated from University of Puerto Rico- Rio Piedras campus with a BS in Environmental Science. During my undergraduate career, I began working on the San Juan ULTRA and it was during this time that I discovered my interest in Urban studies. In the fall of 2013, Cristina enrolled in North Carolina State University’s Master of Science program in Natural Resources with Ecology Restoration as a technical option. This program presented her with a great opportunity to do research in the city of San Juan while taking classes in NC State and gave her the opening to connect with a brilliant and diverse group of forestry students and professionals in different scientific fields that was invaluable to her education and research.

Cristina will continue exploring ecological factors and transferring this knowledge to decision-making system to look for sustainable solutions for humankind. She hopes to use her knowledge and experience to cultivate sustainability and vitality in urban ecosystems.
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Introduction

One of the greatest worldwide challenges is to improve the sustainability of agriculture while reducing soil degradation (Godfray et al. 2010; Amundson et al. 2015). Urban agriculture has an enormous potential to alleviate food demands (Deelstra and Girardet 2000). Studies estimate that urban agriculture produces about 15–25% of the world’s food supply, indicating not only the importance of urban agriculture but also its potential to become a permanent feature of cities in the future (NRCS 2013; Orsini et al. 2013). However, this activity tends to concentrate more in developing countries than in industrialized countries (Martin et al. 2014). Martin et al. (2014) concluded that in the United Kingdom and the United States, only 6% of the food consumed was produced in urban areas, an amount that was limited by the available urban green space and the quality of urban soils. Despite the low percentage, urban agriculture in the United States has gained popularity among different social sectors in the last several decades (Pudup 2008). Since the 90s urban gardening has been practiced within community gardens, corporation gardens, and school gardens, and it can also be developed on patios, rooftops, and walls (Smit et al. 1996). Moreover, ground-based school gardens are receiving more attention from worldwide and United States governments because of their potential contribution to the wellbeing of communities and their environments (FAO 2010; Turner et al. 2014). School gardens are believed to be stepping-stones that can lead future generations to more sustainable ways of living (Joshi et al. 2008).

School gardens provide a wide range of lifestyle benefits, including nutrition, social connections, and environmental services. First, growing crops locally in city schools encourages people to have healthier lifestyles (Ozer 2007). Gardening decreases sedentary
behavior by increasing people’s daily activity and consumption of vegetables and fruits (Alaimo et al. 2008). A second benefit of school gardens is the connection that is fostered between people and their environments and other people (Blair 2009). Gardening improves the sense of community by developing people’s sense of ownership, fostering social interactions, and boosting the local economy (Armstrong 2000; Blair 2009; McClintock 2010). The third benefit of gardening is that it creates a positive impact on the environment by increasing green areas in the cities, creating ecological niches for pollinators, nurturing plant biodiversity, and protecting soil function (Deelstra and Girardet 2000; Edmondson et al. 2014). School gardens can also have other environmental benefits; for example, gardeners often reuse waste products for compost and sustainable food production, thereby reducing ecological footprints (McClintock 2010; Martin et al. 2014).

In addition to the personal, social, and environmental benefits of school vegetable gardens, they also offer garden-based learning to students. Through this learning strategy, the garden is used as a teaching tool that can be applied to any school subject material (e.g., science, mathematics, nutrition, and social studies) (Lawrence and Rayfield 2012). School gardens also provide a means for developing materials for other subjects, such as cooking classes and related agricultural activities. In these ways, the gardens connect children to the processes of food production (Desmond et al. 2004). Above all, school gardens have the potential to develop student morality and confidence, social skills, academic performance, and connection with nature (Joshi et al. 2008; Block et al. 2012; Williams and Dixon 2013).

School gardens have a long history in the United States and worldwide. In lower-income countries, vegetable gardens have been used for vocational agricultural training and
food production for both consumption and trade (FAO 2010). In wealthy nations, school gardens have been predominantly used as laboratories for science, as well as sites for environmental clubs and other subjects such as art and language (FAO 2010). In the United States, the first urban school garden was created in 1891 with the vision of educating children about the benefits of nature, encouraging low criminality, and cultivating political interest (Trelstad 1997). By year 1915, most schools had gardens, and they had documented success in teaching children to work with dignity, help the economy, and have patriotism, honesty, and love of nature (Trelstad 1997). For three decades, these gardens represented a vision of progressive education that encouraged social reform movements (Desmond et al. 2004). As interest in school gardens waned, they were replaced with “cleaner” schoolyards with grass and playgrounds (Trelstad 1997). By the 1960s and 1970s, schools gardens were motivated by the environmental movement (Desmond et al. 2004). Presently, in the twenty-first century, the development of school gardens is motivated by the need for a more sustainable society, food security, environmental protection, and better nutrition (Wortman and Lovell 2013). However, only 27% of elementary schools in the United States currently have gardening programs (Turner et al. 2014).

Previous studies have demonstrated that the best practice for implementing and sustaining a vegetable garden is to have adequate program support. Program support includes school staff, community volunteers, parents, garden coordinators, and district staff (Joshi et al. 2008; Hazzard et al. 2011; Yu 2012; Clabeaux 2013). In addition to institutional factors that must be in place for school gardens to be successful, soil conditions must also meet necessary physical and chemical standards. When choosing a site, it is necessary to keep in mind that soil
nutrients, water availability, pollutants, and soil type, among other factors, affect plant productivity, and thus garden success. Urban soils are often described as highly impacted and disturbed soils with low fertility (Craul 1994; Pouyat et al. 2010). Soils in cities have generalized degraded characteristics of massive structure, high pH values, coarse texture, and high bulk density (Craul 1994; Pickett et al. 2008; Vodyanitskii 2015; Yang and Zhang 2015). Because of constant human influence (e.g., mixing, filling, and contamination), urban soils are difficult to describe, and most have not been surveyed or classified into categories.

Urban soils provide ecosystem services that are essential for a city’s ecosystem (Shuster et al. 2014). For example, they moderate the hydrology cycle by absorbing water (which reduces runoff), and they store and filter water. In addition, urban soils have carbon-storage capacity and can reduce pollutant mobility and availability (Pouyat et al. 2010; Wortman and Lovell 2013). In urban areas, one way to conserve and improve soils is by having gardens or green infrastructure; that through sustainable management, enhance soil functionality (Edmondson et al. 2014). A study in the United Kingdom determined that small-scale urban food production can maintain a higher soil quality than conventional agriculture (Edmondson et al. 2014).

In 1932, the agriculture education in school movement began in Puerto Rico. This program was promoted by Law num. 28 1931, which facilitated the creation of rural school garden projects. This program later developed into the Vocational Technical Education and High Skills Department of Education (18 LPRA § 501 et seq.) (García-Cancio 2009). Most of the current efforts for creating school gardens projects in Puerto Rico have been directed to rural schools, with much less emphasis on gardening in urban schools. One school system
where school gardens are being re-introduced is in the Rio Piedras watershed in Puerto Rico. This school system is largely contained within the municipality of San Juan (capital city of Puerto Rico), and within the largest watershed in Puerto Rico.

Puerto Rico has food insecurity and food desert issues (Comas-Pagan 2009; El Nuevo Día 2014). Food insecurity is defined by the U.S. Department of Agriculture as “limited or uncertain availability of nutritionally adequate and safe food” (Anderson 1990). Puerto Rico’s food insecurity is characterized by high food prices, low food variety, and low availability of quality fresh food. There is a high level of poverty, with 42% of the population is below poverty level (less than $18,900 per year for a family of three) and without sufficient to nutritious food (Quintero 2013; HUD 2015). A study by Serrano Torres et al. (2014) documented that none of the children from elementary school in San Juan had a good quality diet; for example, 55% of the children had with poor quality diets and the other 45% needed improvements in their diets.

Puerto Ricans are concerned about numerous factors that could interfere with food supply: global climate change, reduction of terrain on the island that is devoted to agriculture, natural disaster, and free trade agreements, among others (Crespo Bellido, 2014). Through school gardens, students may be offered opportunities to learn the important agricultural skills that can promote self-reliant communities and adaptive capacity to environmental change. Also, school gardening will provide knowledge to support local decision-making and strategies aimed at addressing school vegetable garden initiatives and urban soils quality.

The purpose of this is study is develop a complete perspective of the potential for gardens in the in elementary schools of San Juan, Puerto Rico. Because urban environments are human-dominated systems, school vegetable gardens have social and soils systems that
should be studied with an interdisciplinary approach. For this reason, this study describes both the social preferences of school principals towards vegetable gardens, and also soil quality at the schools.

**Study Objectives**

The purpose of the study was to determine the feasibility of creating and sustaining vegetable gardens in the elementary public schools of the Rio Piedras watershed. To pursue this aim, I evaluated the social preference of the administration of the school, as well as the physical and chemical properties of the schoolyard soils. The objective of the study was to investigate the following questions:

1. What do the school principals consider to be the opportunities and constraints for the development of school vegetable gardens?
2. Do the soils in schoolyards have chemical and physical properties suitable for sustainable vegetable gardening?

**Methods**

**Study Site**

For this study, I selected 20 public elementary (kindergarten through grade six) schools within San Juan, the capital of Puerto Rico. The schools lie within the Rio Piedras Watershed (Figure 1), which has been the focus of many studies on urban vulnerability and sustainability issues within tropical systems (Munoz-Ericson et al., 2014a, b). The Puerto Rico Department of Education lists a total of 133 public schools, 79 of which are elementary schools servicing 22,364 students within the San Juan municipality (Public School Review 2015). The total number of active garden programs across the island was 30. Focal schools were selected for
this study based on the principal availability, their amount of green space, and their distribution across different soil types within the watershed.

The Rio Piedras watershed presents a land cover gradient that ranges from high-density, urban development near the coast (lower watershed region) to forest cover around the headwaters (higher watershed region; Ramos-González et al. 2014). The green cover of San Juan is 42%, while the impervious surface is 55%, for a per capita green space of 122.2 m²/inhabitant (Ramos-González 2014). The vegetation associations of the Rio Piedras watershed falls within a subtropical moist forest classification (Ewel and Whitmore 1973) based on the Holdridge life zone system (1967). Mean annual rainfall in the watershed ranges from 1509 mm on the coast to 1509–1755 mm at higher elevations (238 mamsl). Mean annual temperature across the watershed is 78.3°F (Lugo et al. 2011).

Geological formations within the watershed are derived from volcaniclastic rocks in the upper area of the watershed, which cover >50% of the area; limestone and alluvium in the middle; and artificial fill in the lower area (Webb and Gómez-Gómez 1998; Lugo et al. 2011). The watershed presents a land-cover gradient that ranges from high-density urban development near the coast to forest cover around the headwaters (Ramos-González et al. 2014). The green cover of San Juan is 42%, and the impervious surface is 55%, for a per capita green space of 122.2 m²/inhabitant.

Natural soils in the Rio Piedras watershed are predominantly Ultisols (Boccheciam 1978). However, about half of the soils (52.5%), mostly located in the lower urban part of the watershed, do not have soil series descriptive information in the Web Soil Survey. Based on the Soil Web Survey (Soil Survey Staff, 2013), 27% of the land cover are soils classifieds as
Soil Not Surveyed and 35% as Urban land-Vega Alta; this last one consisted of 75% urban land. Soil Not Survey and Urban land classifications have no information about soils physical and chemical characteristics. Other soil series that have high land cover are Humatas (Very-fine, parasesquic, isohyperthermic Typic Haplohumults) (12.8% of the soil cover), Vega Alta (Fine, parasesquic, isohyperthermic Typic Hapludults) (8%), and Naranjito (Fine, mixed, semiactive, isohyperthermic Typic Haplohumults) (8%), corresponding to Ultisols soil order. The latter soil series are mostly located in the upper watershed and have in common that had a clay texture, are well drained, and moderately deep or deep from the bedrock (Bocchecciamp 1978).

**Soil Sampling**

For all 20 schools, I carried out a soil profile description and classification, and took soil samples to carry out chemical and physical analyses. The schools whose soils I studied were located at different elevations across the Rio Piedras watershed: 14 of the schools were located in the lower area (0–50m of elevation), four were located in the middle (51–100m of elevation), and two were considered as being in the upper watershed (101–238m of elevation) (Figure 1).

Soil were described at locations deemed to be most suitable for a vegetable garden by a director or teacher in charge. Soil profile descriptions were made from soil cores extracted with a hand auger from the topsoil to a depth of 150 cm whenever possible (from 50–150 cm). Soil diagnostic horizons were identified in the field, and texture, color, structure, consistency, and concentrations were identified in each horizon. Using ArcGIS software these profiles
descriptions were mapped and compared in respect with elevation, previous soil type and parent material (Soil Survey Staff, 2013; USGS, 2015).

Chemical and physical properties were described from randomly selected samples from the topsoil (depth of 0–15 cm) with a soil probe and replicated four times to account for spatial variation. The following properties were determined: nutrient concentrations (P, K, Ca, Na, Mg, Al, S-SO4), heavy metal concentrations (Cd, Cr, Pb), organic matter, pH, Cation Exchange Capacity (CEC), electrical conductivity, and texture. All soil chemical samples were analyzed at the Central Analytical Laboratory of the University of Puerto Rico-Mayaguez Campus at the Rio Piedras Agricultural Experimental Station. Soil pH was determined using 1:2 soil-to-water mixtures using a pH meter. Exchangeable cations (Ca, Mg, K, and Na) were analyzed using a modification of the ammonium acetate method for the extractable/exchangeable fraction. Extractable P was determined by the Olsen P method. The S-SO4 was determined by flow injection analysis. Heavy metals and Al were determined by the EPA Method 3050. The percentage of organic matter (OM) was determined using a modification of the Walkley-Black Method, which was based on the oxidation of OM in soil by dichromate ions (Sparks et al. 1996). Sodium, Na, was used to estimate if soils contain sufficient exchangeable sodium to affect crops by calculating exchangeable sodium percentage (ESP) (Abrol et al. 1988). Bulk density was determined with the cylindrical core method (Arshad et al. 1996). Soil porosity percentage was calculated from bulk density, assuming that the particle density was 2.65 Mg/m³ (Brady 2010).

Soil nutrient data are presented as the cumulative relative frequencies within the soil test. These cumulative frequencies were compared with indices for five crops (cantaloupe,
cucumber, eggplant, onion, tomato) for Puerto Rico developed by Muñiz-Torres (1992). These crops are vegetables that were selected based on their economic importance, ease of harvest, and adaptation to a tropical climate (Muñiz-Torres 1992).

**Interviews**

Qualitative and quantitative information was collected using open-ended interviews with the principals of the schools (Strauss 1987; Tashakkori and Teddlie 1998). The survey was designed in the summer 2014 and approved by the North Carolina State University Institutional Review Board (IRB#: 4156). Interviews started in August 2014 and were conducted in person with a principal of the school to identify factors that facilitated initiatives of vegetable gardening and agriculture programs in elementary schools (Appendix 1). Each interview was recorded with the consent of the interviewee, and then transcribed, coded, and analyzed. The interviews were analyzed using a mixed-methods approach in order to (i) quantify the number of gardens; (ii) determine the causes for garden success (or failure), according to the respondents; (iii) quantify which factors were perceived as opportunities and constraints for the development of gardening; and (iv) understand the school principals’ perspectives on school gardens. We also evaluated other factors that might affect gardening at school, like environmental student clubs, number of people interested, economic status of student, and soil fertility.

**Statistical Analysis**

Descriptive variables were calculated for soil physical and chemical parameters and schools’ social data using JMP (JMP version 11.0, SAS Institute Inc. 2013). We used one sample T-tests to determine whether soil nutrient concentration results were significantly
different than recommended soil fertility values for Puerto Rico, and we used multivariate analyses of variance (MANOVA) to determine whether there were significant relationships between schools with a garden and those without in terms of soil chemical and physical parameters (JMP version 11.0, SAS Institute Inc., 2013). We used Nonmetric Multidimensional Scaling (NMS) to explore and summarize the relationships among soil chemical and physical properties within school social data (income and number of student enrollment) (PCORD version 5.33). For this analysis, soil data were transformed using a general relativization to account for differences in soil data variation.

Qualitative responses to the interviews were coded with Microsoft Excel software (Microsoft Office Professional, 2013). For each question, principal responses were entered into a cell and assigned a factor, which summarized the most important topic within the answers. The next step was to group the factors into categories in order to summarize which factors were perceived as opportunities or constraints for school gardens. Opportunity and constraint factors were grouped into six major categories: Engagement, Logistics, Funding, Ecological conditions, Environmental awareness and Security/Vandalism, and Other (Table 5). Statistical descriptions were made using frequency distribution tables.

Results

Social characteristics of Schools

Elementary schools of the Rio Piedras watershed are mostly low income student with a mean of 80% and the schools have a mean of 261 students (Table 1). There was no correlation between enrollment size and the presence of gardens ($t (18) = 0.71, p = 0.50$). Most students
were from low-income families. Similarly, there was no observable connection between income and gardens ($t(18) = -1.04, p = 0.32$) (Table 1).

Nineteen of the 20 schools had teachers, employees, or parents interested in the development of a garden (Q 3). Despite this prevalent interest, only seven schools had gardens at the time of visit (Q 2). Among the seven principals of these schools, four of them suggested that garden success was motivated by support and engagement within the school community and among parents. At the three other schools with gardens, non-profit organizations were both coordinators and sponsors of the gardens. For five of the seven schools with gardens, the principal indicated that no budget was available for a garden. Instead, gardens at these schools were funded through fundraising activities and/or donations of materials (Q 5).

Of the thirteen schools without gardens, 11 had vegetable gardens in the past, and two never had a garden as far as the administrators know. The loss of gardens in these eleven schools was attributed to a range of problems, from invasive species to the disappearance of government initiatives. For example, four of these schools were part of a government initiative, Ideas Verdes (Green Ideas) that was designed to train and guide elementary school teachers and students in environmental conservation by creating ecological spaces in schools. This initiative only lasted for one year, after which most gardens stopped receiving attention and care. Another four schools reported lack of continuity by teachers or parents, either because of the hard work necessary to maintain the garden, or because a teacher in charge left the school. The other three schools had difficulties with environmental factors such as the location without sun or really dry soils and the presence of the green iguana (*Iguana iguana*), an invasive species that consumes food crops. Others reasons cited for failure of the gardens were high
maintenance requirements, over-worked teachers, abiotic and other environmental limitations, and lack of gardening skills.

Factors that principals cited as opportunities and constraints on the development of vegetable gardens (Q 7–8) are listed in Table 2 by order of frequency. There were 27 factors mentioned as opportunities and 24 factors mentioned as constraints. These factors concerned ecological conditions, engagement, environmental awareness, funding, logistic, security/vandalism, and others. The two most common opportunity factors were engagement of faculty and students (mentioned by 50% or more of the principals) and support of external sponsor (referring to assistance from sources like the community, non-profit organizations, and boy and girl scouts). The fourth most-mentioned opportunity factor was awareness, which is related to the importance of agriculture, food security, and environmental value, among others. At the same frequency as awareness, participants cited engagement of administration and parents. These results indicated that a major opportunity for the establishment of school vegetable gardens was school community engagement (Figure 2A).

Among the responses to the question about constraints to the establishment of school gardens, the most common responses were lack of funding (mentioned by 55% of the school principals), followed by terrain limitations, lack of awareness, and vandalism (Figure 2B) (principal refers to terrain limitation as unfavorable characteristics like for example uneven and steep soils, rocks, erosion, and many tree roots). Lack of awareness was the third most frequent response; this result seems to indicate the need for education and orientation for the people regarding the benefits of having a garden and protecting it. Another concern brought up by school principals was the security of the gardens. Five principals worried that the crops
would be stolen. The fifth factor cited by the principals was the lack of information among those in the school community about how to grow a garden. Some school communities had the desire to establish gardens but failed in the execution, making the experience frustrating and discouraging.

All principals strongly agreed that agricultural activities are important in a school community (Q 9–Q11). Some of the school principals affirmed that there was a social necessity for gardening activities, which could address problems of nutrition, environmental awareness, and economics. The principals talked of the need to develop their students’ palates so that they would learn to enjoy the different tastes of garden vegetables. Principals also wanted to develop the children’s consciences about nature and what it provides. Finally, the principals were concerned about the high cost of food in Puerto Rico and the lack of agricultural opportunities on the island. All the principals stated that agriculture activities could be incorporated into science classes, while more than of 50% of the principals said that they could be incorporated into all classes (social studies, physical education, mathematics, Spanish, and English), and 75% indicated that agriculture should be taught from kindergarten through high school.

**School Soil Characteristics and Fertility**

The soil profiles were grouped into four different types by texture, color, and possible aquic condition (Appendix 2). Group 1 consists mostly of soils with clay soil texture through more than 35 inches of the soil depth, and color ranged from red (2.5 YR 5/6) to dark brown (7.5YR 3/3). Group 2 are soils with sandy texture through more than 25 inches of depth and a yellow color (10YR 4/5). Group 3 are soils with indicators of reduction conditions; they have chroma of 2 or less in layers within 30 inches of the surface, indicating drainage problems.
Finally, Group 4 consists of soils with a shallow profile with an underlying restrictive layer, usually composed of rocks and other hard materials (Figure 3). Soil profiles descriptions and classification are provided in Appendix 2.

Limited information is available about soils in the Rio Piedras watershed. Half of the 20 schools were situated on soils that had not been surveyed, and the other 10 schools were located across three different soil series (Soil Survey Staff, 2013): (a) seven on Urban land (Vega Alta series (Fine, parasquic, isohyperthermic Typic Hapludults), composed 25% of Vega Alta soil series and 75% of Urban); (b) two school with Naranjito silty clay loam (Fine, mixed, semiactive, isohyperthermic Typic Haplohumults), and (c) one school with Humatas clay (Very-fine, parasesquic, isohyperthermic Typic Haplohumults).

Soil chemical and physical properties varied in terms of the optimal range for vegetable gardens across the Rio Piedras watershed (Table 3). There were few differences in the physical and chemical properties of the soils across the watershed; for the majority of these parameters, the coefficient of variation was lower than 40%. Only four properties had high coefficient of variation: S-SO\(_4\) (200%), P (116%), K (80%), and Pb (71.3%).

Across the twenty school sites, I identified five different soil textures, ranging from very fine to medium particle size. The recommended soil texture for vegetables is loam, consisting of 7 to 27% clay, 28 to 50% silt, and less than 52% sand (Brady and Weil 2010; EPA 2012). Two schools fell within loam, while another five were close to the loam classification. The remaining 13 school sites had clay or sandy clay loam textures. Bulk densities were compared to the ideal bulk densities for plant growth among different soil textures (Arshad et al. 1996). Five schools with loam and sandy clay loam had bulk densities
lower than the ideal range for plant growth (Table 4). At the other 15 schools with clay, clay
loam, and sandy clay textures, bulk densities were higher than the ideals for plant growth (BD
< 1.40 g/cm³) but lower than the value for root growth restriction (BD > 1.75) (Table 4). School
yards had a mean soil porosity of 47% and a range between 30-53%. The ideal pore space is
50% of the soil volume, which is close to the mean value for the schoolyard soils (Brady and
Weil 2010).

In general, soil chemical properties of schools that are optimal for vegetable gardens
are electrical conductivity, OM, and S-SO₄ (Table 5). No soil had an electrical conductivity
that exceeded the maximum recommended level (1,200 µS/cm) (Havlin et al. 2013). There
were three schools where soils had less than the recommended 2% OM (Muñiz-Torres 1992).
For S-SO₄, only two schools fell out of the optimum range of 2–20 mg/gm (Muñiz-Torres

Only five schools had soils with pH in the desired range for vegetable gardening (pH 5.5-
7.3) (Muñiz-Torres 1992). High pH is typical of humid urban regions where limestone gravel
from construction increases the soil pH (Pavao-Zuckerman 2008; Soil Survey Staff 2013). Soil
pH affects nutrient availability, which can be ameliorated by adding sphagnum peat, elemental
sulfur, or other acidic materials (Havlin et al. 2013).

All soils were deficient in K, P, Ca, and Mg. Soils with the highest concentration of K
still contained seven times less than the recommended value. Low available P is common in
highly weathered soils such as Oxisols and Ultisols because it tends to precipitate (Havlin et
al. 2013). All of the soils were below the levels of Ca recommended (600 mg/kg) for vegetable
gardening (Muñiz-Torres 1992). At only one school was magnesium optimal in the soil (65
mg/kg Mg). The average exchangeable sodium percentage (ESP) of all schools was 14%, which is below the level considered to have adverse effects on plants (ESP > 15%). However, there were 7 schools that had low to moderate sodic soils (15% > ESP> 30%) (Abrol et al. 1988).

Concentrations of the metals Pb, Cd, and Cr were below the limits of concern of the U.S. EPA, at 400mg/kg, 70 mg/kg, and 230 mg/kg, respectively (U.S. EPA, 2002). None of the schools had soils that exceeded EPA limits for heavy metals. Aluminum was detected at only one school. In that case, it was detected in strongly acidic soils where it was likely to affect plant root growth (Wright 1989).

We did not find any indication of social factors influencing schools’ soil parameters. MANOVA results indicated that schools with vegetable gardens did not have different soil chemical and physical properties than those without gardens (MANOVA F_{2, 17} =1.0, p = 0.6). Results form NMS did not reveal any clustering of schools or any relationships between schools and soil properties (Figure 4). No schools were observed to have any social or spatial attributes that influenced the chemical and physical properties of the soils.

**Discussion**

This study investigated key social practices and soil conditions that are necessary to the implementation and sustaining of vegetable gardens in schoolyards across the Rio Piedras watershed. In this discussion, we point out the key findings of our survey, highlighting school administration opportunities and reasons for vegetable garden success. These findings are compared with those of similar studies conducted at elementary schools across the United States and worldwide. This study found that the soils’ chemical and physical properties did not
meet the minimum requirements for vegetable growth. Therefore, in order to address this problem, we compare these soil properties with those of other urban soils around the world, and we identify how the properties of the RPWS soils can be ameliorated.

A. Social Preference of School Administration

Studies about the sustainability of school gardens have been conducted worldwide, mostly in California (Clabeaux 2013; Azuma et al. 2001; Ozer 2007; Hazzard et al. 2011). As compared with one study made in Los Angeles (52%) (Azuma et al. 2001), the percentage of school with gardens in the Rio Piedras watershed was low (35%). However, these schools have in common two key social factors that contribute to their success with gardens: most importantly, the support and engagement of a leader who will guide the garden, and secondarily, partnerships with non-profit organizations (Azuma et al. 2001). This finding suggests that leadership and partnerships can contribute greatly to the long-term success of school gardens. When school principals were asked about the factors that facilitated the establishment of a garden, they too cited engagement of school community (e.g., faculty, administration, students, and parents) as the most important factor.

The percentage of schools that no longer had a garden in Rio Piedras watershed (55%) was high as compared with schools in Los Angeles (14%) (Azuma et al. 2001) and nationwide (10%) (Yu 2012). Studies conducted in Los Angeles and on a nationwide scale report similar reasons for the discontinuation of gardens: funding (42%); staffing changes (42%); and the maintenance burden on teachers (31%) (Yu 2012; Azuma et al. 2001). The reasons for discontinuing gardens in the Rio Piedras watershed were similar to the schools in these previous studies; with the main factors indicated being teacher overload and staff turnover.
The ending of government initiatives was another reason indicated in our study and was related to isolated initiatives throughout the island. Some of these were run by the local government (e.g., Verde Esperanza Educational Program, Ideas Verdes environmental education program, Siembra Vida Initiative of the First Lady of Puerto Rico), some by non-profit organizations (Volunteers from Fideicomiso de Conservación de Puerto Rico assist with the Biocomiso garden initiatives), others by Federal organizations (EPA-Urban Waters Small Grants), and still others by highly motivated schools (García-Cancio 2009). These initiatives have provided teachers, students, and sometimes the surrounding communities with information and materials promoting the importance of preserving green spaces and increasing food security through the cultivation of vegetable gardens. The duration of these initiatives is usually one year, and when the end date arrives, the schools are left with no support to keep managing the gardens. A last reason mentioned as a limiting factor for the development of gardens was the presence of invasive species. This factor is specifically related to the presence of the Green Iguana (Iguana iguana) on the island with few predators and competitors, the population of this invasive reptile has expanded considerably on the island, making it severe agricultural pest (López-Torres et al. 2012)

Although school principals did not perceive lack of funding as a reason for ending their gardens, they did perceive it as a major constraint to maintaining them. Similarly, Yu (2012) addressed the question, “What factors limit the establishment of school gardens?” She found that lack of funding is a major constraint. In our study, one principal of a school with a garden indicated, “The school has its own funds, but [they are] being used on other things. The school has other types of needs, and before having a garden, the school priorities are paper, ink, and
other school materials”. The reality is that school gardens are not seen as central to the school operation; instead, they are viewed as supplemental educational resources (Azuma et al. 2001; Joshi et al. 2008). No government institution, school district, or local government has normally financed or provided long-term support to school garden programs, making it difficult for these programs to develop, as their leaders always have to keep looking for funding. Another factor mentioned by school principals of the Rio Piedras watershed was awareness. To explain awareness one principal stated: “The effort of constructing a garden will have to go along with orientation to students, community, teachers, employees, parents, and non-teaching employees. This way we can protect the garden and educate the people on the importance of food.”

The comparison of these studies demonstrates that the factors associated with implementing and sustaining school gardens are common across different nations, states, and cultures (Azuma et al. 2001; Joshi et al. 2008; Hazzard et al. 2011; Yu 2012). The factors that our study highlights are (a) engagement of various stakeholders, (b) sponsorship, (c) gardening skills and logistics, and (d) curriculum integration (Hazzard et al. 2011; Yu 2012). Engagement of stakeholders is defined as the committed involvement of at least three committed persons within the following groups: administration, teachers, parents, or volunteers (Hazzard et al 2011). The majority of the sponsors and funding come from fundraising, non-profit organizations, and non-government grants, with little funding coming from government grants (Clabeaux 2013). Gardening skills and logistics include setting goals for the garden, planning the gardening process, and establishing a committee to manage the garden over time. These actions are imperative, and ignoring them can lead to discouragement or even failure. Finally,
integrating gardening into the school curriculum can assure that the school garden that is built can benefit everyone.

**B. School Soil Characteristics and Fertility Compared with Other Urban Soils**

The soils in the school yards had been completely altered and often mixed with other type of soils. There were only 3 schools with soil that had been mapped by the Soil Survey. These soils - Naranjito and Humatas - characteristically have clay textures, red colors, and low pH (Soil Survey Staff 2013); but in the schoolyards instead the soils were mostly sand, with yellow color and slightly alkaline pH was slightly alkaline. Soils mapping has relied on landscape and geological data, without anthropogenic data that reflect human disturbance, reducing their accuracy and usefulness in urban environments (Shuster et al. 2011).

The physical and chemical soil properties of the Rio Piedras watershed schoolyards are similar to those described in other studies of urban soils (Table 6). Bulk density, pH, OM, and heavy metal concentrations all fall within the range of other urban soils worldwide (Short et al. 1986; Ruiz-Cortés et al. 2005; Pouyat et al. 2007; Tume et al. 2007; Hagan et al. 2012). High bulk density (1.0-1.7 g/cm$^3$ urban soils, 1.4 g/cm$^3$ our results) is the most serious and common soil degradation in urban areas (Yang and Zhang 2015). Under this level of density, soils’ potential to developed root growth is reduced, as well as their ability to infiltrate and store water, diffuse gases (e.g., O$_2$ or CO$_2$), and foster the activity of soil organisms (Yang and Zhang 2015). However, mean soil porosity was within the ranges of optimal air and water space (40-60%) for a well-granulated medium to fine texture soil (Brady 2005).

Another common characteristic of urban soils is high pH (6.2–8.7 urban soils, 7.5 in our schoolyard soils), which is attributed to additions of concrete, cement, and plaster (Scheyer
and Hipple 2005; Pouyat et al. 2007; Short et al. 1986). Finally, studies have shown that high OM is common in cities because of high organic pollutants, decelerating mineralization of plant residue due to heavy metals, and high vegetation productivity caused by elevated temperatures, high carbon dioxide, and fertility inputs (Vodyanitskii 2015). Long-term climatological data of 40 years comparing temperature trends in urban and natural or rural areas suggest that San Juan has developed a marked urban heat island effect has (Velazquez-Lozada 2006).

Although heavy metal levels are below EPA-recommended maximum concentrations, there has been some inconsistency about the maximum levels of heavy metals that are acceptable for gardening, for growing consumable produce crops, and for children’s exposure (Gorospe 2012; Ruiz-Cortes et al. 2005). Children’s exposure to lead is a major public concern because lead is a neurotoxin, and its intestinal absorption is approximately five times greater in children than adults (Clark et al. 2008). Official guidelines from government agencies of several other countries disagree on what levels of various heavy metal concentrations are safe for gardening (Ruiz-Cortes et al. 2005). Although 400 ppm of lead in soil is generally considered a protective screening level for residential soils, this standard may not be suitable for children (Gorospe 2012, EPA 2014). California’s Human Health Screening Level promotes a safe concentration level of 80 ppm based on the exposure through “incidental soil ingestion, dermal contact, and inhalation of vapors or dust,” for children (Gorospe 2012). According to the EPA, the low-risk concentration of lead in soil is less than 100 (EPA 2014). Lead concentrations from 100 to 400 pose potential risks, and thus necessitate following specific recommendations for gardening practice and plant choice. In our study, only one school had
levels higher than 100 ppm (155 ppm Pb). In the urban soils studied, trace metals were likely to be largely immobilized at the soil particle surface because of high pH or organic matter content (Ge et al. 2000).

Calcium, Na, CEC, and texture differed among the Rio Piedras watershed soils. Normally, urban soils have high levels of charge ions (Ca, K, Mg, and P), as well as high sand and low clay percentage textures (Pickett et al. 2008). However, the Rio Piedras watershed schoolyards did not conform to this norm. Instead, the soils had high clay content with low CEC, which is characteristic of soils with kaolinite clay mineral, common in wet tropical regions where nutrients are leached out by abundant rain (Juo and Franzluebbers 2003). The CEC indicates that these soils do not have the potential to hold onto nutrients (Havlin et al. 2013).

Other components that were measured and that can be harmful to crops are Al, Pb, and ESP. Soils with low pH have H⁺ ions that are absorbed by clay and attack mineral structure (e.g., aluminum oxides) releasing exchangeable and soluble aluminum (Havlin et al. 2013). This mechanism creates high Al⁺ content in soils, with the strong tendency of Al⁺ to hydrolyze water molecules which in turn results in a more acidic soil (Brady 2005). Based on ESP, there are seven schools that are consider sodic soils. Plants will be adversely affected by excesses sodium, which affect soil structure and plant growth (Abrol 1988; Juo and Franzluebbers 2003). Thus, in order for schoolyards of the Rio Piedras watershed to sustain vegetable gardens, soils physical and chemical properties need to be improved.
All schoolyard soils had high BD and clay content that could limit productivity. The physical properties are the most important because they limit water intake, root development, soil aeration and soil porosity (Hickman and Whitney 1987). Attempts to change soil physical properties are often not recommended because of the high amounts of organic matter needed (McCall 1980). However, because of the small areas of these gardens, it should be feasible. The most effective way to improve physical properties is to break up the soil by tilling and adding soil conditioners (e.g., manure, and compost) (McCall 1980; EPA 2011). Once the physical condition is improved, the soil nutrient levels will have to be reassessed, as adding organic conditioners will also increase nutrient concentration. However, we expect that because of the low nutrient concentrations, additional inputs of nutrients will still be needed.

There are a few schoolyard soils that will need additional treatment (e.g., for sodic soils, high concentration of Al, Pb, and redox conditions). Sodic soil management is needed to remove sodium cations that are bound to clay particles and replace them with more favorable cations such as calcium ions (Abrol et al. 1988). This can be accomplished with different amendments materials for example gypsum, acids (e.g., sulfuric acid), and low solubility calcium salts (e.g., ground limestone). There are different types of tree and grasses that can be used to improve sodic conditions for example Eucalyptus hybrids or wheatgrass (Agropyron spp.) (Abrol et al. 1988). Amendments for high concentrations of Al include lime application to increase soil pH above 7, causing the $\text{Al}^{3+}$ to precipitate as an uncharged ion (Wright 1989). There are certain plants that tolerate aluminum like maize (Zea mays L.), wheat (Triticum aestivum L.), and ornamental plants (e.g., Melastoma affine, Hydrangea) (Wright 1989).
Finally, for redox conditions from possible aquatic conditions could be improve by building raised beds.

Another possibility that ought to be explored for these soils is the potential of using plants to withstand or alleviate high metal concentrations (e.g. bioremediation) (EPA 2011). Lead can be phytoremediated by using plants that sequester Pb extracting it from soils (EPA 2012). For example, Indian mustard (Brassica juncea) has been found to accumulate Pb. Specifically, research in Puerto Rico have found that Rhizophora mangle and Laguncularia racemosa accumulate heavy metals concentrations in their leaves (Mejias-Rivera 2012).

**Conclusion**

Our findings reveal that in order to develop vegetable gardens, RPWS schools require soil management. Equally important are the engagement of various stakeholders and more structured vegetable garden curricula in schools. There is no universal model of garden-based learning that can be applied to every community, but the findings of this study can be used to improve the likelihood of school garden success. Ultimately, each school must design its own plan to address the needs of its particular learners and educators.

More research is needed to identify effective practices for developing and maintaining school gardens, and how to transfer that information to other schools so that it can be replicated. It is also necessary to determine how non-profits organizations and government initiatives can be organized to make these gardens sustainable over the long term. Through these elementary school gardens, soil quality should be monitored in adaptive management programs to improve urban ecosystem function.
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Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.


Figures:

Figure 1: The Rio Piedras watershed located at the north east part of the island is the most urbanized watershed in Puerto Rico. The map on the right shows the locations (circles) of the elementary schools visited.
Figure 2. Top ten factors mentioned by school principals that represent opportunities (A) and constraints (B) for the establishment of vegetable gardens in elementary schools.
Figure 3: The soil classification group for each school (indicated by colored dots) as determined from our study, overlain on a geologic formation map from USGS soils classification. Group 1 (dark blue dots) are the soil profiles that were mostly clay content. Group 2 (yellow dots) are the soil profiles that were mostly sandy soils. Group 3 (grey dots) are the soil profiles that had drainage problem and redoximorphic features. Finally, Not Completed are the group 4, were soil profiles did not reach the 60”.
Figure 4. NMS analysis of physical and chemical soil parameters with school social factors (income and number of student enrollment). Elementary schools are represented with triangles (n=20). Indicate what the soils variables are.
Table 1: Descriptive statistics for the schools surveyed.

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Mean</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schools with garden at time of visit</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schools without a garden at time of visit that previously had a garden</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schools than never had a garden</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student enrollment</td>
<td>261</td>
<td>691</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>% of students from low-income families</td>
<td>80%</td>
<td>100%</td>
<td>47%</td>
<td></td>
</tr>
<tr>
<td>Elevation (mamsl) of the school</td>
<td>48</td>
<td>238</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. School principals’ responses for factors considered as opportunities and constraints for the development of a garden, grouped by main categories.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Opportunity Factors</th>
<th>Frequency</th>
<th>Constrains Factors</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological conditions</td>
<td>Availability of space</td>
<td>4</td>
<td>Terrain limitations</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Interest in crops</td>
<td>3</td>
<td>Lack of fertility</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Adequate climate/microclimate</td>
<td>1</td>
<td>Invasive species</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Adequate terrain</td>
<td>1</td>
<td>Insufficient space</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inadequate Climate/microclimate</td>
<td>1</td>
</tr>
<tr>
<td>Engagement</td>
<td>Engagement of faculty</td>
<td>11</td>
<td>Lack engagement of parents</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Engagement of students</td>
<td>10</td>
<td>Lack of volunteers</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Engagement of administrator</td>
<td>6</td>
<td>Lack of engagement of faculty</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Engagement of parents</td>
<td>6</td>
<td>Lack of engagement of students</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>General Motivation</td>
<td>3</td>
<td>Lack of community engagement</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Government help</td>
<td>3</td>
<td>Lack of government help</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Volunteers availability</td>
<td>3</td>
<td>No sense of ownership</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Community engagement</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sense of ownership</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental awareness</td>
<td>Awareness</td>
<td>6</td>
<td>Lack of awareness</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Benefits of food and nutrition</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Funding</td>
<td>Support of external sponsor</td>
<td>7</td>
<td>No budget</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Having a budget</td>
<td>2</td>
<td>Lack of external support</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Support of internal sponsor</td>
<td>1</td>
<td>Internal sponsor</td>
<td>1</td>
</tr>
<tr>
<td>Logistic</td>
<td>Fencing</td>
<td>3</td>
<td>No gardening Skills</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Organization/ Structure</td>
<td>2</td>
<td>Necessity of maintenance</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Technical support/project coordination</td>
<td>2</td>
<td>Insufficient time</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>2</td>
<td>Absence of technical support</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Tools</td>
<td>2</td>
<td>Absence of organization/ Structure</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Gardening Skills</td>
<td>1</td>
<td>Lack of tools</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security/Vandalism</td>
<td>Security</td>
<td>1</td>
<td>Vandalism</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>Government policy for children’s nutrition</td>
<td>1</td>
<td>None</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 3: Descriptive statistics for chemical and physical properties of the top 15 cm of soil of the school yards visited in the Rio Piedras watershed (n=20)

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>Std Err</th>
<th>Std Dev</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.5</td>
<td>5.2</td>
<td>8.5</td>
<td>0.1</td>
<td>0.7</td>
<td>8.8</td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>320.9</td>
<td>97.1</td>
<td>512.0</td>
<td>30.0</td>
<td>134.3</td>
<td>41.8</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>2.9</td>
<td>1.3</td>
<td>4.3</td>
<td>0.2</td>
<td>0.9</td>
<td>32.3</td>
</tr>
<tr>
<td>CEC (meq/100g)</td>
<td>2.1</td>
<td>1.0</td>
<td>4.0</td>
<td>0.2</td>
<td>0.7</td>
<td>34.2</td>
</tr>
<tr>
<td>Phosphorus (mg/Kg)</td>
<td>3.3</td>
<td>0.4</td>
<td>16.4</td>
<td>0.9</td>
<td>3.8</td>
<td>115.5</td>
</tr>
<tr>
<td>Potassium (mg/Kg)</td>
<td>4.8</td>
<td>0.4</td>
<td>18.4</td>
<td>0.9</td>
<td>3.8</td>
<td>80.0</td>
</tr>
<tr>
<td>Calcium (mg/Kg)</td>
<td>364.1</td>
<td>122.2</td>
<td>502.5</td>
<td>22.9</td>
<td>102.3</td>
<td>28.1</td>
</tr>
<tr>
<td>Magnesium (mg/Kg)</td>
<td>21.1</td>
<td>5.8</td>
<td>65.2</td>
<td>3.0</td>
<td>13.6</td>
<td>64.2</td>
</tr>
<tr>
<td>Sodium (mg/Kg)</td>
<td>2.9</td>
<td>1.7</td>
<td>5.8</td>
<td>0.3</td>
<td>1.2</td>
<td>39.8</td>
</tr>
<tr>
<td>S-SO₄ (mg/Kg)</td>
<td>16.2</td>
<td>3.3</td>
<td>140.0</td>
<td>7.3</td>
<td>32.4</td>
<td>199.9</td>
</tr>
<tr>
<td>Cadmium (mg/kg)</td>
<td>2.2</td>
<td>1.3</td>
<td>3.1</td>
<td>0.1</td>
<td>0.5</td>
<td>21.7</td>
</tr>
<tr>
<td>Chromium (mg/kg)</td>
<td>70.0</td>
<td>34.2</td>
<td>126.0</td>
<td>4.9</td>
<td>22.1</td>
<td>31.5</td>
</tr>
<tr>
<td>Lead (mg/kg)</td>
<td>42.1</td>
<td>3.6</td>
<td>155.0</td>
<td>6.7</td>
<td>30.0</td>
<td>71.3</td>
</tr>
<tr>
<td>Clay %</td>
<td>39.2</td>
<td>21.2</td>
<td>70.0</td>
<td>2.8</td>
<td>12.7</td>
<td>32.4</td>
</tr>
<tr>
<td>Sand %</td>
<td>39.2</td>
<td>15.3</td>
<td>56.0</td>
<td>2.9</td>
<td>12.9</td>
<td>33.0</td>
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<tr>
<td>Bulk Density (g cm⁻³)</td>
<td>1.4</td>
<td>1.2</td>
<td>1.8</td>
<td>0.0</td>
<td>0.2</td>
<td>10.8</td>
</tr>
<tr>
<td>Gravimetric Water Content (g/g)</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.0</td>
<td>0.1</td>
<td>27.2</td>
</tr>
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</table>
Table 4. Mean bulk density by texture of the top 15 cm of soil of the school yards visited in the Rio Piedras watershed (n=20). The ideal BD and BD that restricts root growth are also shown (NRCS, citation)

<table>
<thead>
<tr>
<th>Texture</th>
<th>Number of Schools</th>
<th>Mean of BD (g cm(^{-3}))</th>
<th>Ideal BD for plan growth (g cm(^{-3}))</th>
<th>BD restrict root growth (g cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>11</td>
<td>1.43</td>
<td>&lt;1.10</td>
<td>&gt;1.47</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>2</td>
<td>1.44</td>
<td>&lt;1.40</td>
<td>&gt;1.75</td>
</tr>
<tr>
<td>Loam</td>
<td>1</td>
<td>1.29</td>
<td>&lt;1.40</td>
<td>&gt;1.75</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>2</td>
<td>1.50</td>
<td>&lt;1.10</td>
<td>&gt;1.58</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>4</td>
<td>1.32</td>
<td>&lt;1.40</td>
<td>&gt;1.75</td>
</tr>
</tbody>
</table>
Table 5: Soil chemical properties of the school yards, with indications of where the values fall in the recommend ranges for five crops: cantaloupe (Ca), cucumber (Cu), eggplant (E), onion (O), tomato (T).

<table>
<thead>
<tr>
<th>Soil variables</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>Above range</th>
<th>Below range</th>
<th>Within range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nutrients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.51</td>
<td>5.23</td>
<td>8.45</td>
<td>Cu</td>
<td></td>
<td>Ca, E, O, T</td>
</tr>
<tr>
<td>Conductivity (uS/cm)</td>
<td>320.86</td>
<td>97.1</td>
<td>512</td>
<td></td>
<td>Cu</td>
<td>Ca, Cu, E, O, T</td>
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<td>Organic Matter (%)</td>
<td>2.94</td>
<td>1.25</td>
<td>4.33</td>
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<td>CEC (meq/100g)</td>
<td>2.1</td>
<td>1.0</td>
<td>4.0</td>
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<td>Ca, Cu, E, O, T</td>
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<td>Phosphorus (mg/Kg)</td>
<td>3.31</td>
<td>0.4</td>
<td>16.4</td>
<td>Ca, Cu, E, O, T</td>
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<tr>
<td>Potassium (mg/Kg)</td>
<td>4.78</td>
<td>0.44</td>
<td>18.41</td>
<td>Ca, Cu, E, O, T</td>
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<tr>
<td>Calcium (mg/Kg)</td>
<td>364.13</td>
<td>122.2</td>
<td>502.5</td>
<td>Ca, Cu, E, O, T</td>
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<td>Magnesium (mg/Kg)</td>
<td>21.11</td>
<td>5.78</td>
<td>65.19</td>
<td>Ca, Cu, E, O, T</td>
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<tr>
<td>Sodium (mg/Kg)</td>
<td>2.95</td>
<td>1.68</td>
<td>5.83</td>
<td>Ca, Cu, E, O, T</td>
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<tr>
<td>S-SO₄ (mg/Kg)</td>
<td>16.23</td>
<td>3.29</td>
<td>140</td>
<td>Ca, Cu, E, O, T</td>
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Table 6: Soil physical and chemical properties of the school yards of the Rio Piedras watershed compared with other urban studies locations. Points (.) represent data no collected for that particular soil parameter.

<table>
<thead>
<tr>
<th>Location/Place</th>
<th>Land use</th>
<th>Bulk density (g cm$^{-3}$)</th>
<th>pH</th>
<th>Sand %</th>
<th>Clay %</th>
<th>Silt %</th>
<th>OM %</th>
<th>CEC (meq/100g)</th>
<th>Cd (mg/kg)</th>
<th>Cr (mg/kg)</th>
<th>Pb (mg/kg)</th>
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<tr>
<td>Washington DC</td>
<td>park</td>
<td>1.6</td>
<td>6.4</td>
<td>49</td>
<td>18</td>
<td>33</td>
<td>1.97</td>
<td>11.2</td>
<td>0.57</td>
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<td>Short et al. 1986</td>
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<td>Florida soils</td>
<td>residential</td>
<td>1.0</td>
<td>6.2</td>
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<td>5.1</td>
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<td>0.43</td>
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<td>Hagan et al. 2012</td>
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<td>Spain</td>
<td>urban park or golf course</td>
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<td>7.2</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>15.4</td>
<td>.</td>
<td>2.89</td>
<td>38.4</td>
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<td>Ruiz-Cortés et al. 2005</td>
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<tr>
<td>Baltimore</td>
<td>park or golf course</td>
<td>1.2</td>
<td>6.4</td>
<td>51</td>
<td>19</td>
<td>30</td>
<td>5.9</td>
<td>.</td>
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<td>91.0</td>
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<td>Hong Kong urban</td>
<td>urban</td>
<td>1.7</td>
<td>8.7</td>
<td>81</td>
<td>7</td>
<td>12</td>
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<td>0.36</td>
<td>17.8</td>
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<td>Jim 1998, Lee et al. 2006</td>
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<td>Chile</td>
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<td>1</td>
<td>6.7</td>
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<td>37.8</td>
<td>35</td>
<td>Tume et al. 2007</td>
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<tr>
<td>Rio Piedras Watershed schools yards</td>
<td>1.4</td>
<td>7.5</td>
<td>39</td>
<td>39</td>
<td>22</td>
<td>2.90</td>
<td>2.1</td>
<td>2.20</td>
<td>70.0</td>
<td>42</td>
<td>This study</td>
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</table>
Appendix 1: Soil Profiles

1. Aberaldo Diaz Alfaro
Latitude: 18.31255
Longitude: -66.062875

Ap- 0- 13 inches- brown (10 YR 5/3) sandy clay loam; strong brown (7.5 YR 5/8) common prominent concentration, very dark grayish brown (2.5 Y 3/2) few distinct depletions, weak medium subangular blocky structure, slightly plastic, slightly sticky, friable.

Bt- 13-25 inches- olive brown (2.5 Y 4/4) sandy clay; strong brown (7.5 YR 5/8) common prominent concentration, brown (10 YR 4/3) few distinct concentration, weak medium subangular blocky, slightly plastic, slightly sticky, friable.

Bw- 25-62 inches- light yellowish brown (2.5 Y 6/4) sand; structureless fine granular structure, loose, non sticky, non plastic.

2. Felisa Rincon de Gautier
Lat: 18.3394806
Long: -66.0858639

A – 0-3.5 inches- dark brown (10 YR 3/3) sandy clay; weak fine granular structure, very friable, slightly sticky, moderate plastic, about 30 percent of fine roots.

AB- 3.5-7.8 inches- olive brown (2.5 Y 4/3) sandy clay; moderate fine granular structure, very friable, slightly sticky, moderate plastic, about 10 percent of fine roots and 20 percent of small rocks.

BA- 7.8- 11.7 inches- dark yellowish brown (10 YR 4/4) sandy clay; very dark gray (10 YR 3/1) few faint concentrations; yellowish brown (10 YR 5/8) common distinct concentration; moderate medium subangular blocky structure, friable, slightly sticky, moderate plastic, about 20 percent of small rocks.

Bt- 11.7- 19.0 inches- dark yellowish brown (10 YR 3/6) silty clay; very dark brown (10 YR 2/2) few distinct concentrations; yellowish brown (10 YR 5/8) few distinct concentration; moderate medium subangular blocky structure, friable, moderately sticky, moderately plastic.

Bt2- 19-33 inches- yellowish brown (10 YR 5/6) silty clay; black (5 Y 2.1/1) few prominent masses; brown (10 YR 4/3) few distinct concentrations; yellowish red (5YR 5/8) common prominent concentrations; moderate coarse subangular blocky structure, moderate sticky, moderate plastic.
B- 33- 50 inches- yellowish brown (10 YR 5/8) sandy loam; weak fine granular structure, friable, non sticky, slightly plastic.

3. Jose M. Rivera Soils (EPA unpublish data)
Lat: 18.3592944
Long: -66.0457111

Ap- 0- 3.9 inches; dark yellowish brown (10 YR 4/4) sandy clay; weak fine granular structure, loose, moderate sticky, moderate plastic.

C1- 3.9- 9.1 inches- red (2.5 YR 5/6) clay; common dark yellowish brown (10 YR 4/4) concentrations.

C2- 9.1- 11.8 inches- light gray (10 YR 7/1) sandy loam; many anthropogenic artifacts (crushed concrete).

C3- 11.8- 55.1 inches- red (2.5 YR 5/6) clay; many white (10 YR 8/1) concentrations.

4. Ana Roque De Duprey
Lat: 18.3876417
Long: 66.0888028

Ap- 0-3 inches; dark brown (7.5 YR 3/4) clay; structureless very fine granular structure, loose, slightly sticky, slightly plastic, common fine roots.

B- 3- 19 inches; dark yellowish brown (10 YR 3/4) sandy clay; strong brown (7.5 YR 5/8) few prominent concentration; moderate fine subangular blocky, friable, slightly sticky, moderate plastic; man-made crystal artifact.

Bt1 19- 34 inches; reddish brown (5 YR 4/4) clay; yellowish red (5 YR 4/6) common faint concentration; moderate medium angular blocky structure, firm, slightly sticky, moderate plastic, about 12 percent of small minerals.

Bt2 - 34-44.5 inches; yellowish red (5 YR 5/8) clay; moderate fine granular structure, friable, moderate sticky, slightly plastic, many small minerals.

Bt3 - 44.5 – 53 inches; yellowish red (5 YR 5/8) clay; yellow (2.5 Y 7/8) common prominent concentration, moderate fine granular structure, friable, slightly sticky, slightly plastic, many small minerals.

C - 53-60 inches; yellowish red (5 YR 4/6) sandy clay; moderate fine granular structure, friable, slightly sticky, slightly plastic.
5. Rafael Quiñones Vidal
Lat: 18.3505056
Long: -66.0803083

Ap- 0-9 inches; reddish brown (5 YR 4/4) silty clay loam; reddish black (2.5 YR 2.5/1) many prominent concentration, red (2.5 YR 4/8) common prominent concentration, weak fine granular structure, friable, moderate sticky, very plastic, common fine roots.

C1- 9–15 inches; red (2.5 YR 4/8) silty clay; yellowish red (5 YR 4/6) many (about 40 percent) distinct concentration, reddish black (2.5 YR 2.5/1) common prominent concentration, moderate medium granular structure, firm, very sticky, very plastic.

C2- 15-36 inches; yellowish red (5 YR 5/8) clay; olive yellow (2.5 Y 6/6) few prominent concentrations, moderate fine subangular blocky, firm, very sticky, very plastic.

C3- 36-59 inches; red (2.5 YR 4/8) clay loam; red (10 R 4/8) many faint concentration, olive yellow (5 Y 6/8) common prominent concentration, olive grey (5 Y 4/2) common prominent concentration, moderate medium subangular blocky structure, friable, moderate sticky, moderate plastic.

C4- 59-65 inches; strong brown (5 YR 5/8) silty clay loam; olive yellow (5 Y 6/6) many prominent concentration, red (10 R 4/8) many faint concentration, moderate medium subangular blocky structure, friable, moderate sticky, very plastic.

6. Carmen Sanabria Figueroa
Lat: 18.3713139
Long: -66.0548861

A- 0- 6 inches- dark brown (10 YR 3/3) sandy clay; reddish brown (2.5 YR 5/4) few prominent concentrations, moderate medium granular structure, slightly sticky, moderate plastic, few fine roots.

Bt₁- 6- 18 inches- dark brown (7.5 YR 3/3) silty clay; very dark red (2.5 YR 2.5/2) many faint concentrations, red (2.5 YR 4/6) common prominent concentrations, reddish black (2.5 YR 2.5/1) distinct concentrations, contains few brownish yellow (10 YR 6/8) sand content, moderate very thin platy structure, moderate sticky, moderate plastic, few medium roots.

Bt₂- 18- 31.5 inches- brown (10 YR 5/3) silty clay; red (2.5 YR 4/8) many prominent concentrations, light brownish gray (10 YR 6/2) few faint concentration, very thin platy structure, moderate sticky, very plastic, few fine roots.
Btg₁- 31.5 – 41 inches- dark reddish brown (5 YR 3/3) silty clay; common prominent light gray (5 YR 7/1) concentrations, dark reddish brown (2.5 YR 2.5 /4) common faint concentrations, strong coarse subangular blocky structure, very sticky, very plastic.

Btg₂- 41- 61 inches- dark reddish brown (5 YR 3/3) silty clay; light gray (5 YR 7/1) many prominent concentrations, dark reddish brown (2.5 YR 2.5 /4) many faint concentrations, moderate fine granular structure, very sticky, very plastic.

7. El Señorial
Lat: 18.3604583
Long: -66.0606639

A- 0- 3 inches- very dark grayish brown (10 YR 3/2) silty clay; black (2.5 Y 2.5/1) common faint concentrations, moderate fine granular structure, slightly sticky, slightly plastic, very friable, fine common roots.

AB- 3-8 inches- dark yellowish brown (10 YR 4/4) silty clay; red (2.5 YR 4/8) many prominent concentrations, black (5 Y 2.5/1) common prominent concentrations, pale olive (5 Y 6/3) few distinct concentrations, weak fine subangular blocky, moderate sticky, moderate plastic, friable, very few fine roots.

B- 8- 22.5 inches- yellowish brown (10 YR 5/6) sandy clay loam; common prominent light gray (10 YR 7/1) concentration, few prominent black (2.5 Y 2/0) concentration, weak fine subangular blocky, friable, moderately sticky; moderately plastic,

Bₙ₁- 22.5- 37.8 inches- yellowish brown (10 YR 5/6) sandy loam; many distinct red (2.5 YR 4/6) concentration, many prominent gray (10 YR 6/1) concentration, few prominent black (10 YR 2.5/1) concentration; moderate fine granular structure; friable, slightly stick; slightly plastic.

Bₙ₂- 37.8- 46.46 inches- yellowish red (5 YR 4/6) loamy sand; common prominent gray (10 YR 6/1) concentration, common prominent black (5 YR 2.5/1) concentration; moderate fine granular structure, non sticky, slightly plastic.

Bₙ₃- 46.46- 59.10 inches- yellowish brown (10 YR 5/8) loamy sand; common prominent gray (10 YR 6/1) concentration; few prominent very dark brown (10 YR 2/2) concentration; moderate fine granular structure, non sticky, non plastic.

8. Julio Selles Sola
Lat: 18.3972194
Long: -66.0666111
A- 0 -3.5 inches- dark brown (10YR 3/3) sandy clay loam; common prominent light olive gray (5Y 6/2) concentration; few prominent yellowish brown (10 YR 5/8) concentration; weak fine granular structure, slightly sticky, moderately plastic, few fine roots.

Bw- 3.5-12 inches- yellowish brown (10 YR 5/8) sandy loam; common prominent very dark grayish brown (10 YR 3/2), moderate medium granular structure, slightly sticky, slightly plastic, lots or rocks bigger than 4cm.

9. Jose Colomban Rosario
Lat: 18.3768333
Lon: 66.0649639

A 0-6 inches; brown (7.5 YR 4/4) clay; few distinct reddish yellow (7.5 YR 6/6) concentrations; few prominent strong brown (7.5 YR 5/8) concentrations; few prominent black (7.5 YR 2/0) concentration; moderate fine granular structure, slightly sticky, moderate plastic, common fine roots.

Bt1- 6-13 inches; brown (7.5 YR 4/4) clay loam; common prominent red (2.5 YR 4/8) concentrations, common distinct very dusky red (2.5 YR 2.5/2) concentrations, few prominent reddish yellow (7.5 YR 7/8) concentrations, few prominent brownish yellow (10 YR 6/8) concentrations; strong medium granular structure, slightly sticky, moderately plastic.

Bt2 - 13- 27 inches; brown (7.5 YR 4/4) sandy clay loam; many distinct dark brown (7.5 YR 3/2) concentrations; many prominent red (2.5 YR 4/8) concentrations, common prominent white (10 YR 8/1) concentrations; few prominent dark reddish gray (10 R 3/1) concentrations; strong medium granular structure, moderate sticky, slightly plastic.

Btg - 27-37 inches; yellowish red (5 YR 4/6) sandy loam; many distinct yellowish brown (10 YR 5/8) concentrations; common prominent white (5YR 8/1) concentrations; common distinct red (2.5 YR 4/8) concentrations; few prominent dusky red (10 R 3/2) concentrations; strong fine subangular blocky structure, moderately plastic, slightly sticky.

Bt4 - 37-45 inches; yellowish red (5 YR 5/8) silty clay; common prominent dark brown (7.5 YR 3/3) concentrations; few prominent white (5 YR 8/1) concentrations; few prominent olive brown (2.5 Y 5/6) concentrations; few prominent olive (5 Y 4/3) concentrations; strong fine subangular block structure, moderate sticky, moderately plastic.

BC - 45- 62 inches; reddish brown (5 YR 4/3) silty clay loam; many prominent light gray (7.5 YR 7/1) concentrations; many faint weak red (10 R 4/3) concentrations; common prominent yellowish brown (10 YR 5/6) concentrations; common prominent strong brown (7.5 YR 5/8), weak very fine structureless; moderate sticky, slightly plastic.

10. Victor Parés Collazo (EPA unpublish data)
Lat: 18.4063  
Long: -66.06023

A- 0-5.9 inches- dark brown (10 YR 3/3) sandy clay loam; common prominent white (5 YR 8/1) depletions; common prominent pink (7.5 YR 8/3) concentrations; few prominent red (2.5 YR 4/8) concentrations; massive structureless; moderately sticky, slightly plastic; small rocks content.
C1- 5.9- 15.8 inches- yellowish brown (10 YR 5/6) sandy clay; common yellowish red (5 YR 4/6) concentrations; few prominent white (5 YR 8/1) concentrations; massive structureless; moderately sticky, moderately plastic; many medium rocks.
C2- 15.8- 20 inches- red (2.5 YR 4/6) sandy clay; massive structureless.
C3- 20- 33.5 inches- yellowish brown (10 YR 5/6) sandy clay loam; many red (2.5YR 4/6) concentrations; massive structureless.
C4- 33.5-43.3 inches- brownish yellow (10 YR 6/6) clay.
A- 43.3-53.1 inches- weak red (2.5 Y 4/2) clay.
C- 53.1- 55 inches- light gray (10 YR 7/1) silty loam.
Cg- 55- 61 inches- dark gray (10 YR 4/1) clay; gleization.

11. Rafael Rivera Otero
Lat: 18.3887944  
Long: -66.0979889

A- 0-6 inches; yellowish red (5 YR 4/6) sandy loam; few prominent dark reddish brown (5 YR 3/2) concentrations; moderate fine granular structure, moderately sticky, slightly plastic, few fine roots.

Bt1- 6-12 inches; dark reddish brown (5 YR 3/2) sandy clay loam; few prominent red (2.5 YR 4/8) concentrations; moderate fine granular structure, moderately sticky, moderately plastic.

Bt2- 12-34 inches; yellowish red (5 YR 4/6) sandy clay loam; common distinct dark reddish brown (5 YR 3/4) concentrations; few distinct light red (2.5 YR 6/8) concentrations; moderate medium granular structure, moderately sticky, slightly plastic.

Bt3- 34-46 inches; dark reddish brown (5 YR 3/3) loamy sand; many prominent red (2.5 YR 4/6) concentrations; moderately medium granular structure, slightly sticky, slightly plastic.

Bt4- 46.3- 60 inches; yellowish red (5 YR 4/6) sandy loam; common distinct dark reddish brown (5 YR 3/3) concentrations; few prominent gray (2.5 Y 6/0) concentrations; moderate medium granular structure; slightly sticky, slightly plastic.

12. República de Brasil
Lat: 18.3954278
A-0-11 inches; very dark grayish brown (10 YR 3/2) clay loam; few dark yellowish brown prominent (10 YR 4/6) concentrations; weak medium granular; moderately plastic, moderately sticky, low fine roots.

Bt1- 11-22 inches; dark grayish brown (10 YR 4/2) clay; common prominent strong brown (7.5 YR 5/8) concentrations; few faint black (10 YR 2/1) concentrations; weak medium granular structure, very plastic, moderately sticky.

Bt2- 22- 31.5 inches; olive brown (2.5 Y 4/4) clay; common prominent red (2.5 YR 4/8) concentrations; common prominent very dark yellowish brown (10 YR 6/8) concentrations; few prominent light gray (10 YR 7/2) concentrations; few distinct very dark grayish brown (2.5 Y 3/2) concentrations; massive structureless very plastic, very sticky.

Btg-31.5-42 inches; olive brown (2.5 Y 4/4) silty clay; many prominent red (2.5 YR 4/8) concentrations; many faint brown (10 YR 4/3) concentrations; common prominent light gray (10 YR 7/1) concentrations; few prominent very dark gray (7.5 YR 3/0) concentrations; massive structureless, very plastic, very sticky, rock content.

BCg- 42-50 inches; very dark grayish (2.5 Y 3/2) clay; common prominent black (7.5 YR 2/0) concentrations; few prominent red (2.5 YR 5/8) concentrations; common prominent gray (10 YR 5/0) concentrations; concentrations; massive structureless, moderately plastic, moderately sticky.

13. Eugenio María de Hostos
Lat: 18.4109889
Long: -66.0818278

A- 0-11 inches; dark brown (10 YR 3/3) sandy loam; common faint olive brown (2.5 Y 4/3) concentrations; few prominent strong brown (7.5 YR 5/6) concentrations; weak fine granular structure, slightly sticky, slightly plastic, big rocks content.

14. Luis Muñiz Soufront
Lat: 18.3964444
Long: -66.0918444

A-0-5 inches; dark brown (10 YR 3/3) sandy clay; many prominent very dark gray (2.5 Y 3/0) concentrations; massive structureless, slightly sticky, moderately plastic, friable, high rock content, common fine roots.
AB-5-22 inches; yellowish red (5 YR 4/6) sandy clay; common prominent light yellowish brown (2.5 Y 6/3) concentrations; few prominent yellow (2.5 Y 7/6) concentrations; weak fine subangular blocky structure, very plastic, moderately sticky, firm, rock content.

Bt₁-22-41 inches; yellowish red (5 YR 5/8) silty clay; many faint red (2.5 YR 4/8) concentrations; many prominent pale yellow (5 Y 8/2) concentrations; few prominent olive yellow (5 Y 6/6) concentrations; massive structureless, very sticky, very plastic, firm.

Bt₂- 41-51 inches; strong brown (7.5 YR 5/6) silty loam; many prominent pinkish white (7.5 YR 8/2) concentrations; many prominent weak red (10 R 4/4) concentrations; weak fine granular structure, non sticky, non plastic, loose.

Btg- 51-61 inches; white (10YR 8/1) silt loam; many prominent yellowish red (5 YR 5/6) concentrations; common prominent dark red (10 R 3/6) concentrations; common prominent dark yellowish brown (10 YR 4/6) concentrations; moderate fine granular structure, non sticky, non plastic, very friable.

15. Rafael Hernández Marín
Lat: 18.3979889
Long: -66.1007611

A-0-6 inches; dark brown (10 YR 3/3) sandy clay loam; few faint brown (7.5 YR 4/4) concentrations; weak fine granular structure, slightly sticky, slightly plastic, friable, few fine root.

Bt₂- 6-11.5 inches; strong brown (7.5 YR 4/6) sandy clay; many prominent very dark grayish brown (10 YR 3/2) concentrations; many prominent red (2.5 YR 5/8) concentrations, weak fine granular structure, moderately sticky, moderately plastic, high fine rocks.

Bt₃- 11.5-16.5 inches; yellowish red (5 YR 5/8) sandy clay; common prominent light yellowish brown (2.5 Y 6/3) concentrations; few prominent olive gray (5 Y 4/2) concentrations; moderate fine granular structure, moderately sticky, moderately plastic.

Bt₄- 16.5- 21 inches; olive brown (2.5 Y 4/3) sandy clay; many distinct black (2.5 Y 2/0) concentrations; common faint light yellowish brown (2.5 Y 6/3) concentrations; few prominent strong brown (5 YR 4/6) concentrations; moderate medium granular structure, moderately sticky, moderately plastic.

Bt₅- 21-32 inches; yellowish red (5 YR 4/6) sandy clay; many prominent black (2.5 Y 2/0) concentrations; weak medium granular structure, moderately sticky, moderately plastic.

C₁- 32-52 inches; yellowish red (5 YR 5/8) silty clay; many prominent light gray (5 Y 7/1) concentrations; many distinct red (10 R 4/8) concentrations; common prominent weak red
(10 R 4/2) concentrations; few prominent distinct (10 YR 6/8) concentrations; massive structureless, very sticky, very plastic.

C2- 36-56 inches; red (10 R 4/8) sandy clay; many prominent white (5 Y 7/1) concentrations; many distinct dark red (10 R 3/6) concentration; massive structureless, moderate sticky, moderately plastic.

16. Fair View
Lat: 18.3627556
Long: -66.0338278

A- 0-6 inches; brown (10 YR 4/3) sandy loam; moderate fine granular structure, slightly plastic, slightly sticky, common fine roots, human artefacts.

Bt1- 6-15.5 inches; yellowish brown (10 YR 5/8) loamy sand; strong very fine granular or single grain structure, non sticky, non plastic.

Bt2- 15.5-48 inches; yellowish brown (10 YR 5/6) loamy sand; few prominent light gray (2.5 Y 7/0) concentrations; strong very fine granular structure, non sticky, non plastic.

Bt3- 48-57 inches- yellowish brown (10 YR 5/8) loamy sand; few prominent red (10 R 5/8) concentrations; strong very fine granular structure, non sticky, non plastic.

17. Nemesio Canales
Lat: 18.4218666666667
Long: -66.0790611

A- 0-16 inches; dark brown (10 YR 3/3) loamy sand; moderate fine granular structure, non sticky, non plastic, high rock contentment, common fine roots, human artifacts (crystals).

Bt-16-20 inches; strong brown (7.5 YR 5/6) silty clay; many distinct reddish yellow (5 YR 6/8) concentrations; common prominent light gray (10R 7/1) concentrations; common prominent light red (2.5 YR 6/6) concentrations; few prominent dark red (10 R 3/6) concentrations; few prominent white (7.5 YR 8/1) concentration; weak medium granular structure, very sticky, moderate plastic, high rock content.

18. Escuela Elemental de la Universidad de Puerto Rico
Lat: 18.4006639
Long: -66.0502750

A- 0-6.5 inches; dark brown (7.5 YR 3/3) clay loam; few distinct gray (7.5 YR 6/0) concentrations; few prominent yellowish red (5 YR 5/8) concentrations; few distinct black (7.5 YR 2/0) concentrations; weak fine subangular blocky, very fine roots.
Bw- 6.5-13 inches; dark brown (7.5 YR 3/4) sandy clay; many prominent red (2.5 YR 4/8) concentrations; many prominent light gray (7.5 YR 7/0) concentrations; few prominent black (7.5 YR 2/0) concentrations; weak medium subangular blocky, moderately sticky, moderately plastic.

**19. Escuela la Esperanza**

Lat: 18.4169778  
Long: -66.0809417

A- 0-16 inches; red (2.5 YR 4/6) clay loam; many prominent light yellowish brown (2.5 Y 6/4) concentrations; massive structureless, very sticky, moderately plastic, few very fine roots.

C₁- 16-31 inches; red (10 R 4/8) silty clay; many prominent light gray (10 YR 7/2) concentrations; massive structureless, very sticky, very plastic.

C₂- 31-46 inches; red (2.5 YR 4/8) clay; many prominent dark reddish brown (2.5 YR 2.5/4) concentrations; common prominent very pale brown (10 YR 7/3) concentrations; massive structureless, very sticky, very plastic.

Cg- 46-62 inches; pale yellow (2.5 Y 7/3) clay; common prominent yellowish red (5 YR 4/6) concentrations; common prominent dark reddish brown (2.5 YR 2.5/4) concentrations; massive structureless, very sticky, very plastic.

**20. Dr. Antonio S. Pedreira**

Lat: 18.4072972  
Long: -66.0782167

A- 0-7 inches; dark brown (10 YR 3/3) sandy clay loam; moderate fine granular structure, moderately sticky, moderately plastic, many fine roots, coarse gravel.

AB- 7-18 inches; dark grayish brown (10 YR 4/2) sandy clay; few prominent red (2.5 YR 4/8) concentrations; moderate medium subangular blocky, moderately sticky, moderately plastic, coarse gravel.

B- 18-24 inches; olive brown (2.5 Y 4/4) sandy clay; common prominent reddish yellow (7.5 YR 6/8) concentrations; few prominent reddish black (2.5 YR 2.5/0) concentrations; weak medium subangular blocky, moderately sticky, moderately plastic.
B- 24-43.5 inches; yellowish red (5 YR 5/8) sandy loam; many distinct brownish yellow (10 YR 6/8) concentrations; common prominent light gray (10 YR 7/1) concentrations; strong very fine granular structure, slightly sticky, slightly plastic.

B-43.5-52 inches; strong brown (7.5 YR 5/8) loamy sand; many prominent light gray (10 YR 7/2) concentrations; common faint brownish yellow (10 YR 6/8) concentrations; strong very fine granular structure, non sticky, non plastic.

B-52-62 inches- brownish yellow (10 YR 6/8) loamy sand; common prominent light gray (2.5 Y 7/2) concentrations; strong very fine granular structure, non sticky, non plastic.
Appendix 2: Classification of Soils

Group 1

Group 1 are soil profile consists mostly of clay texture through more than 35 inches of the soil depth. They are mostly located in the middle of Rio Piedras watershed, are well drained and moderately slowly permeable soils.


**Range in characteristics:** Thickness of the soil is 60”.

The A horizons range from 3 to 11 inches, colors hue of 5YR to 10 YR, value of 3 to 4, and chroma of 2 to 4. Texture is clay, clay loam, silty clay, and silty clay loam.

The B horizons has hue of 2.5 YR to 2.5 Y, value 3 to 5, and chroma 3 to 8. Texture is clay, silty clay, clay loam, sandy clay loam, and sandy loam.
Group 2

Group 2 soil profiles consist mostly of sand texture through more than 25 inches of soil depth. They are mostly located in the upper and middle low of Rio Piedras watershed are well drained soils. **Schools:** 1. Aberaldo Diaz Alfaro; 2. Felisa Rincón de Gautier; 11. Rafael Rivera Otero; 16. Fair View

**Range in characteristics:** Thickness of the soil is 60”.

The A horizons range from 3.5 to 13 inches, colors hue of 5YR to 10 YR, value of 3 to 5, and chroma of 3 to 6. Texture is sandy clay and sandy loam. The B horizons has hue of 2.5 Y to 10 YR, value 3 to 6, and chroma 3 to 8. Texture is sandy, silty clay, sandy clay loam, loamy sand, and sandy loam.
Group 3

Group 3 soil profiles contain drainage problems and consist mostly of low chroma in through more than 30 inches of soil depth. They are mostly located in the lower and middle of Rio Piedras watershed.


**Range in characteristics:** Thickness of the soil are until 60”. The soil have a wide range of color and texture.

The A horizons range from 5 to 16 inches, colors hue of 2.5 YR to 10 YR, value of 3 to 4, and chroma of 3 to 6. Texture is sandy clay loam, sandy clay, clay loam.

The B and C horizons has hue of 2.5 Y to 10 YR, value 4 to 8, and chroma 1 to 8. Texture is silty clay, silty loam, loamy sand, clay, sandy clay, and sandy loam. The horizons had no structure and has many light and white redoximorphic Features.

Structureless matrix with many light gray (5 Y 7/1) redoximorphic Features.
Group 4

Group 4 are soil profiles that could not be completed because there were rocks or really hard soils that it was not possible to do with a hand drill.


Clay cementation
Appendix 3: Interview Questions

Title: Evaluation of the potential for urban agriculture in schools in the Rio Piedras watershed.

Interview question guides for school principal

1. Does the school have environmental or science clubs?
   a. If you answer Yes: How many? What is about?
   b. If you answer No: Why?

2. Has the school have initiatives related to the development of a vegetable garden? Have they been successful?
   a. If you answer Yes: what factors were key in the development of the garden?
   b. If you answer No Yes factors attributed to the lack of success?

3. There are teachers, employees or any group of people who have expressed interest in developing school gardens?

4. Does the school have an area to develop a vegetable garden?
   a. If you answer Yes: indicates where and how much space
   b. If you answer NO: indicate why?

5. Does the school have budget to create a vegetable gardening?

6. How would you describe the type of maintenance that receive the green areas of the school? Who provides this support?

7. Could you mention 5 Factors that limit the development of gardening in school?

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8. Could name five factors that facilitate the development of gardening in school?
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9. What is your opinion regarding the implementation of agricultural activities within the school curriculum?

10. Which material may be included these activities?

11. To which grade level could be incorporated?

12. Which is the socio-economic profile of the school?
   a. Average level of household income
   b. Educational level of parents
   c. Distribution of marital status of parents
   d. Levels of student achievement
   e. % Passing Test
   f. % Sixth Grade Graduates