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A Socio-Ecological Assessment of the Potential for Vegetable Gardens in Elementary Schools Across an Urban Tropical Watershed in Puerto Rico

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School vegetable 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. For a school to create and sustain a vegetable garden, both social and physical environment (soils) must be favorable. We evaluated 20 elementary schools in the Rio Piedras watershed of San Juan, Puerto Rico. At these schools, we surveyed school principals to identify social factors that are considered opportunities and constraints to establishing and sustaining a school garden. We also described the physical and chemical properties of the soils from the most suitable locations for vegetable gardens in the schoolyards. For social factors, some schools had discontinued gardening because of dwindling funding, waning interest of teachers and parents. Through in-person interviews, principals identified factors that help in implementing and sustaining long-term vegetable gardens: engagement of stakeholders, sponsorship, gardening skills and logistics, and curriculum integration. For ecological factors, the destruction of crops by exotic iguanas was also a reason that stopped school garden activities in some cases. Generally, school soils were highly disturbed, with high bulk density and low nutrient availability. The soils will require considerable remediation and management to sustain vegetable gardens in Rio Piedras schools. A social-ecological approach like that used here could be used to evaluate school gardens at other jurisdictions to increase the likelihood of success of gardening activities.

INTRODUCTION

Urban agriculture produces 15-25% of the world's food supply (NRCS 2013; Orsini et al. 2013). It is more common in developing countries than in industrialized ones. In the first decade of the 21st century in the United Kingdom and the United States, only 6% of fruits and vegetables consumed was produced locally, an amount limited by available urban green space and the quality of urban soils (Martin et al. 2014). Despite the low yield, urban agriculture in the United States has gained popularity among different social sectors in the last several decades (Pudup 2008) and is an activity that makes positive contributions to overall urban sustainability (Lovell 2010).

School gardens provide a wide range of lifestyle benefits, including nutrition, social connections, and environmental services. Growing crops in city schools encourages healthier lifestyles (Ozer 2007) by increasing physical activity and consumption of vegetables and fruits (Alaimo et al. 2008). Gardening improves the sense of community by developing a sense of ownership, fostering social interactions, and boosting the local economy (Armstrong 2000; Blair 2009; McClintock 2010). Another benefit is an increase in green areas in cities, which provide ecological niches for pollinators, nurture plant biodiversity, provide soil function, and even provide reuse of waste products for compost and sustainable food production (Deelstra and Girardet 2000; McClintock 2010; Edmondson et al. 2014; Martin et al. 2014). Perhaps more importantly, gardening is a teaching tool that can be applied to traditional and nontraditional school subject materials, e.g., science, mathematics, nutrition, social studies, cooking, and farming (Lawrence and Rayfield 2012; Desmond et al. 2004). School gardens not only enhance connections with nature, but also help develop student morality, confidence, social skills, and academic performance (Joshi et al. 2008; Block et al. 2012; Williams and Dixon 2013). Although beneficial to students, only 27% of elementary schools in the United States have gardening programs (Turner et al. 2014). The most important factor for successfully implementing and sustaining a vegetable garden appears to be adequate program support (Joshi et al. 2008; Hazzard et al. 2011; Yu 2012; Clabeaux 2013). On the other hand, in addition to institutional factors that must be in place for a school garden to be successful, the garden site must have adequate soil physical and chemical conditions. Urban soils are often highly disturbed, with low fertility, massive structure, high pH, coarse texture, and high bulk density (Craul 1994; Pouyat et al. 2010; Pickett et al. 2008; Vodyanitskii 2015; Yang and Zhang 2015). Nevertheless, 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. Urban soils can provide essential ecosystem services (Shuster et al. 2014), e.g., they absorb water which is stored and filtered, thus reducing stormwater runoff. They have carbon-storage capacity and can reduce pollutant mobility and availability (Pouyat et al. 2010; Wortman and Lovell 2013). One way to conserve and improve urban soil functionality is by developing gardens and other types of green infrastructure. At least one study in the United Kingdom has shown that small-scale urban food production can maintain higher soil quality than conventional agriculture (Edmondson et al. 2014).

Residents of the Caribbean island of Puerto Rico are concerned about numerous factors that interfere with food supply, including global climate change, reduction of land devoted to agriculture, natural disaster, and free trade agreements (Crespo Bellido 2014). Over 85% of food consumed on the island is imported. This has led to public concern about the vulnerability of the food supply and lack of food security, therefore increasing the public demand for greater

agricultural activity in the island including even in local cities (Rosario-Mejías and Dávila-Román, 2012; Comas and Sagebien 2009). School gardens may offer students with the opportunity to learn the agricultural skills that can promote self-reliant communities and adaptive capacity to environmental change. One urban school system where gardens have been promoted is in the municipality of San Juan, located within the Rio Piedras watershed, the largest urban watershed in Puerto Rico.

In this study, we sought to develop a broad perspective of the potential for vegetable gardens in the elementary schools of San Juan, Puerto Rico. School vegetable gardens are social and environmental systems that can be studied with an interdisciplinary approach. In particular, we described the social preferences of school principals towards vegetable gardens, as well as soil quality at the schools. Our objective was to evaluate the feasibility of creating and sustaining vegetable gardens in public elementary schools of the Rio Piedras watershed. We sought to answer the following questions: 1) What do elementary school principals consider to be the opportunities and constraints for the development of school vegetable gardens? 2) Are the soils in schoolyards suitable for sustainable vegetable gardening? Our focus on elementary schools had three reasons. First, they were highly accessible. Second, it allowed for standardization of academic targets. Third it facilitated comparisons with other studies. Most studies on the social dimensions of school gardening have been conducted with elementary-age students, because children at early age are more curious, active, and potentially more inclined to learn by doing (Blair 2009; Smith et al. 2005). In addition, school garden interventions have shown considerable promise in promoting healthful dietary behaviors among young children (Aguilar et al. 2008).

A Brief History

In lower-income countries, vegetable gardens have been used for vocational agricultural training and food production for both consumption and trade (FAO 2010). In wealthier nations, school gardens have been predominantly used as laboratories for science, as well as sites for environmental clubs and other interests 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 1915, most schools had gardens as a way to teach children values like 'working with dignity, local economy development, patriotism, 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 subsequently waned, they were replaced by "cleaner" schoolyards with grass and playgrounds (Trelstad 1997). In the 1960s and 1970s, a renewed interest in school gardens was motivated by the environmental movement (Desmond et al. 2004). In the 21st century, the development of school gardens is now motivated by the desire for a more sustainable society, food security, better nutrition, and environmental protection (Wortman and Lovell 2013).

In Puerto Rico, the "agricultural education in school" movement began in 1932. It was promoted by Law num. 28 1931, which created 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). While many of the recent efforts in school gardening in Puerto Rico have been directed to rural schools, since 2012 government platforms of the two
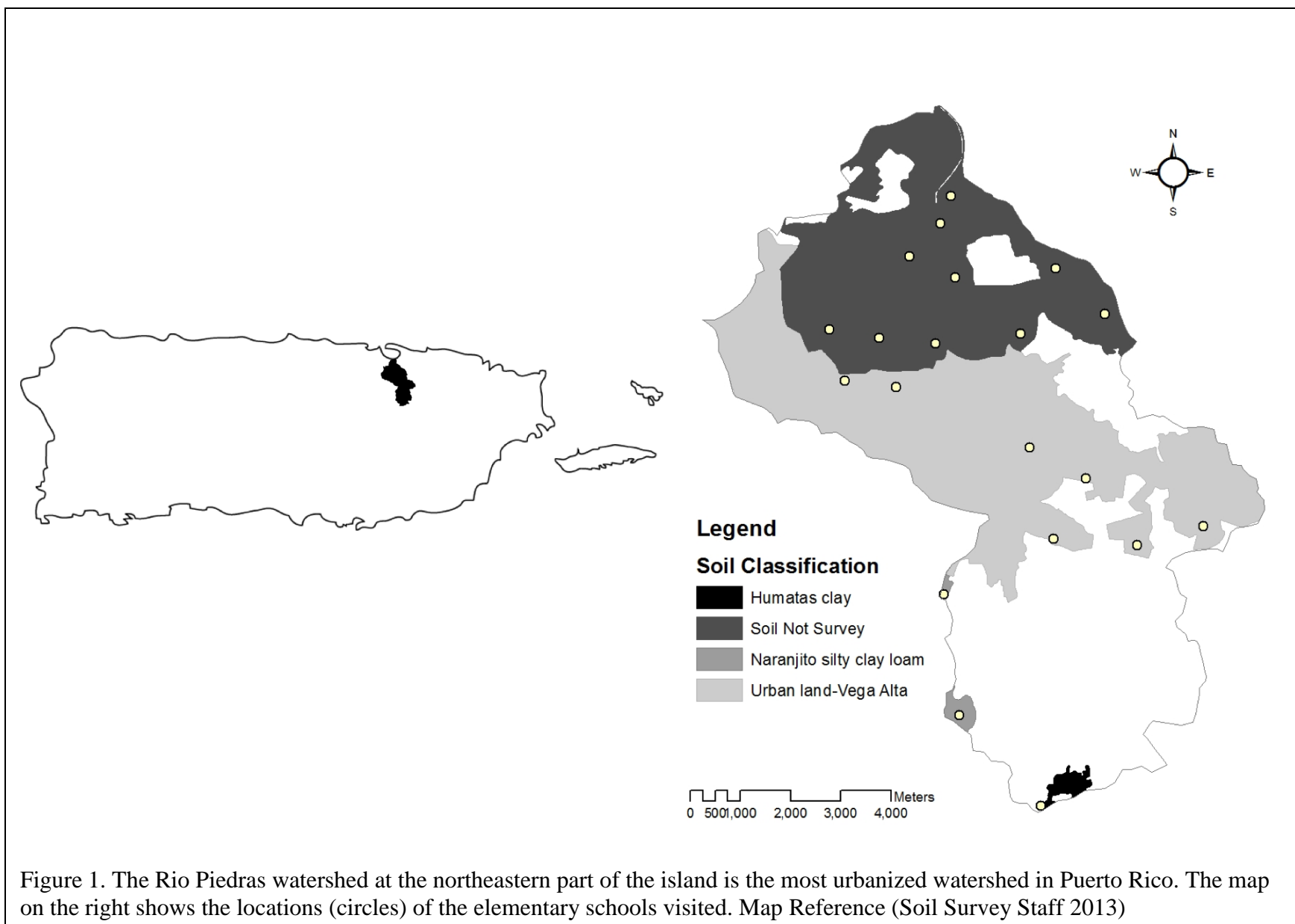
major parties and a recent law have emphasized the need to integrate the development of school gardens within the Department of Education and encourage initiatives in urban schools motivated at least in part by sustainability visions (Partido Popular Democratico 2012; Lexjuris Puerto Rico 2015; Partido Nuevo Progresista 2016). 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 or limited or uncertain ability to acquire acceptable foods in socially acceptable ways" (Anderson 1990). Puerto Rico's food insecurity is characterized by high food prices, low food variety, and low availability of quality fresh food. Forty-two percent of the population lives below poverty level (less than $18,900 per year for a family of three) and without sufficient access to nutritious food (Quintero 2013; HUD 2015). Serrano et al. (2014) documented at an elementary school in San Juan that 55% of the children had poor quality diets and the other 45% needed improvements in their diets.

METHODS

The experimental design of this paper intends to complement social and ecological data to explain gardens sustainability in schools. Because urban environments are ecological system dominated by human decisions is important to recollect different type of data (Felson and Pickett 2005). Using a mixed method approach, we incorporated school principal interviews and soils chemical analysis to the data collection (Creswell 2013). One advantage of this approach is that it allows to integrate complementary data to evaluate complex social problems (Small 2011). In treating, school gardens as a social-ecological system we recognize the complexity of the problem and that ecological as well as social-factors may ultimately limit opportunities for success in the development of school gardens. This inquiry method often termed 'social-ecological research' that integrates social and ecological data analyses has been used for over two decades to address complex questions about urban systems that have human and natural dimensions (Grove and Burch 1997; Pickett et al. 2001). Many of them have been generated, especially in the past decade, to evaluate the social and ecological drivers of urban vegetation and within the context of urban sustainability (e.g. Grove et al. 2006; Zhu et al 2008; Chowdhury et al. 2011; Cook et al. 2012). The social-ecological approach used in this study makes important methodological contribution to the body of work that has accumulated on the factors that contribute to the success of school garden activities which tend to rely solely on social methods to evaluate their suitability and likelihood of success (e.g. Trelstad 1997; Azuma et al. 2001; Ozer 2007; Hazzard et al. 2011; Yu 2012; Clabeaux 2013).

Study Sites

There were 133 public schools serving 22,364 students within the San Juan municipality of Puerto Rico (Public School Review 2015). We selected 20 of the 79 public elementary (kindergarten through grade six) schools within the Rio Piedras watershed of San Juan (Fig. 1), which has been the focus of many studies on urban vulnerability and sustainability issues within tropical systems (Muñoz-Erickson et al. 2014a and b). Selection of these 20 schools was based on the willingness and readiness of the principal to participate. Also, the schools needed to have planting space and be located across different soil types of the watershed. Land cover across the

Figure 1. The Rio Piedras watershed at the northeastern 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. Map Reference (Soil Survey Staff 2013)

Rio Piedras watershed is a gradient ranging from high-density, urban development near the coast (topographically lower region) to forest cover around the headwaters (topographically higher region). Fourteen of the schools were located in the lower area (0–50 m of elevation), four were in the middle (51–100 m of elevation), and two were in the upper watershed (101–238 m of elevation) (Fig. 1). The vegetative cover of San Juan is 42% with impervious cover of 55% and a per capita green space of 122 m^2/inhabitant (Ramos-González 2014). The vegetation associations of the watershed fall within a subtropical moist forest classification (Ewel and Whitmore 1973) in the Holdridge (1967) life zone system. Mean annual rainfall ranges from 1509 mm on the coast to 1509–1755 mm at higher elevations (238 mamsl), with a mean annual temperature of 25.7°C (Lugo et al. 2011).

Geological formations within the watershed are derived from volcaniclastic rocks in the upper area, limestone and alluvium in the middle, and artificial fill in the lower area (Webb and Gómez-Gómez 1998; Lugo et al. 2011). Natural soils are predominantly Ultisols (Boccheciamp 1978). Located mostly in the lower urban part of the watershed, 35% of the soils are categorized as Urban Land-Vega Alta (defined as consisting of at least 75% urban land) and 27% as Soil Not Surveyed (27%) (Soil Survey Staff, 2013), with no information about physical and chemical characteristics for these classifications. Other soil series occurring mainly in the upper watershed 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%). Common features of these ultisols are clay texture, good drainage, and depths of moderately deep to deep from the bedrock (Boccheciamp 1978).

Interviews

Interviews were conducted in person with the principal of the school to identify factors that facilitated initiatives of vegetable gardening and agriculture programs in elementary schools (the questionnaire is provided in the supplemental files). Each interview was recorded with the consent of the interviewee, then transcribed and coded. Using an emergent coding process, the interviews were carefully read and classified open responses into six broader categories (Engagement, Logistics, Funding, Ecological Conditions, Awareness, and Other) to facilitate further analysis. Some of the categories are also similar to the social framing used in studies that evaluate social drivers and processes associated to school gardens (e.g. Azuma et al. 2001; Joshi et al. 2008; Hazzard et al; 2011, Yu 2012) and allow comparisons with other sites. The interviews were analyzed by collecting qualitative and quantitative information in order to: 1) quantify the number of gardens; 2) determine the causes for garden success (or failure); 3) quantify which factors were perceived as opportunities and constraints for the development of gardening; and 4) 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 (i.e. faculty, administration, students, and parents), economic status of student, and soil fertility.

Soil Descriptions

Soils were described at locations deemed to be most suitable for a vegetable garden by a director or teacher in charge, depending on environmental factors such as terrain level and amount of sun light it received. Some of the most commonly recommended vegetables to grow in Puerto Rico gardens are: cantaloupe, cucumber, eggplant, onion, and tomato (Muñiz-Torres 1992). Other aspects taking in consideration were that the gardens had easy and safe access for student to visit. Soil profile descriptions were made from soil cores extracted by hand with a bucket auger to a depth of 150 cm whenever possible (from 50–150 cm). Soil diagnostic horizons were identified in the field, with soil texture, color (Munsell 2000), structure, consistency, and concentrations were identified in each horizon. These profiles descriptions were mapped and compared with respect to elevation, previous soil type and parent material (Soil Survey Staff 2013; U.S. Geological Survey 2015).

Four samples of topsoil (0–15 cm depth) were pooled, and chemical analyses were performed at the Central Analytical Laboratory of the University of Puerto Rico-Mayaguez Rio Piedras Agricultural Experimental Station. Soil texture was determined by the Bouyoucos hydrometer method (Day 1965). Electrical conductivity was measured in a 1:1 soil water mixture. The pH was determined with a meter using 1:2 soil: water mixtures. Exchangeable cation (Ca, Mg, K, and Na) concentrations were determined using a modification of the ammonium acetate method for the extractable/exchangeable fraction. The cation exchange capacity (CEC) was calculated using the quantities of Al, Ca, Mg, Na, and K. Extractable P was determined by the Olsen P method. The $S-SO_4$ was determined by flow injection analysis. Cd, Cr, Pb, and Al concentrations were determined by EPA Method 3050. The percentage of organic matter was determined using a modification of the Walkley-Black Method based on the oxidation of organic matter by dichromate ions (Sparks et al. 1996).

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

Data Analyses

We calculated descriptive statistics for both physical environment (soils) and social factors. Significance is defined as $p \leq 0.05$ in statistical comparisons. Qualitative responses to the interviews were coded. Responses were assigned a factor which summarized the most important topic within the answers. Then these factors were grouped into categories to summarize which factors were perceived as opportunities or constraints for school gardens. Statistical descriptions were made using frequency distribution tables.

We used one sample T-test to determine if soil nutrient concentrations were different than recommended soil fertility values for Puerto Rico, and we used multivariate analyses of variance (MANOVA) to determine if soil chemical and physical parameters were related to the presence of school gardens (all of the preceding analyses were performed with JMP version 11.0, SAS

Institute Inc., 2013). We used nonmetric multidimensional scaling (NMS) to explore relationships among soil properties (relativized) and social data (income and number of student enrollment) (McCune and Medford 2011).

RESULTS

Social Characteristics of Schools

Mean student enrollment at the 20 schools was 261, with 80% from low-income families (Table 1). There were no differences in enrollment ($t(18) = 0.71$, $p = 0.50$) or % of students from low-income families ($t(18) = -1.04$, $p = 0.32$) among schools with and without gardens. Opportunity and constraint factors were grouped into major categories: Engagement, Logistics, Funding, Ecological Conditions, Awareness, and Other (Fig. 2; also, Table 5 in the supplemental file). All of the school principals agreed that agricultural activities in school were important. Some affirmed that there was a social necessity for gardening activities, which could address problems of nutrition, environmental awareness, and economics. The principals were concerned about the high cost of food in Puerto Rico and the lack of agricultural opportunities on the island. They spoke of the need to develop their students' palates for the tastes of garden vegetables, and that they want to develop student consciousness about nature and what it provides. All the principals stated that agriculture activities could be incorporated into science classes, while more than of half said that they could be incorporated into all classes (social studies, mathematics, languages, and physical education). Seventy-five percent indicated that agriculture should be taught from kindergarten through high school.

Nineteen of the 20 schools had teachers, employees, or parents interested in development of a garden. Despite this prevalent interest, only seven schools had gardens. Principals of four out of these seven schools attributed garden success to support and engagement within the school community. At three of the schools, non-profit organizations were both sponsors and coordinators of the gardens. Among the seven studied schools, five of them had no designated budget for gardening; these gardens were funded through fundraising activities and/or donations of materials.

Table 1. Characteristics of the twenty schools surveyed.

	Frequency	Mean	Maximum	Minimum
Schools with garden at time of visit	7			
Schools without garden that previously had one	11			
Schools than never had a garden	2			
Student enrollment		261	691	105
% of students from low-income families		80%	100%	47%
Elevation (mamsl) of the school		48	238	2
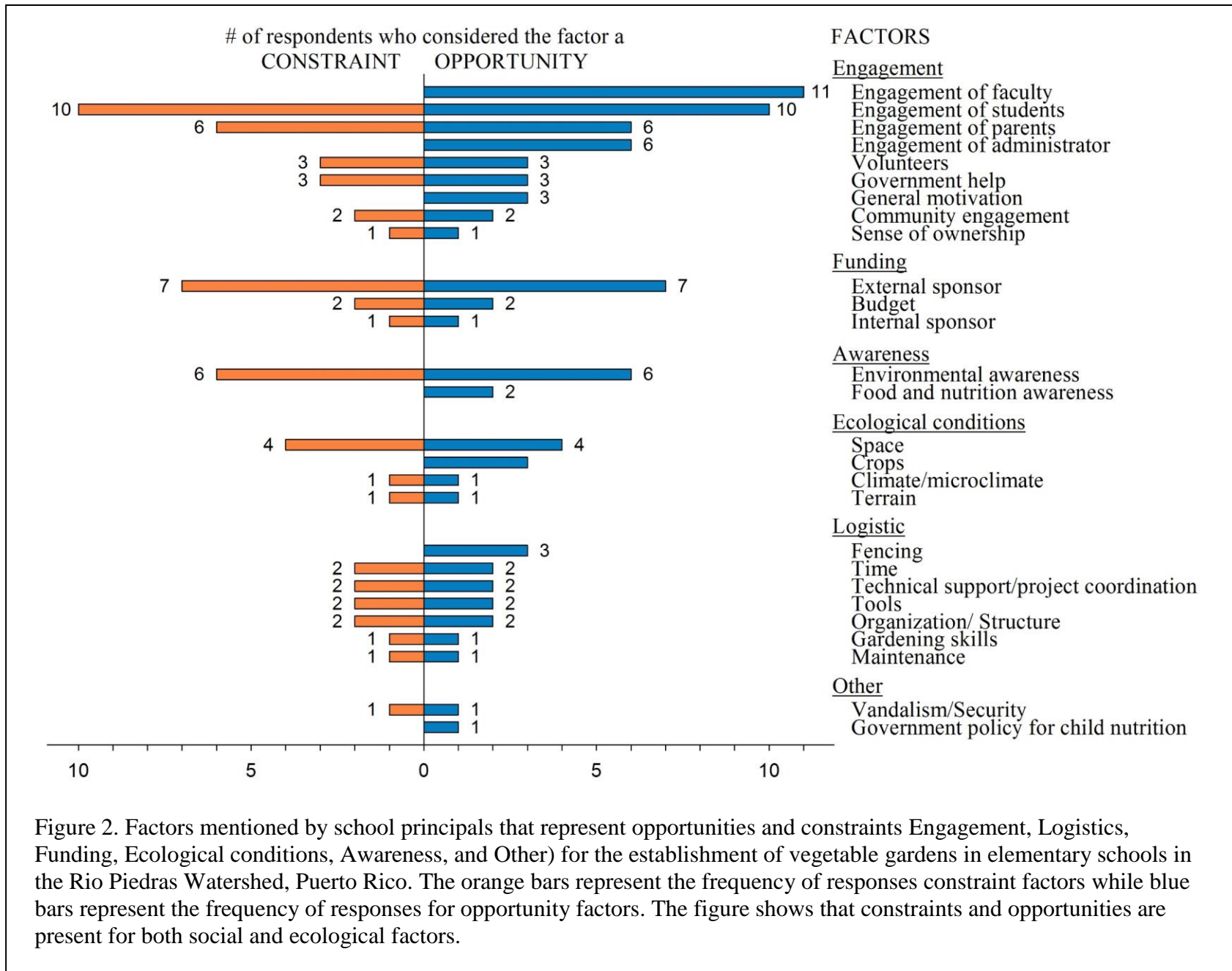
Figure 2. Factors mentioned by school principals that represent opportunities and constraints Engagement, Logistics, Funding, Ecological conditions, Awareness, and Other) for the establishment of vegetable gardens in elementary schools in the Rio Piedras Watershed, Puerto Rico. The orange bars represent the frequency of responses constraint factors while blue bars represent the frequency of responses for opportunity factors. The figure shows that constraints and opportunities are present for both social and ecological factors.

There were 11 schools that had gardens in the past and two which never had a garden. The loss of gardens was attributed to a range of factors, from invasive species to the loss of government initiatives. For example, four schools were part of the 'Ideas Verdes '(Green Ideas), a local government program that was designed to support education in environmental conservation by creating ecological spaces in schools. This initiative only lasted for a year, after which most gardens were abandoned. 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 key teacher left the school. The other three schools had difficulties with environmental factors such as shade, dry soils, and green iguana (*Iguana iguana*, an invasive species that consumes crops). Others reasons cited for failure of the gardens were other abiotic and environmental limitations, over-worked teachers, and lack of gardening skills.

The opportunity factors for garden development most cited by principals were engagement of faculty and students (mentioned by > 50% of the principals) and support of external sponsors such as the local community, non-profit organizations, and Boy and Girl Scouts (Fig. 2). The constraints most often cited were lack of funding, terrain limitations (unfavorable characteristics like uneven and steep soils, rocks, erosion, and many tree roots), lack of awareness from school and nearby community, and vandalism. Lack of awareness indicates the need for education regarding the benefits of a school garden. Another concern brought up by school principals was security. Five principals worried that the crops would be stolen. There were some school that had the desire to establish gardens and did so but because of the lack of skills the garden failed resulting in overall frustration which discouraged new gardening initiatives in the school.

School Soil Characteristics and Fertility

Half of the 20 schools were situated on soils that had not been surveyed, and the others were located across three different soil series: seven on Urban land-Vega Alta series, two with Naranjito silty clay loam, and one with Humatas clay. The profiles were grouped by texture, color, and aquic condition (Fig. 3; soil classifications and profiles are described in Appendices A and B). Group 1 consists mostly of soils with clay texture through more than 89 cm of depth, with color ranging from red (2.5 YR 5/6) to dark brown (7.5YR 3/3). Group 2 are soils with sandy texture through more than 63 cm of depth and a yellow color (10YR 4/5). Group 3 is soils with indicators of reduction conditions; they have chroma of 2 or less in layers within 76 cm of the surface, indicating possible 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.

We identified five different soil textures, ranging from very fine to medium particle size (Table 3). The recommended soil texture for vegetables is loam (7-27% clay, 28-50% silt, and < 52% sand; Brady and Weil 2010; U.S. EPA 2012). Soils at two schools were loam, while those at another five were close to loam. The remaining 13 soils had clay or sandy clay loam textures. Five of the loam and sandy clay loam soils had bulk densities lower than the ideal range for plant growth (Arshad et al. 1996). At the other 15 schools with clay, clay loam, and sandy clay textures, bulk densities were higher than ideal for plant growth (< 1.40 g/cm^3) but lower than the
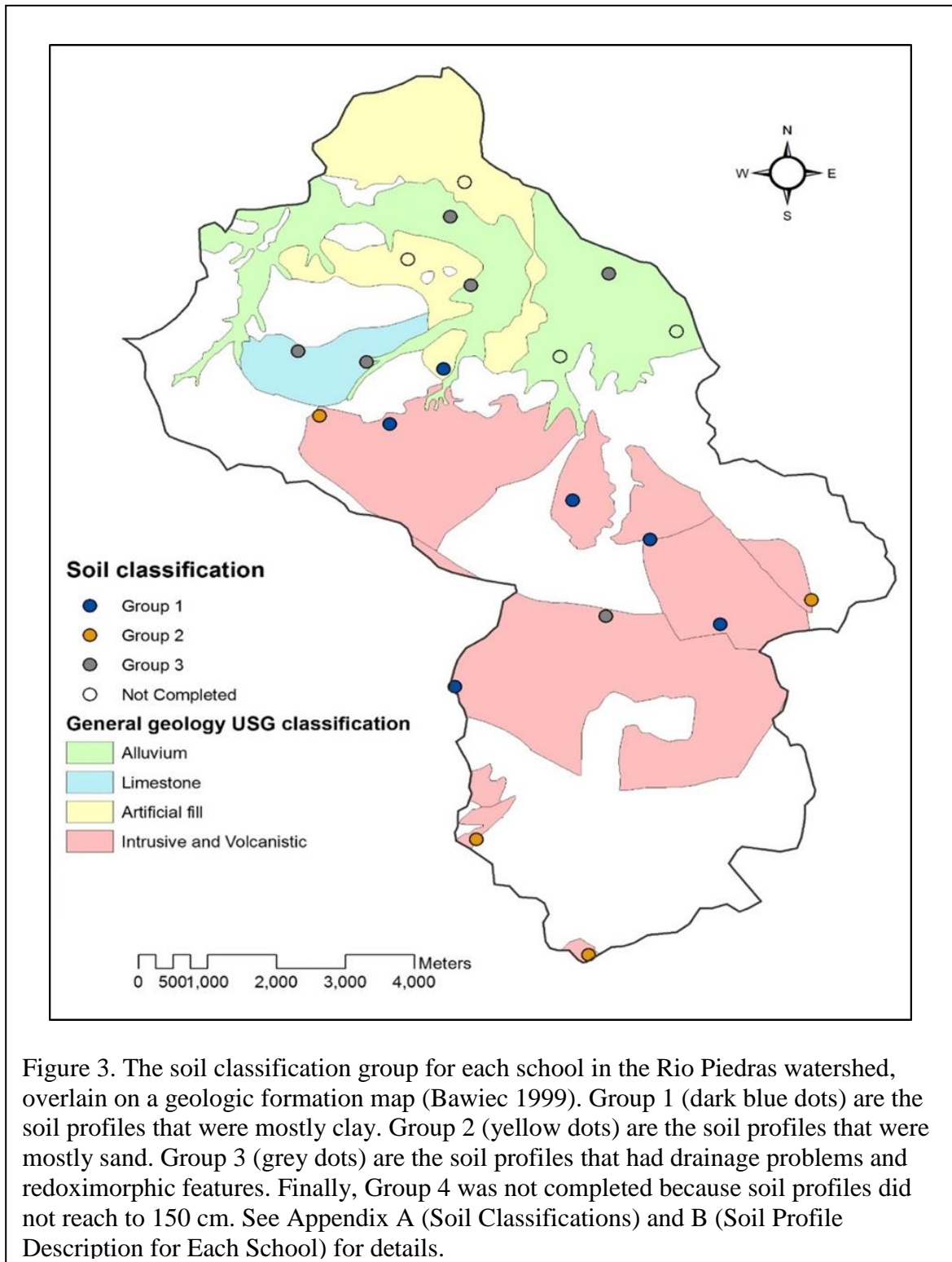
value for root growth restriction (> 1.75 g/cm^3). Mean soil porosity of 47% (range of 30-53%), which compares favorably with the ideal pore space of 50% of soil volume (Brady and Weil 2010).

There were few differences in the physical and chemical properties of the soils across the watershed; for most these parameters, the coefficient of variation was lower than 40% (Table 2). In general, electrical conductivity, organic matter, and S-SO$_4$ are optimal for vegetable gardens. 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 areas where limestone gravel from construction increases the soil pH (Pavao-Zuckerman 2008; Soil Survey Staff 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). Some of the schools had Ultisols while others may have had weathered material mixed with alkaline material from construction. The Ca was below the recommended level (600 mg/kg) in all of the soils. The Mg was optimal (65 mg/kg) at only one school. None of the soils exceeded EPA limits for Cd, Cr, or Pb (U.S. EPA 2012). There were 7 schools with low to moderate sodic soils (15% < ESP< 30%) (Abrol et al. 1988).

This could be a constraint for the growth of vegetables that are susceptible to sodic conditions, e.g., beans and corn (Abrol et al. 1988). Al was detected at only one school, in strongly acidic soils where it is likely to affect plant root growth (Wright 1989). Overall, soils at schools with gardens did not have different chemical and physical properties than those at schools without gardens (MANOVA $F_{2, 17} =1.0$, $p = 0.6$). Using NMS, we did not find any relationships between social or spatial attributes of schools and soil properties (T < -0.36, p >0.05).

Table 2: Soil chemical properties of the school yards in the Rio Piedras watershed, with indications of where the values fall in the recommended ranges for five crops: cantaloupe (Ca), cucumber (Cu), eggplant (E), onion (O), and tomato (T) (Muñiz-Torres 1992).

	Mean	Minimum	Maximum	Above range	Below range	Within range
pH	7.51	5.23	8.45	Cu		Ca, E, O, T
Conductivity (µS/cm)	320.86	97.1	512			Ca, Cu ,E, O, T
Organic Matter (%)	2.94	1.25	4.33			Ca, Cu, E, O ,T
CEC (meq/100g)	2.1	1.0	4.0		Ca, Cu, E, O, T	
Phosphorus (mg/Kg)	3.31	0.4	16.4		Ca, Cu, E, O, T	
Potassium (mg/Kg)	4.78	0.44	18.41		Ca, Cu, E, O, T	
Calcium (mg/Kg)	364.13	122.2	502.5		Ca, Cu, E, O, T	
Magnesium (mg/Kg)	21.11	5.78	65.19		Ca, Cu, E, O, T	
Sodium (mg/Kg)	2.95	1.68	5.83		Ca, Cu, E, O, T	
S-SO$_4$ (mg/Kg)	16.23	3.29	140		Ca, Cu, E, O, T	

Figure 3. The soil classification group for each school in the Rio Piedras watershed, overlain on a geologic formation map (Bawiec 1999). Group 1 (dark blue dots) are the soil profiles that were mostly clay. Group 2 (yellow dots) are the soil profiles that were mostly sand. Group 3 (grey dots) are the soil profiles that had drainage problems and redoximorphic features. Finally, Group 4 was not completed because soil profiles did not reach to 150 cm. See Appendix A (Soil Classifications) and B (Soil Profile Description for Each School) for details.

DISCUSSION

Preferences of School Administrations

An important finding of this study was that the number of schools with gardens was much lower than the number of schools with people interested in establishing a garden. Studies of the sustainability of school gardens have been conducted worldwide, with most in California (Clabeaux 2013; Azuma et al. 2001; Ozer 2007; Hazzard et al. 2011). With a recent nationwide survey, Yu (2012) addressed the question, "What factors limit the establishment of school gardens?" The author found that 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 viewed as supplemental educational resources that are not seen as central to the school operation (Azuma et al. 2001; Joshi et al. 2008). No government institution or school district has normally financed or provided long-term support to school garden programs, making it difficult for these programs to develop as their leaders are always looking for funding.

The percentage of schools in the Rio Piedras watershed that discontinued gardening was high (55%) when compared with schools in Los Angeles (14%) (Azuma et al. 2001) and nationwide (10%) (Yu 2012). The reasons for ending gardening programs are similar: lack of funding, turnover of staff, and the burden on teachers (Yu 2012; Azuma et al. 2001). In Los Angeles, most of the sponsors and funding come from fundraising, non-profit organizations, and non-government grants, with much less from government grants (Clabeaux 2013). Programs that had supported school gardens in Puerto Rico were run by local government (e.g., Verde Esperanza Educational Program, Ideas Verdes environmental education program, Siembra Vida Initiative of Office of the First Lady of Puerto Rico), non-profit organizations (volunteers from Fideicomiso de Conservación de Puerto Rico assisted with the Biocomiso garden initiatives), federal organizations (EPA-Urban Waters Small Grants), and by individual 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, after which the schools are left without support for the gardens. Median household income in Puerto Rico for 2015 was $18,626 well below that of California ($64,500); and that of the national level for 2011-2015 ($55,775 US Census Bureau 2015) in the US. Given that student attending public schools in San Juan come predominantly from low income households, the lack of funding might have been a more critical factor in the persistence of school gardens in our study relative to other studies.

Strong leadership and partnerships can contribute greatly to the long-term success of school gardens. When school principals in the Rio Piedras watershed were asked about factors that facilitated the establishment of a garden, they cited engagement of school community (faculty, administration, students, and parents) as the most important factor. Another factor mentioned 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."

A limiting factor unique to Puerto Rico compared to other U.S. school jurisdictions is the green iguana. With few predators and competitors, this invasive reptile has become a severe agricultural pest as its population has expanded considerably on the island (López-Torres et al. 2012). One of the principals stated, "We had tomatoes plants but the iguanas ate it, even when we covered them over the weekend and we got back there were no tomatoes." Animal pests in gardens represent a threat for intended crops but they also represent an opportunity for students to have a deep understanding about the agricultural food system and the relationship between animals and plants (Trexler 2000). To the extent that school gardens are well-integrated to the curriculum, a variety of topics can be developed around them such as pest monitoring, insect's identification, non-chemical pest removal, and biological control and others (Trexler 2000).

The factors associated with implementing and sustaining school gardens are common across communities, nations, and cultures (Azuma et al. 2001; Joshi et al. 2008; Hazzard et al. 2011; Yu 2012). Our study highlights (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 the involvement of at least three committed persons within the following groups: administration, teachers, parents, or volunteers (Hazzard et al 2011). 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, and most importantly integrating gardening into the school curriculum can assure that the school garden that is built can persist and benefit everyone. Curricular integration while acknowledged as important by all teachers may not be as developed in this school network. Of all teachers, only one articulated which specifics courses were more amenable to curricular integration of gardens and how that integration could be achieved.

This study had identified unique factors that will help school's administration to develop and sustain vegetable gardens in the Rio Piedras watershed elementary schools, as well as confirm similar factors with schools worldwide. However, there are some differences and we need to keep exploring the relevance of institutional factors and initiatives to gardens. For example, more research about how to implement and gardens curriculum in the conventional school plans and how non-profit organization and local government can develop long term support for this activity.

School Soils Compared With Other Urban Soils

The soils in the schoolyards had been severely altered and often mixed with other types of soil. There were only three schools with soils 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, they were mostly sand, with yellow color and slightly alkaline pH. Soil mapping relies on landscape and geologic data, without anthropogenic data that reflect human disturbance, limiting its accuracy and usefulness in urban environments (Shuster et

al. 2014). Many of the physical and chemical properties of the schoolyard soils described here are similar to those described in other studies of urban soils although there are some differences (Table 3). Bulk density, pH, organic matter, and heavy metal concentrations all fall within the range of urban soils worldwide (Short et al. 1986; Ruiz-Cortés et al. 2005; Pouyat et al. 2007; Tume et al. 2008; Hagan et al. 2012). High bulk density (1.0-1.7 g/cm^3 across urban soils, 1.4 g/cm^3 in our schoolyards) is the most serious and common soil degradation in urban areas (Yang and Zhang 2015). Another common characteristic of urban soils is high pH (6.2-8.7 across urban soils, 7.5 in these schoolyards), which is attributed to additions of concrete, cement, and plaster (Scheyer and Hipple 2005; Pouyat et al. 2007; Short et al. 1986). Indeed, urban soils in San Juan tended to be on the high end of the spectrum among cities with documented soil characteristics (Table 3) which may suggest that this practice is rather common in this city. Soil pH affects nutrient availability, which can be ameliorated by adding sphagnum peat, elemental sulfur, or other acidic materials (Havlin et al. 2013). Organic matter content in cities may be high or low depending on local conditions. High organic matter contents in cities may result from high organic pollutants, decelerating mineralization of plant residue due to heavy metals, and high vegetation productivity caused by elevated temperatures, high CO_2 levels, and nutrient inputs (Vodyanitskii 2015). However, the percent organic matter in San Juan school soils was rather low relative to two other cities (Table 3) perhaps a reflection of the extremely low vegetation cover in schools either via current maintenance practices that tend to favor lawns over woody cover or the fact that construction practices often rely on clearing land of all existing vegetation and topsoil prior to construction contributing to long-term footprints of low soil organic content (pers obs). This type of activity which is common in cities may lead to soil compaction and low levels of soil organic content through reduced porosity and soil microbial activity (Vodyanitskii 2015).

Urban soils typically have high levels of Ca, K, Mg, and P, as well as high sand and low clay percentages (Pickett et al. 2008), but this was not the case in the Rio Piedras watershed schoolyards. These soils exhibited high clay content with low CEC, which is common of soils in wet tropical regions where nutrients are leached by abundant rain (Juo and Franzluebbers 2003; Havlin et al. 2013). On the other hand, we can't discard the possibility that differences in soil texture and composition between San Juan and other cities are also the result of local soil management practices and variability in what is used as fill for urban development projects. Puerto Rico is unique from other places, in that it has one of the highest number of soils series per area (over 175 for the island, Beinroth et al. 2003). This spatial variability in soil origins may allow for different sources fill to be used across different localities and lead to observed differences between San Juan and other cities but also account for the high variability observed in soil Ca, Na, CEC, and texture among schoolyard soils within the Rio Piedras watershed (Table 2).

Generally, under the soil conditions described for urban soils, their potential to provide ecosystem services (facilitate root growth, water infiltration and storage, diffusion of gases like O_2 and CO_2, garden development) may be limited when one considers the high cost and the immense amount of effort that would be needed to reduce the top soil bulk density and add soil amendments (McCall 1980). However, at the small scale of school gardens remediation should be feasible. For example, soil can be tilled and soil conditioners (e.g., manure and compost)

added, improving soil structure, reducing bulk density and facilitating water infiltration and soil air flux (McCall 1980; U.S. EPA 2011). Once the physical condition is improved, the soil nutrient levels will have to be reassessed, as organic conditioners will increase nutrient concentrations. Because of the existing low nutrient concentrations, additional inputs of nutrients are likely to be needed.

In San Juan soils, some heavy metals like Cd and Cr were on the high end of the spectrum of soil variability across cities but all were below maximum allowed concentrations. High levels of heavy metals in urban soils may result from their proximity to roads and high traffic density (Rodríguez-Flores and Rodríguez-Castellon 1982). 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 child exposure (Gorospe 2012; Ruiz-Cortes et al. 2005). Exposure to lead is a major public concern because it is a neurotoxin, and intestinal absorption is approximately five times greater in children than adults (Clark et al. 2008). Guidelines from government agencies of several countries disagree on the concentrations of various heavy metals that are safe for gardening (Ruiz-Cortes et al. 2005). Although 400 ppm of Pb is generally considered a protective screening level for residential soils, this standard may not be suitable for children (Gorospe 2012; U.S. EPA 2014). California's Human Health Screening Level, which considers exposure through "incidental soil ingestion, dermal contact, and inhalation of vapors or dust," and represents concentrations "below thresholds of concern for risks to human health" is 80 ppm of Pb in for children (Ca. EPA 2005; Gorospe 2012). According to the U.S. EPA, the low-risk concentration of Pb in soil is less than 100 ppm (U.S. EPA 2014). Lead concentrations from 100 to 400 ppm pose potential risks. In our study, only one school had a Pb level higher than 100 ppm (155 ppm). 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).

Other chemicals harmful to crops are Al, Pb, and Na. Soils with low pH have H^+ ions that are absorbed by clay and attack mineral structure (e.g., aluminum oxides) releasing exchangeable and soluble Al (Havlin et al. 2013). This creates high Al^+ content in the soil, with the strong tendency of Al^+ to hydrolyze water molecules which results in a more acidic soil (Brady and Weil 2010). Remediating high Al soils by applying lime to increase soil pH above 7 will cause Al to precipitate as an uncharged ion (Wright 1989). Some plants tolerate high Al, including maize (*Zea mays*) and some ornamentals (e.g., *Melastoma affine, Hydrangea* spp.) (Wright 1989). Based on ESP, there are 7 schoolyards with enough Na to adversely affect soil structure and plant growth (Abrol 1988; Juo and Franzluebbers 2003).

Sodic soils can be remediated with materials such as gypsum, low solubility calcium salts (e.g., ground limestone), acids (e.g., sulfuric acid), and even some types of tree and grasses (e.g., Eucalyptus hybrids and wheatgrass (*Agropyron* spp.) (Abrol et al. 1988). Another possibility for reducing concentrations of Na, Al, and Pb is bioremediation (U.S. EPA 2011). For example, Pb can be sequestered by plants such as *Brassica* spp. (mustards), though extreme care must be taken to ensure that any plants used for this purpose are not eaten.

Table 3. Soil physical and chemical properties of the schoolyards compared to other urban soils (CEC = cation exchange capacity. For the Rio Piedras Watershed values represent averages across 20 schools.

Location/ Place	land use	bulk density (g/cm)	pH	% sand	% clay	% silt	% organic matter	CEC (meq/ 100g)	Cd (mg/kg)	Cr (mg/kg)	Pb (mg/kg)
Washington DC [1]	park	1.6	6.4	49	18	33	1.97	11.2	0.57	-	184
Florida [2]	residential	1.0	6.2	-	-	-	5.12	.	0.43	-	38
Spain [3]	urban	-	7.2	-	-	-	-	15.4	2.89	38.4	156
Baltimore [4]	park or golf course	1.2	6.4	51	19	30	5.90	-	-	91.0	109
Hong Kong [5]	urban	1.7	8.7	81	7	12	-	-	0.36	17.8	88
Chile [6]	urban	-	6.6	99	0	1	6.70	-		37.8	35
Rio Piedras Watershed [7]	urban schoolyards	1.4	7.5	39	39	22	2.90	2.1	2.20	70.0	42

[1] Short et al. 1986, [2] Hagan et al. 2012, [3] Ruiz-Cortés et al. 2005, [4] Pouyat et al. 2007, [5] Jim 1998, [6] Tume et al. 2008, [7] this study

While the soil remediation mentioned above can help to restore soils functions and their ecosystem services, raised beds can be a more feasible option for vegetable gardens. Using raised beds is the most popular approach to grow vegetable gardens across schools and other urban gardeners because enables gardening on different terrain conditions and soil capacities to sustain vegetables (Dirks 2011). Advantages for raised beds garden includes: reduction in the exposure of plants to soil and water contaminants, are usually more productive than gardening directly in the ground, provide good drainage, are easy to manage, and tend to be constructed with at a low cost and using recycle material (Berle and Westerfield 2013). However, a disadvantage is that beds dry quickly and thus need constant irrigation to maintain an adequate amount of water for vegetables. In addition, not all crops are well suited for raised beds; for example, corn, large root vegetables, watermelons and other type of climbing plants (Berle and Westerfield 2013).

CONCLUSION

School gardens are promoted as stepping-stones for leading future generations to more sustainable ways of living (Joshi et al. 2008; FAO 2010; Turner et al. 2014). Successful development of vegetable gardens at schools in the Rio Piedras watershed is dependent on both social factors (the engagement of stakeholders and more structured garden curricula) and soil management (good soil management). Even when our study targeted elementary schools, lessons learned from this study could well be applied to other school levels. Indeed, there is no universal model of garden-based learning that can be applied to every community, but our findings can be used to highlight the social and ecological perspectives of school gardens and give some paths for better problem-solving approaches, which may lead to improvements of school gardening in Puerto Rico. For example, even when there is willingness is high external, funding for school garden development may be an important issue in jurisdictions where per capita income is particularly low. Moreover, soil conditions may be poor and prevent good yields in school gardens. Ultimately, each school must design its own plan depending on their individual needs of social (curriculum integration, engagement, sponsorship, skills and logistics) and ecological factors. Designing such plans may benefit from adaptive management approaches that evaluate the success of school garden interventions over time. Socio-ecological research using mixed methods such as the one presented here is needed to integrate environmental initiatives that will contribute to restore soils and look for efficient partnership between schools and institutional organizations to address the needs of its learners and educators. In that context, our results provide the groundwork for Rio Piedras school communities to improve garden success by identifying common constrains in the school district.

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Appendix A. Soil Classifications
Group 1

12"	**Characteristics**
	The soil profile consists mostly of clay texture through more than 35″ of the soil depth. They are mostly located in the middle of Rio Piedras watershed, are well drained and moderately slowly permeable soils.
24"	Thickness of the soil is 60″. Texture is clay, clay loam, silty clay, and silty clay loam. The A horizons range from 3 to 11″, with colors hue of 5YR to 10 YR, value of 3 to 4, and chroma of 2 to 4. The B horizons have hue of 2.5 YR to 2.5 Y, value 3 to 5, and chroma 3 to 8.
	Schools with soils in this group
	3. José M. Rivera Solis
36"	4. Ana Roque De Duprey
	5. Rafael Quiñones Vidal
	6. Carmen Sanabria Figueroa
	9. José Colomban Rosario
	12. República de Brasil
48"	
60"	

Group 2


12" 24" 36" 48" 60"	**Characteristics** The soil profile consists mostly of sand texture through more than 25″ of soil depth. They are well drained soils mostly located in the upper and middle low of Rio Piedras watershed. Thickness of the soil is 60". Texture is sandy clay and sandy loam. The A horizon textures are sandy clay and sandy loam range from 3.5 to 13″, with colors hue of 5YR to 10YR, value of 3 to 5, and chroma of 3 to 6. The B horizons are sandy, silty clay, sandy clay loam, loamy sand, and sandy loam, with hues of 2.5Y to 10YR, values 3 to 6, and chroma 3 to 8. **Schools with soils in this group** 1. Aberaldo Diaz Alfaro 2. Felisa Rincón de Gautier 11. Rafael Rivera Otero 16. Fair View

Group 3

12" 24" 36" 48"	**Characteristics** Group 3 soil profiles are characterized by poor drainage, with of low chroma through more than 30″ of depth. They are mostly located in the lower and middle of Rio Piedras watershed. Thickness of the soil is approximately 60", with a wide range of color and texture. The horizons had no structure and has many light and white redoximorphic features. The A horizons range from 5 to 16″, with textures of sandy clay loam, sandy clay, and clay loam. Color hues are 2.5YR to 10YR, values 3 to 4, and chroma 3 to 6. The B and C horizons are silty clay, silty loam, loamy sand, clay, sandy clay, and sandy loam with hues of 2.5Y to 10YR, values 4 to 8, and chroma 1 to 8. **Schools with soils in this group** 7. El Señorial 14. Luis Muñiz Soufront 15. Rafael Hernández Marín 19. Escuela la Esperanza 20. Dr. Antonio S. Pedreira. Structureless matrix with many light gray (5Y 7/1) redoximorphic features

Group 4

12"	**Characteristics** Stones and really tight soils made it impossible to make profiles of these soils with a hand auger. **Schools with soils in this group** 8. Julio Selles Sola 10. Victor Parés Collazo 13. Eugenio María de Hostos 17. Nemesio Canales El Señorial Clay cementation

Appendix B - Soil Profile Description for Each School

1. Aberaldo Diaz Alfaro (geographic coordinates: 18.31255, -66.062875)

Ap: 0-13″ - brown (10 YR 5/3) sandy clay loam; strong brown (7.5 YR 5/8) common prominent concentrations, 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″ - olive brown (2.5 Y 4/4) sandy clay; strong brown (7.5 YR 5/8) common prominent concentrations, brown (10 YR 4/3) few distinct concentrations, weak medium subangular blocky, slightly plastic, slightly sticky, friable.

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

2. Felisa Rincon de Gautier (geographic coordinates: 18.3394806, -66.0858639)

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

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

BA: 7.8-11.7″ - 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 concentrations; moderate medium subangular blocky structure, friable, slightly sticky, moderate plastic, about 20% of small rocks.

Bt: 11.7-19.0″ - 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 concentrations; moderate medium subangular blocky structure, friable, moderately sticky, moderately plastic.

Bt$_2$: 19-33″ - 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″ - yellowish brown (10 YR 5/8) sandy loam; weak fine granular structure, friable, non sticky, slightly plastic.

3. Jose M. Rivera Soils (geographic coordinates: 18.3592944, -66.0457111) (unpublished data from study described in U.S. EPA 2015)

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

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

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

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

4. Ana Roque De Duprey (geographic coordinates: 18.3876417, -66.0888028)

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

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

Bt_1: 19-34″ -; reddish brown (5 YR 4/4) clay; yellowish red (5 YR 4/6) common faint concentrations; moderate medium angular blocky structure, firm, slightly sticky, moderate plastic, about 12% of small minerals.

Bt_2: 34-44.5″ - yellowish red (5 YR 5/8) clay; moderate fine granular structure, friable, moderate sticky, slightly plastic, many small minerals.

Bt_3: 44.5-53″ - yellowish red (5 YR 5/8) clay; yellow (2.5 Y 7/8) common prominent concentrations, moderate fine granular structure, friable, slightly sticky, slightly plastic, many small minerals.

C: 53-60″ - yellowish red (5 YR 4/6) sandy clay; moderate fine granular structure, friable, slightly sticky, slightly plastic.

5. Rafael Quiñones Vidal (geographic coordinates: 18.3505056, -66.0803083)

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

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

C2: 15-36″ - 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″ - red (2.5 YR 4/8) clay loam; red (10 R 4/8) many faint concentrations, olive yellow (5 Y 6/8) common prominent concentrations, olive grey (5 Y 4/2) common prominent concentrations, moderate medium subangular blocky structure, friable, moderate sticky, moderate plastic.

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

6. Carmen Sanabria Figueroa (geographic coordinates: 18.3713139, -66.0548861)

A: 0-6″ - 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.

Bt_1: 6-8″ - 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.

Bt_2: 18-31.5″ - 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 concentrations, very thin platy structure, moderate sticky, very plastic, few fine roots.

Btg_1: 31.5-41″ - 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.

Btg_2: 41-61″ - 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 (geographic coordinates: 18.3604583, -66.0606639)

A: 0-3″ - 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″ - 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″ - yellowish brown (10 YR 5/6) sandy clay loam; common prominent light gray (10 YR 7/1) concentrations, few prominent black (2.5 Y 2/0) concentrations, weak fine subangular blocky, friable, moderately sticky; moderately plastic,

Bg$_1$: 22.5-37.8″ - yellowish brown (10 YR 5/6) sandy loam; many distinct red (2.5 YR 4/6) concentrations, many prominent gray (10 YR 6/1) concentrations, few prominent black (10 YR 2.5/1) concentrations; moderate fine granular structure; friable, slightly stick; slightly plastic.

Bg$_2$: 37.8-46.46″ - yellowish red (5 YR 4/6) loamy sand; common prominent gray (10 YR 6/1) concentrations, common prominent black (5 YR 2.5/1) concentrations; moderate fine granular structure, non-sticky, slightly plastic.

Bg$_3$: 46.46-59.10″ - yellowish brown (10 YR 5/8) loamy sand; common prominent gray (10 YR 6/1) concentrations; few prominent very dark brown (10 YR 2/2) concentrations; moderate fine granular structure, non-sticky, non-plastic.

8. Julio Selles Sola (geographic coordinates: 18.3972194, -66.0666111)

A: 0-3.5″ - dark brown (10YR 3/3) sandy clay loam; common prominent light olive gray (5Y 6/2) concentrations; few prominent yellowish brown (10 YR 5/8) concentrations; weak fine granular structure, slightly sticky, moderately plastic, few fine roots.

Bw: 3.5-12″ - 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 1.5″.

9. Jose Colomban Rosario (geographic coordinates: 18.3768333, 66.0649639)

A: 0-6″ - 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) concentrations; moderate fine granular structure, slightly sticky, moderate plastic, common fine roots.

Bt$_1$: 6-13″ - brown (7.5 YR 4/4) clay loam; common prominent red (2.5 YR 4/8) concentrations, common 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.

Bt$_2$: 13-27″ - 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.

Bt$_3$: 27-37″ - 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.

Bt$_4$: 37-45″ - 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″ - 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 (geographic coordinates: 18.4063, -66.06023) (unpublished data from study described in U.S. EPA 2015)

A: 0-5.9″ - 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.

C$_{1u}$: 5.9-15.8″ - 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.

C$_{2u}$: 15.8-20″ - red (2.5 YR 4/6) sandy clay; massive structureless.

C$_3$: 20-33.5″ - yellowish brown (10 YR 5/6) sandy clay loam; many red (2.5YR 4/6) concentrations; massive structureless.

C$_4$: 33.5-43.3″ - brownish yellow (10 YR 6/6) clay.

A$_u$: 43.3-53.1″ - weak red (2.5 Y 4/2) clay. (This is likely the surface horizon of the original soil that was covered with fill that formed the horizons now above it.)

C$_u$: 53.1-55″ - light gray (10 YR 7/1) silty loam.

Cg: 55- 61″ - dark gray (10 YR 4/1) clay; gleization.

11. Rafael Rivera Otero (geographic coordinates: 18.3887944, -66.0979889)

A: 0-6″ - 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.

Bt$_1$: 6-12″ - 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.

Bt$_2$: 12-34″ - 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.

Bt$_3$: 34-46″ - 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.

Bt$_4$: 46- 60″ - 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 (geographic coordinates: 18.3954278, -66.0818278)

A: 0-11″ - 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″ - 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″ - 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″ - 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″ - 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 (geographic coordinates: 18.4109889, -66.0864667)

A: 0-11″ - 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 (geographic coordinates: 18.3964444, -66.0918444)

A: 0-5″ - 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″ - 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″ - 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″ - 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″ - 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 (geographic coordinates: 18.3979889, -66.1007611)

A: 0-6″ - 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 roots.

Bt₁: 6-11.5″ - 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.

Bt$_2$: 11.5-16.5″ - 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.

Bt$_3$: 16.5- 21″ - 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.

Bt$_4$: 21-32″ - 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″ - 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″ - red (10 R 4/8) sandy clay; many prominent white (5 Y 7/1) concentrations; many distinct dark red (10 R 3/6) concentrations; massive structureless, moderate sticky, moderately plastic.

16. Fair View (geographic coordinates: 18.3627556, -66.0338278)

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

Bt$_1$: 6-15.5″ - yellowish brown (10 YR 5/8) loamy sand; strong very fine granular or single grain structure, non-sticky, non-plastic.

Bt$_2$: 15.5-48″ - 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.

Bt$_3$: 48-57″ - 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 (geographic coordinates: 18.4218667, -66.0790611)

A: 0-16″ - 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).

B$_t$: 16-20″ - 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) concentrations; weak medium granular structure, very sticky, moderate plastic, high rock content.

18. Escuela Elemental de la Universidad de Puerto Rico (geographic coordinates: 18.4006639, -66.0502750)

A: 0-6.5″ - 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.

B$_w$: 6.5-13″ - 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 (geographic coordinates: 18.4169778, -66.0809417)

A: 0-16″ - 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.

C$_1$: 16-31″ - red (10 R 4/8) silty clay; many prominent light gray (10 YR 7/2) concentrations; massive structureless, very sticky, very plastic.

C$_2$: 31-46″ - 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″ - 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 (geographic coordinates: 18.4072972, -66.0782167)

A: 0-7″ - 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″ - 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$_1$: 18-24″ - 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$_2$: 24-43.5″ - 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$_{g1}$: 43.5-52″ - 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$_{g2}$: 52-62″ - 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.