Assessing and managing soil quality for urban agriculture in Ohio

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Abstract

Urban agriculture (UA) is rapidly expanding in the majority of Ohio's cities and is widely recognized as a means of improving the ecological conditions, quality of life, and food security in urban areas. This project will apply the soil quality evaluation process to soils being used for specialty crop production in urban areas in Ohio with the goal of better understanding their soil properties and identifying appropriate management strategies. The project is focused around two major components: an experimental research site and a field study of production sites. The experimental site is located in a series of adjacent vacant urban lots in Youngstown OH where vacant houses were recently demolished and removed. The demolition process often leaves soils severely degraded and this experiment will document the soil's initial condition following demolition, as well as the ability for the soil to be improved for UA by applying organic matter. Experimental treatments focused on applying organic soil amendments produced from urban green wastes will be applied in a replicated, complete block experimental design, including the following treatments: 1) control, 2) leaf compost, 3) leaf compost + intensive cover cropping, 4) leaf compost + hardwood biochar. All plots are split plots comparing in ground cultivation with cultivation in 20cm raised beds. The experiment will be run for the 2011 and 2012 growing seasons. Data will be collected on vegetable crop yield and on soil physical, chemical and biological properties and analyzed through both hypothesis testing and soil quality indexing.

Compaction is a primary constraint at the site with bulk density values of 1.79 g cm^{-3} for in ground plots and 1.55 g cm^{-3} for raised beds. Crop yield data from 2011 demonstrate strong treatment effects on both crop yield ($p=0.002$) and harvest index ($p=0.008$). Both compost amended and compost + biochar amended plots had significantly greater crop yields than control plots, while compost + biochar plots had the highest harvest index values. An additional study in 2012 will conduct soil quality assessment at urban market gardens in Ohio and provide producers with a soil quality report and management recommendations. Expected outcomes include improved knowledge and management of UA soils in the region.

1. Introduction

The formerly industrial cities of the North Central region have become a rapidly expanding frontier for urban agriculture (UA) in the US. As populations in these cities have declined, a legacy of vacant land and properties has been left behind (Table 1). The city of Cleveland currently has more than 1,500 hectares (ha) of vacant land in the city, while Youngstown, Ohio contains more than 20,000 vacant city parcels (CUDC 2008). UA has emerged as an important means of utilizing vacant land and is capable of producing numerous societal benefits, including: improved nutrition, increased food security, and income generating opportunities (Smit et al. 1996). Urban soils, however, are highly variable and subject to high levels of anthropogenic degradation (Lehman and Stahr 2007). An understanding of local soil properties is a basic starting place for sustainable agriculture, yet this information is simply not available in most urban areas.

UA has been expanding rapidly in the North Central region of the U.S. during the past few years. Extension personnel in Cleveland and Detroit estimate that 40-50 and over 20 market-based urban farms have come online in the past five years in those two cities, respectively (Pers. Comm.). Many UA sites are located in "urban food deserts," or areas where citizens do not have access to nutritious foods in the quantities required by dietary recommendations (Wrigley 2002, CUDC 2008). Participation in UA has been linked to increased consumption of fruits and vegetables at both the household (Alaimo et al. 2008) and neighborhood (Zezza and Tasciotti 2010) levels. UA has also demonstrated the potential to generate economic revenue in impoverished areas in the region (Mallach and Brachman 2010; CUDC 2008). A recent report by the Brookings Institute suggested that UA can play a significant role in improving quality of life in urban areas in Ohio, but that greater technical support is needed to increase success among urban producers (Mallach and Brachman 2010). Currently, very little information exists about the characteristics of urban soils or options for their management in the North Central region, and little research has been conducted on crop production in urban areas in the U.S. as a whole. Even the published soil surveys lack specific information about urban soils and tend to group them together into generic urban land complexes. This project will address this unique knowledge gap by generating important background data and management recommendations for urban soils.

Table 1. Vacant land and urban agriculture in shrinking cities.

	Youngstown, OH	Cleveland, OH	Detroit, MI
% Change in Population (1950-2007)	- 61%	- 57%	-55%
Number of Vacant Parcels	23,000	>18,000	>60,000
Area of Vacant Land	>2,800 ha	>1,500 ha	1,900 - 10,000 ha
Urban Farms and Community Gardens	15 *	75 *	>300
Market/Production-based Urban Farms	2 *	25-35 *	20

* Indicates sites founded during past five years. Table adapted from Beniston and Lal (2012).

The soil quality framework is a useful tool for assessing site-specific soil conditions and developing adaptive management strategies. The concept of soil quality (or soil health) is generally defined as “the ability of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant, animal and human health”(Doran and Parkin 1994). Healthy soil function promotes the robust functioning of the wider ecosystem. Many essential ecological services are provided by soils, including: hydrological cycling, supporting plant growth, the cycling and storage of plant nutrients, the decomposition of organic matter, and the moderation of biogeochemical cycles (Daily et al. 1997). Deriving these functions from soils may be especially critical in urban areas, where areas of soil and vegetation must provide ecosystem services within a much larger landscape of impervious surfaces.

Soil quality is typically evaluated by field and laboratory analyses of a suite of soil physical, chemical, and biological properties. Values measured for individual properties are then scored with scoring functions that represent the range in expected values for that soil property based on soil type, soil texture, and ecological conditions (Karlen and Stott 1994; Andrews et al. 2004). Individual property scores are then tabulated into an index which results in an overall soil quality score.

This study will utilize soil and ecosystem science methods to address a current and timely topic for natural resource management for the North Central U.S.: the utilization of vacant and degraded urban land for UA. Large areas of vacant land exist in many cities of our region and these areas are increasingly being used for UA and public green spaces (Table1). Many of these sites, like the study site in this project, have undergone a demolition process to remove vacant houses and buildings. The demolition process often leaves soils at these sites severely compacted to the extent that plant growth and water infiltration are inhibited (USEPA 2011). Importing topsoil to improve soil conditions is an option for improving these sites, but requires higher costs and ecological impacts associated with sourcing the topsoil. Soil amendments made from processed organic matter such as compost and biochar offer a potential solution to revitalizing these disturbed soils by applying materials from the urban green waste stream to them. This process has the potential to improve soil restoration and UA outcomes at these sites, reduce costs associated with amending these soils, and reduce the export of green wastes from urban areas.

This study has established a soil research garden on a series of vacant urban lots where houses were demolished during the previous year with the following research objectives: 1) To assess soil properties and soil quality in a vacant lot soil where buildings have recently been demolished; 2) To determine the ability of organic matter amendments to improve soil quality and vegetable crop production in a recently disturbed vacant lot soil; and 3) To compare crop growth and soil properties in plots with raised beds with 10cm of soil from the site with plots where plants were grown directly in the ground. Data are being collected on numerous soil properties both in the time directly after building demolition and after the soil has been amended with different types of organic matter, thus providing unique and valuable information relevant to the management and restoration of urban soils following building demolition.

2. Methods

2.1 Study Site

The experimental site for this project is located in the Idora Neighborhood, on the south side of Youngstown, OH. Youngstown is a city whose population has decreased dramatically through the past 50 yrs (Table 1) and vacant property/land reuse is currently a major topic of interest in the city. The Idora neighborhood contains a large number of vacant lots and is also home to a few very active community groups.

The experimental plots were established during spring 2011 on 3 contiguous urban lots where vacant homes were deconstructed and demolished the previous autumn and winter. This provides the opportunity to assess soil conditions and the effect of our management directly following the heavy disturbance of deconstruction.

2.2 Experimental design

The experimental plots for this project are laid out according to a split plot randomized complete block design. There are three primary treatments of differing organic matter inputs to the soil, and a fourth unamended treatment that serves as a control. The treatments are replicated six times for a total of twenty-four main plots. Additionally, all plots contain a split-plot treatment comparing cultivation in raised beds, with additional soil from the site added, with planting crops directly into the ground. Each full plot is 6 m long by 1.5 m wide, and the split plots are 3 m long by 1.5 m wide.

The treatments all contain compost that was produced from urban leaf wastes by a landscaping company near the site (Table 2). The compost (Cmp) was added to all treatment plots at a rate of 15 kg m^{-2} or 150 Mg ha^{-1}. This consisted of applying an approximately 10 cm deep layer of compost to each plot and incorporating through tillage, which is equivalent to approximately 50% by volume application to the soil surface (0-10 cm). The compost + biochar (C+B) treatment also received 20 Mg ha^{-1} application of biochar produced from hardwood feedstock. The compost + intensive cover cropping (ICC) treatments was planted to Sorghum x Sudangrass (*Sorghum bicolor X Sorghum bicolor subsp. drummondii*) for the first summer season. Tillage radish (*Raphanus sativus*) was then be sown into the Sorghum x Sudangrass as an autumn cover crop. All plots were planted with annual ryegrass (*Lolium multiflorum*) as a winter cover crop.

Table 2. Experimental treatments.

Primary Experimental Treatments	Split Plot Treatment
1) Control	1) In Ground Cultivation
2) Compost (15 kg m^{-2})	
3) Compost (15 kg m^{-2}) + Biochar (2 kg m^{-2})	2) 20cm Wooden Raised Beds with 10cm additional soil from on site
4) Compost (15 kg m^{-2}) + Cover Cropping (Sorghum X Sudangrass)	

Crop plants were established in the plots in early June 2011. In 2011, paste tomatoes (*Solanum lycopersicum*), swiss chard (*Beta vulgaris* subsp. *cicla*), and sweet potatoes (*Ipomoea batatas*) were each planted in two full replications of soil treatments. This planting scheme was utilized to simulate the diverse cropping systems found in small scale vegetable production and to represent vegetable crops of fruiting, vegetable, and root types. Crops were primarily rain irrigated with supplemental irrigation through dry periods. A drip irrigation system was used to provide uniform irrigation throughout all plots.

2.3 Soil analysis methods

Soil samples were collected from each split plot at 0-10 and 10-20 cm depths. Samples included both intact core samples and composited bulk soil samples. All plots were sampled prior to the onset of treatments to assess baseline conditions at the site. Soil analyses will be performed on both the baseline samples and those collected in autumn 2012 following two full growing seasons.

Soils from the site are being analyzed for a suite of soil physical, chemical and biological properties. Results presented in this report, however, reflect preliminary findings and thus contain results from a small subset of the soil analyses. Analyses presented include the physical methods of penetration resistance (Bradford 1986) and bulk density (core method) (Blake and Hartge 1986), and the chemical method of microwave assisted digestion and full element analysis (U.S. EPA 1994). Penetration resistance (PR) was measured using static hand cone penetrometer (Eijkelkamp, Giesbeek, The Netherlands). The penetrometer was inserted vertically downward into the soil at a speed of approximately 1 cm s^{-1}. Measurements were taken in triplicate for each split plot for both the 0-10 and 10-20 cm depth. Field PR was calculated by dividing the penetrometer reading (in N) by the base area (cm^2) of the penetrometer cone, and the units then converted to MPa. Field PR was measured in early June on baseline soil conditions, and in mid-August and late September after treatments were applied.

For the elemental analysis air dried soil was passed through a 2mm sieve. Samples were then analyzed according to U.S. EPA method 3051a (U.S. EPA 1994), microwave-assisted aqua regia digestion followed by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) analysis at the Environmental Soil Chemistry Lab at The Ohio State University.

2.4 Crop plant analyses

Vegetable crop yields were recorded at field moisture content. Swiss chard was harvested completely and yield recorded on 8-12-11. Tomatoes yields reflected two harvest dates 9-1-11 and 9-19-11. Vegetable crop yields were sorted according to visual inspection, and only those deemed of marketable condition were included in the yield measurement. For vegetable crops, a harvest index was calculated by dividing the mass of marketable crop yield by the total plant biomass for each crop. Sorghum sudangrass was also harvested at two dates 8-5-11 and 9-27-11, and its yield values are presented in dry weight, following oven drying at 60 ˚C for 24 h.

2.4 Statistical analyses

Baseline soil properties were analyzed using a one-way analysis of variance (ANOVA) in JMP v 9 (SAS Inc., Cary NC) with organic matter treatments as the treatment effect. Tukey's honest significant difference (HSD) test (α=0.05) was utilized as a mean separation procedure. Crop yield data were analyzed using a split-plot analysis of variance ANOVA in PROC GLM of SAS v9.2 (SAS Inc., Cary NC). Organic matter treatments were treated as the primary treatment effect and raised beds as the split plot.

3. Results

Results presented in this report reflect measurements taken during the first growing season of a two year project, and are thus considered preliminary. A full presentation of all measurements will be in preparation following the 2012 growing season.

3.1 Soil physical properties

Baseline soil penetration resistance (PR) were significantly higher in the In Ground (G) plots than in the Raised Bed (RB) plots in both the 0-10 cm (G 8.31 MPa, RB 3.01 MPa) and the 10-20 cm depth (G 9.43 MPa, RB 7.63 MPa) (Table 3). These values all reflect conditions that can be considered compacted. The Cornell Soil Health Program has reported that PR levels above 2.07 MPa (or 300 psi) are restrictive to root growth (Gugino et al. 2009).

PR levels showed a significant reduction from the control plots under all of the experimental treatments during the second sampling date at both the 0-10 and 10-20 cm depths (Table 4). Control plots also showed decreased PR levels after planting, compared with the baseline values. At the third PR sampling date, Cmp and C+B treatments both demonstrated significant decreases in PR levels compared with the control at the 0-10 cm depth (Table 4). C

+B and ICC treatments demonstrated significantly reduced PR values compared with the control at the 10-20 cm depth.

Table 3. Baseline soil physical properties.

Depth	**Split Plot**	**Bulk Density ($g\ cm^{-3}$)**		**Field Penetration Resistance (MPa)**	
10cm	In Ground	1.79	A	8.31	A
	Raised Bed	1.55	B	3.01	B
20cm	In Ground			9.43	A
	Raised Bed			7.63	B

Capital letters indicate t-groupings from Tukey's HSD test of means (α=0.05).

Results from the baseline sampling date indicated that the soils in the RB plots had significantly lower bulk density (BD) (1.55 g cm^{-3}) than the soils in the G plots (1.79 g cm^{-3}). Both of these results indicate significant soil compaction at the site, as BD values ranging from 1.4 - 1.7 g cm^{-3} , depending on soil type, have been reported to have negative effects on root growth, while BD values ranging from 1.5 - 1.8 g cm^{-3} are considered restrictive to root growth (NRCS 2000).

Compaction has been observed in a number of previous studies of urban soils (Beniston and Lal 2012) and has often been associated with decreased rates of water infiltration in urban areas (Gregory et al. 2006; Pit et al. 1999). Results presented here support earlier observations by U.S. EPA (2011) that vacant urban lots where building demolition has occurred are subject to severe soil compaction. These results also indicate, however, that widely available soil treatments such as green-waste compost are effective in reducing reducing soil compaction levels (Pit et al. 1999).

Table 4. Field penetration resistance (PR) measurements for 2 dates.

Depth (cm)	Date - 8/12/11			Date - 9/25/11		
	Treatment	Field PR (MPa)		Treatment	Field PR (MPa)	
0-10	Control	3.50 (0.32)	A	Control	1.80 (0.18)	A
	Cmp	1.16 (0.32)	B	Cmp	0.91 (0.18)	B
	Cmp + Biochar	1.26 (0.32)	B	Cmp + Biochar	0.76 (0.18)	B
	Cmp + ICC	1.08 (0.32)	B	Cmp + ICC	1.14 (0.18)	AB
10-20	Control	6.36 (0.41)	A	Control	4.47 (0.22)	A
	Cmp	3.92 (0.41)	B	Cmp	3.64 (0.22)	AB
	Cmp + Biochar	3.73 (0.41)	B	Cmp + Biochar	3.12 (0.22)	B
	Cmp + ICC	4.26 (0.41)	B	Cmp + ICC	3.55 (0.22)	B

Values in parentheses are standard errors and capital letters indicate t-groupings from Tukey's HSD test of means (α=0.05).

3.2 Soil chemical properties

Trace element data from the baseline sampling at the site indicate that the soils at the site do not contain high enough levels of heavy metal trace elements to merit concern. The analysis included several metals of concern in urban areas (Table 5) including: arsenic (As), cadmium

(Cd), chromium (Cr), copper (Cu), lead (Pb) and zinc (Zn). All of the metals demonstrated levels that were background or slightly elevated.

The primary heavy metal of concern in urban soils is Pb. Large quantities of Pb were deposited in urban soils in the U.S. during the twentieth century through the use of Pb-based paints and leaded gasoline (Mielke et al. 2011; Mielke 1999). Soils are now considered a primary risk vector for Pb contamination and Pb poisoning in many cities in the U.S. (Fillipelli and Laidlaw 2010). The U.S. EPA has suggested that >400 ppm concentration of Pb in soils requires further testing and remediation at sites to be used for playgrounds or public greenspaces (U.S. EPA 2001) and that number is now often used to indicate the level of risk for urban gardens and UA (Beniston and Lal 2012). The Pb results presented here reflect an intensive sampling of urban lots following building demolition. Thus, the measured value of 112 (mg kg^{-1}) (or ppm) Pb presented here (Table 5) suggests that it is possible for vacant houses to be demolished without causing high levels of contamination of the soil remaining at the site.

Table 5. Baseline trace element analysis.

Trace Element	**Concentration (mg kg^{-1})**	**Comments**
As	17.99	background level
Cd	3.96	slightly elevated
Cr	25.94	
Cu	37.07	slightly elevated
Pb	**112.22**	urban background
Zn	159.77	slightly elevated

3.3 Crop yields

The crop yield data reflects an analysis in which the tomato and swiss chard yields were both analyzed together, simply as total crop yield. The sweet potato crop was destroyed by deer pressure, before fencing was completed at the site. The data from two crops were analyzed together to achieve a higher number of replications.

Plots receiving the Cmp and C+B treatments both had more than double the crop yields (Cmp 2.34 kg m^{-2} ; C+B 2.42 kg m^{-2}) of the control plots (1.07 kg m^{-2}) (Table 6). Similarly, the C+B amended plots demonstrated a significantly higher harvest index (0.52) than the control plots (0.40), and the Cmp treatment (0.47) also demonstrated increasing trend in harvest index from the control, despite not being statistically significant.

Table 6. Crop yields for the 2011 growing season.

Treatment	Crop Yield (kg m^{-2})		Harvest Index	
Control	1.07 (0.24)	A	0.40 (0.02)	A
Compost (Cmp)	2.34 (0.24)	B	0.47 (0.02)	AB
Compost + Biochar (C+B)	2.42 (0.24)	B	0.52 (0.02)	B

Overall Effects (p-value)	Treatment	Split plot
Crop Yield (kg m^{-2})	0.002	0.36
Harvest Index	0.008	0.75

Values in parentheses are standard errors and capital letters indicate t-groupings from Tukey's HSD test of means (α=0.05).

The overall treatment effect for the organic matter also demonstrated significant differences for both crop yield (p=0.002) and harvest index (0.0008) (Table 6). Collectively, these results suggest that urban green waste composts and biochars applied in large quantities can successfully improve soil conditions in physically degraded urban soils to an extent that vegetable crops can yield well in the first season. This is consistent with previous observations that large applications of compost can improve degraded urban soils for ornamental plant growth (Cogger 2005).

The split plot treatment of raised beds (RB) did not demonstrate a significant effect on either crop yield (0.36) or harvest index (0.75) (Table 5). This was unexpected, as the RB plots had significantly lower bulk density values (Table 3) which indicates improved soil structure, aeration, and rooting conditions compared with the in ground plots.

The sorghum sudangrass produced large quantities of biomass in both the G (10.54 Mg ha^{-1}) and RB (9.42 Mg ha^{-1}) (Table 7). These values were not significantly different and they are consistent with previous reports of high biomass production (Clark 2007). Sorghum sudangrass was identified as the cover crop with the strongest ability to decrease compaction levels in vegetable crop soils in New York (Wolfe et al. 1997). It demonstrated significant decreases in field PR in in the 10-20 cm depth in this study. The ability to produce large quantities of both above and below ground biomass and to decrease compaction may make sorghum sudangrass an ideal warm season cover crop for degraded urban soils.

Table 7. Sorghum sudangrass dry matter yields for 2011.

Plot Type	2011 Yield (Mg ha^{-1})	
In Ground (G)	10.54 (1.57)	A
Raised Bed (RB)	9.42 (1.57)	A

Values in parentheses are standard errors and capital letters indicate t-groupings from Tukey's HSD test of means (α=0.05).

4. Conclusions

The results presented in this study suggest that following the demolition of buildings soils in vacant urban lots may be heavily compacted. Contamination by Pb and other trace elements was not, however, a serious issue at this research site. Organic matter treatments of compost, compost + biochar, and compost + intensive cover cropping demonstrated reductions in soil compaction at the site. The compost and compost + biochar treatments both doubled crop yields and significantly increased the harvest index compared with unamended control plots. The raised bed split plot treatment did not demonstrated a statistically significant increase in crop production during the initial growing season. The results suggest that soil amendments produced from urban green-waste can improve soil function and facilitate viable specialty crop production in vacant urban lots following building demolition.

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