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► To cite this version:

S. Dadio, W. Shuster, A. Barkasi, R. Losco. Demolition and its role in urban soil development and its impact on stormwater management. Novatech 2013 - 8ème Conférence internationale sur les techniques et stratégies durables pour la gestion des eaux urbaines par temps de pluie / 8th International Conference on planning and technologies for sustainable management of Water in the City, Jun 2013, Lyon, France. <hal-03303466>

HAL Id: hal-03303466

<https://hal.science/hal-03303466v1>

Submitted on 28 Jul 2021

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Demolition and its role in urban soil development and its impact on stormwater management

La démolition et son rôle dans le développement du sol urbain et son impact sur la gestion des eaux pluviales

Dadio, Stephen¹, Shuster, William², Barkasi, April¹, Losco, Russell³

1 – Cedarville Engineering Group, LLC, 1218 Kimberton Road, Suite 200, Chester Springs, Pennsylvania, USA 19425

2- United States Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, Ohio, USA 45221

3 – Lanchester Soil Consultants, 311 East Avondale Road, West Grove, Pennsylvania, USA 19390

RÉSUMÉ

Le rôle de la démolition est souvent négligé dans la rénovation urbaine. Une des premières étapes dans les projets de rénovation urbaine pour les quartiers insalubres est de démolir les propriétés abandonnées. Cependant, il existe très peu d'informations connues sur les conditions du sol avant la démolition, sur les pratiques de démolition elles-mêmes ou sur le remblayage subséquent du sol dans l'enveloppe de l'ancien bâti. Avec une bonne planification, ces sols peuvent être utilisés comme une base pour l'infrastructure verte, qui peut fournir un contrôle à la source du volume des eaux de ruissellement, ajouter des espaces verts dans les zones urbaines et créer de la valeur foncière en rendant ces services à la population. Une étude complète doit être menée des sols avant la démolition pour assurer la cohérence des sols et de leur qualité pour les GI et dans le paysage urbain.

ABSTRACT

One often overlooked area in urban redevelopment is the role of demolition. One of the first steps in urban renewal projects for blighted neighborhoods is to demolish abandoned properties. However, there is very little information known about the existing soil conditions prior to demolition, the practice of the demolition itself, and then the subsequent backfilling of soil into the former building envelope. With good planning, these soils can be used as a basis for green infrastructure, which can provide source control for stormwater runoff volume, add greenspace to urban areas, and create land value through rendering these human services. A thorough accounting of pre-demolition soils must be conducted prior to demolition to ensure a consistency of soils and their quality with regard to supporting GI, and throughout the urban landscape.

KEYWORDS

Demolition, Green infrastructure, Planning, Stormwater, Urban soils

1 INTRODUCTION

1.1 Urban Population Decline

Due to shifting economic conditions many major cities throughout the United States have seen their populations in steady decline since the 1950's. More recently, the sub-prime loan and residential home foreclosure crisis has accelerated the process of urban population loss and housing abandonment throughout many middle and lower class neighborhoods. Like many cities throughout the Midwestern United States, Cleveland is a city in the north central area of the United States, and lies along the shores of Lake Erie in Cuyahoga County and is the largest city in the state of Ohio. The city is known for its industrial past, with significant industrial contributions to both the automobile and steel industry. Cleveland has undergone a significant loss in population over the last 60 years. According to data from the United States Census, Cleveland has lost more than half of its population from 1950 to 2010 (United States Census).

1.2 Demolition

The result of these factors is a glut of abandoned homes across wide portions of major cities throughout the United States. These abandoned homes are both an eyesore and also a breeding ground for criminal activities. In many instances, the presence of abandoned homes reduces property values of occupied residences within the same neighborhood. In an spiral of degradation, blocks that had one or several vacancies have become progressively more vacant, and city managers have used demolition as a way of removing properties that attract criminal activity, have no net worth, and no foreseeable future as an occupied residence. Cities are now charged with the task of formally implementing demolition on a large scale of abandoned properties. Prior to this point, cities have generally dealt with demolition on a case-by-case basis; as demolition was an infrequent event, and applied only after a fire or other catastrophic event.

Depending on the thoroughness of the demolition and clearing of debris, the vacant lot may have minimally disturbed soils outside the footprint of the residence, substantial addition of imported fill soil, and varying degree of demolition debris buried in the fill. Soil investigations by Shuster, et al (2011) suggested that the thoroughness of demolition was a major impact on the condition of the vacant lot. In the case of Cleveland, it was found that there were substantial differences in soil morphology, physical, and chemical properties between the pre-1996 and post-1996 demolished properties. Given the large amount of acreage available as vacant land, there is a great deal of interest in how this land mass might be used to detain, infiltrate, and redistribute stormwater runoff volume. While the principal reason for the demolition of abandoned homes is public safety, the physical act of demolition can dramatically alter the hydrology of an urban watershed. Whereas an occupied residence with a driveway and garage often has a net impervious coverage of 65 to 80%, a demolished residence will have no net impervious coverage, though the surface may be vegetated, bare, and at least partially sealed, presenting a barrier to infiltration. In addition, most of these lots are landscaped toward streets, so as to shed water to the centralized sewer system. Given current thinking, it is undesirable to have any of this excess water in the sewer system that would otherwise be detained in parcel-level green infrastructures. While city planners can propose redevelopment projects for these demolished properties, in most instances these properties will remain in their post-demolition state for years to decades.

1.3 Implications for Green Infrastructure (GI)

However, we posit that the demolished lot with its elimination of impervious coverage is a form of infiltrative Green Infrastructure (GI). One potential use is via green infrastructure, the concept of which aspires to connect landscapes together into contiguous vegetated landscapes, that may generate a wide variety of ecosystem services, including stormwater volume management through losses via infiltration-redistribution (e.g., rain gardens), evaporation-transpiration, and retention (e.g., wetlands). Given the scale of demolition of abandoned properties within the City of Cleveland, there is an unprecedented amount of GI that is activated as properties are demolished. This GI could have beneficial effects on stormwater attenuation, particularly in helping mitigate Combined Sewer Overflow (CSO) events. However, if the demolition is not carried out properly, debris is left buried in fill, further degrading soil conditions, compaction, lack of vegetative cover all conspire to render the vacant lot as just another piece of impervious surface. We examine the demolition process to see how these

activities can be guided by new expectations (i.e., green demolition specifications) carried out to yield vacant lots that can be used for stormwater management, redevelopment, pocket parks, among other productive land uses.

2 MATERIALS AND METHODS

2.1 Study Area

The study area was five residential lots in the Slavic Village section of Cleveland, in the southern portion of the city. These sites were all scheduled for demolition by the CCLRC during our investigation in July 2012. The sites had a wide variety of native soil parent materials, including aeolian deposits, glacio-fluvial sediments, glacial till, and residual soils (Table 1), which pattern a wide variety of soil permeability.

2.2 Analyses

2.2.1 Geophysical

Geospatial data for lot was obtained from the CCLRC and exact sampling positions were determined based on the demolition of each property. Geophysical measurements were taken around the home prior to demolition and then taken in the envelope of the demolished home after the completion of the demolition with all debris removed. The Trimble GeoExplorer 2008 Series GPS was connected to an Acumen GPS data logger (Trimble Navigation, Sunnyvale CA) to record geographic coordinates. The ground penetrating radar (GPR) system used was a SIR-3000 (Subsurface Interface Radar) with a 400 MHz antenna (Geophysical Survey Systems Inc. (GSSI), Salem NH). Accurate depth estimations (y-axis on radar profile) were determined by calibration at each site. Calibration was performed by burying a metal object at approximately 25 cm depth and determining the propagation velocity through the soil material. Radar scans were processed using RADAN 7 software (GSSI, Salem NH).

2.2.2 Soil Morphological and Hydraulic Measurements

The soil morphology was described at each location to a depth of at least 1 meter below the bottom of the excavated area (these depths varied as there are discrete depths for each basement or foundation area. In some instances, the soil profile was continued with a hand auger to a deeper depth. The soil morphology was described in accordance with the standards of the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) Field Guide for Describing Soils (Schoeneberger, et al, 2002). Soil samples were collected for both the soil surface and at the most restrictive soil layer. Soil samples of both the imported subsoil and topsoil were collected. All backfilling actions were observed to verify compliance with the policies and procedures set forth by the CCLRC.

Table 1. Soil sample test locations. Subsoil sampling was undertaken at the depth of excavation.

<u>Test Location</u>	<u>Basement Present ?</u>	<u>Depth of Excavation (cm)</u>	<u>Parent Material(s)</u>
Carpenter	YES	483	Aeolian sands over glacio-fluvial
Dercum	YES	240	Anthropogenic over aeolian over glacio-fluvial over lacustrine
East 59th Street	NO	375	Aeolian sands over glacio-fluvial
East 81st Street	YES	240	Glacial till over residual
Homestead	YES	240	Anthropogenic fill over glacial-fluvial over lacustrine

2.2.3 Soil Laboratory Analyses

Particle size analyses for both the surface and soil horizon at the depth of excavation were conducted using the hydrometer method (Gee and Bauder, 1986), soil pH was measured using a Ross combination glass electrode (Thermo Fisher Scientific; Beverly MA) with a 1:1 suspension (Eckert and Sims, 1995); available Ca, Cu, Mg, P, K, S, and Zn were measured using the Mehlich 3 extraction with inductively coupled plasma atomic emission spectroscopy (Varian 730-EOS; Agilent Corp., Santa Barbara CA) quantification (Wolfe and Beegle, 1995); with cation exchange capacity (CEC) subsequently calculated by summation (Ross, 1995). Ignition methods were used to determine total C (Nelson and Sommers, 1996) and total N (Bremner, 1996) with a CE Instruments (Wigan UK) EA1110 CHNS-O analyzer.

2.2.4 Statistical Analysis

This study was a comparison of demolition practices as conducted by 5 different contractors. Each contractor was educated with regard to land bank goals for demolitions. The actual demolition of each of five houses was observed by the authors so as to identify possible impacts of demolition practice on land and soils. Therefore, we qualitatively compare five independent demonstration demolitions.

3 RESULTS AND DISCUSSION

3.1 Soil Physical Properties

3.1.1 Soil texture

The native soil surface textures were all sandy loams, which is a common soil texture for the City of Cleveland (Table 2), though an aeolian influence is prevalent and was observed for the Slavic Village soils studied herein. The fill materials imported as the surface soils for three of the lots were found to be finer textured than soils native to these locations. On the other hand, the other two lots exhibited fill-imported soils that were much coarser textured than what was originally at these locations. The differences in physical properties of the imported surface soils lies wholly with the contractor that is importing the surface soil material for a demolition. There are many different sources of topsoil, with a wide range of soil physical and chemical properties. Given this variability in soil conditions, it is difficult to plan and design GI when the imported soils differ from what was originally at a particular location. This suggests that investigations are required to understand specific conditions so that GI designs can account for these differences that control the hydrology of these vacant lots. Furthermore, these investigations can indicate a direction for soil management.

The differences between native and imported subsoils was more striking compared to the soil surface. At the Carpenter site, the native subsoil texture was a sand, with only 4.0% clay. The imported subsoil for this location was a loam, with 26.4% clay, effectively severing any hydraulic connectivity between the surface and the highly-permeable sand base. The case of the Carpenter demolition process is the prime example of what should not happen to yield a functional vacant lot. The fill soil texture should be matched as well as possible with that which is native to the site, or at least provide some sort of transition from the surface to the subsoil texture. What has happened is that the high infiltration capacity of the deep sand subsoil at Carpenter is no longer accessible, and so an opportunity has been squandered by not retaining some degree of hydraulic connectivity between a reasonably permeable topsoil (that is graded away from the street) and the highly permeable subsoil, and altogether a system that would drain within 24-36 hours after a rainfall event. The other sites had more silty or clayey textural attributes, making them less than ideal for infiltration of stormwater runoff volume.

Table 2. Soil Physical Properties for surface and subsoil samples

<u>Location</u>	<u>Sample</u>	<u>Texture</u>	<u>Sand%</u>	<u>Silt%</u>	<u>Clay%</u>	<u>VC Sand%</u>	<u>Coarse Sand%</u>	<u>Medium Sand%</u>	<u>Fine Sand%</u>	<u>VF Sand%</u>
Carpenter	Surface-N	sl	55.7	25.2	19.1	10.72	16.70	30.72	32.58	9.28
Dercum	Surface-N	sl	65.7	20.2	14.1	7.48	11.23	26.82	40.75	13.72
East 59th	Surface-N	sl	54.3	32	13.7	7.41	12.14	26.54	33.13	20.78
East 81st	Surface-N	sl	54.0	28.7	17.2	14.97	14.97	20.81	29.44	19.80
Homestead	Surface-N	sl	69.1	18.5	12.4	18.98	22.71	22.71	23.73	11.86
Carpenter	Surface-F	l	39.7	38.2	22.1	20.60	18.43	18.70	30.89	11.38
Dercum	Surface-F	sl	75.5	13.7	10.9	8.78	13.83	26.20	40.43	10.77
East 59th	Surface-F	s	90.8	4.7	4.6	1.62	3.24	38.30	53.07	3.78
East 81st	Surface-F	l	48.7	30.3	21.1	13.24	15.48	18.33	30.14	22.81
Homestead	Surface-F	scl	62.2	17.1	20.8	14.03	17.78	33.12	27.73	7.34
Carpenter	Subsoil-N	s	93.0	3.0	4.0	9.17	31.82	48.07	10.06	0.88
Dercum	Subsoil-N	l	45.9	33.6	20.5	1.30	4.16	25.19	44.94	24.42
East 81st	Subsoil-N	cl	34.4	30.7	34.9	2.88	5.04	21.58	43.88	26.62
Homestead	Subsoil-N	c	16.4	38.0	45.6	10.89	11.88	15.84	30.69	30.69
Carpenter	Subsoil-F	l	31.8	41.8	26.4	11.75	12.06	16.83	34.92	24.44
East 81st	Subsoil-F	sl	61.5	27.0	11.5	12.94	14.59	15.59	31.67	25.21
Homestead	Subsoil-F	sl	53.9	33.0	13.1	7.05	9.17	16.05	36.51	31.22

3.2 Soil Chemical Properties

3.2.1 Soil Surface

There were differences between the native and imported surface soils (Tables 4a and 4b). The native soils generally had higher levels of Carbon and Nitrogen in the soil. These increased values can be due to the natural fertility of these native soils, coupled with the presence of inorganic carbon sources due to anthropogenic activities. The imported surface soils had elevated pH, and by turns contained more calcium and sulfur than the native soils. These differences are due to the source of the imported surface soils. These elevated levels may be due to a mixing of construction debris, especially concrete, into the imported surface material. The levels of sulfur were highly variable, and may have acted to depress pH, especially on East 81st.

Table 3a. Soil chemical properties for surface and subsoil samples

Location	Sample	Ph	P (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	CEC	K Saturation %	Mg Saturation %	Ca Saturation %
Carpenter	Surface-N	7.1	331	136	284	2347	14.4	2.4	16.4	81.2
Dercum	Surface-N	6.9	21	89	258	2092	20.98	1.8	16.7	81.5
East 59th	Surface-N	6.8	86	101	144	1909	11.0	2.4	10.9	86.7
East 81st	Surface-N	7.1	91	65	213	3265	16.9	1.0	10.5	88.5
Homestead	Surface-N	7.7	20	169	414	3808	18.9	2.3	18.3	79.4
Carpenter	Surface-F	8.1	3	54	249	3050	17.2	0.8	12.1	87.1
Dercum	Surface-F	7.5	65	86	272	3379	17.5	1.3	13.0	85.8
East 59th	Surface-F	8.3	8	437	372	2588	17.2	6.5	18.1	75.4
East 81st	Surface-F	7.4	17	111	314	5879	17.9	1.6	14.6	83.8
Homestead	Surface-F	6.9	100	571	556	2907	27.6	7.1	22.5	70.4
Carpenter	Subsoil-N	7.7	21	30	68	374	2.5	3.1	22.5	74.4
Dercum	Subsoil-N	7	9	134	94	768	5.0	6.9	15.8	77.3
East 81st	Subsoil-N	7.5	3	85	367	2909	17.8	1.2	17.2	81.6
Homestead	Subsoil-N	7.9	3	94	374	1834	12.5	1.9	24.9	73.2
Carpenter	Subsoil-F	7.4	8	69	300	4031	17.7	1.0	14.1	84.9
East 81st	Subsoil-F	7.8	4	47	219	6534	16.9	0.7	10.8	88.5
Homestead	Subsoil-F	7.7	4	41	249	4470	17.2	0.6	12.1	87.3

3.2.2 Subsoil

In the subsoil, the data indicates a greater amount of calcium, sulfur, and carbon in the imported subsoil compared to the native subsoil. These elevated values are likely caused by the unique location of the source of the subsoil for these demolitions. In these instances, the imported material came from a quarry. It is common for quarries to be located in industrial areas; these locations may be near power plants, where elevated amounts of atmospheric sulfur deposition would be common. Additionally, other industrial processes may be contributing calcium to these soils as well..

It is interesting to note tha the imported carbon content of the sbubsoil is greater than in the imported suface soil. In a naturally occuring landscape, soil carbon content decreases with depth. At these imported locations, the carbon content increases with depth. This change in carbon chemistry could become an issue in assessing the overall biogeochemistry of these systems.

The data indicates that given more samples, significance could be found with zinc, copper, and sulfur. In this study, neither heavy metals nor organic contaminants were tested. However, these elevated levels S, Cu, and Zn indicate that it may be advisable to test for investigate whether contaminants are present in these fill soils.

Table 3b. Soil chemical properties for surface and subsoil samples

<u>Location</u>	<u>Sample</u>	<u>Zinc (ppm)</u>	<u>Copper (ppm)</u>	<u>Sulfur (ppm)</u>	<u>Carbon %</u>	<u>Nitrogen %</u>
Carpenter	Surface-N	51.1	14.1	27.6	2.69	0.19
Dercum	Surface-N	28.8	6.0	14.9	2.23	0.14
East 59th	Surface-N	95.2	95.9	40.5	4.57	0.14
East 81st	Surface-N	86.9	13.6	34.3	11.68	0.29
Homestead	Surface-N	50.7	8.6	111.7	10.14	0.30
Carpenter	Surface-F	2.4	4.1	95.4	0.93	0.04
Dercum	Surface-F	28.6	15.7	156.2	1.50	0.08
East 59th	Surface-F	179.3	10.4	659.7	0.90	0.03
East 81st	Surface-F	19.3	4.9	2307.0	3.94	0.12
Homestead	Surface-F	197.3	4.1	122.6	9.81	0.40
Carpenter	Subsoil-N	2.8	2.5	3.3	0.12	<0.02
Dercum	Subsoil-N	0.4	0.8	7.2	0.13	0.02
East 81st	Subsoil-N	1.5	2.0	6.9	0.61	0.05
Homestead	Subsoil-N	1.0	1.9	10.4	0.38	0.06
Carpenter	Subsoil-F	2.5	3.9	208.4	1.22	0.05
East 81st	Subsoil-F	0.9	1.4	1171.4	1.65	0.03
Homestead	Subsoil-F	2.2	2.0	410.3	1.19	0.03

4 CONCLUSIONS

One often overlooked area in urban redevelopment is the role of demolition. One of the first steps in urban renewal projects for blighted neighborhoods is to demolish abandoned properties. However, there is very little information known about the existing soil conditions prior to demolition, the practice of the demolition itself, and then the subsequent backfilling of soil into the former building envelope. In many instances, the resulting vacant lot sits for a period of years and acts as a sort of unmanaged Green Infrastructure (GI) until redevelopment commences. Detailed soil investigations were conducted on five lots in the city of Cleveland, Ohio pre- and post-demolition to determine their soil properties and how soils were to the process of demolition, and better understand the sources and nature of backfill soils. Our results indicated a wide variety “native” urban soils prior to demolition; these soils have discrete soil physical and chemical properties that lend themselves to certain types of GI. We found that the subsequent backfilling was conducted without regard to what the pre-demolition soil conditions were. This led to an alteration of the landscape and a change in the soil physical and chemical properties of the soils that may lend themselves to other types of GI. A thorough accounting of pre-demolition soils must be conducted prior to demolition to ensure a consistency of soils throughout the landscape.

The role of demolition has not been fully examined as to its impacts on converting these vacant lots into passive forms of green infrastructure. Based on data collected in our limited study, there are differences between the native soils encountered and the imported fill soils for these demolition sites. A prime example is the lot on Carpenter Street. In it, we found soils with an extremely high sand content that could prove to accommodate large amounts of stormwater through an infiltration or recharge system. However, the subsoil fill consisted of loam material that had 1/3 of the sand and 6 times the clay of the native soil. These soils would be more suitable for a bioretention type of stormwater system. Essentially, through the act of demolition, potentially a very large net stormwater sink was capped with less permeable soils, rendering this vacant lot as more or less a permanent runoff generator.

Going forward, it will be vital to all major cities in the United States and elsewhere that they develop standards for the proper demolition and restoration actions on abandoned homes. There already has

been an evolution in this process as cities have discontinued allowing the process of collapsing homes and burying the debris into the basement of these lots. Now that these cities are having contractors remove all of the debris from a vacant lot, attention must be paid to both the backfilling practices and materials used in this restoration.

LIST OF REFERENCES

- Lee, S.E., Jenkin, D., Koopman, B.L. and Lewis, R. (1982). *The effect of aeration basin configuration on activated sludge bulking at low organic loading*. Wat. Sci. & Tech., 14(6/7), 407-427.
- Abell, B.C., Tagg, R.C. and Push, M. (1974). *Enzyme catalyzed cellular transaminations*. In: Advances in Enzymology, A.F. Round (Ed.), Vol.2, 3rd ed. Academic Press, New York, 125-247.
- Grady, C.P.L. and Lim, H. (1980). *Biological Wastewater Treatment: Theory and Application*. Marcel Dekker, New York.
- Bremner, J.M. 1996. Nitrogen - total. In D.L. Sparks (ed). Methods of soil analysis. Part 3. SSSA Book Ser. 5. ASA, Madison, WI.
- Eckert, D., and J.T. Sims. 1995. Recommended soil pH and lime requirement tests. p. 11-16. In J. Thomas Sims and A. Wolf (ed.) Recommended soil testing procedures for the Northeastern United States. Northeast Regional Bulletin #493. Agricultural Experiment Station, University of Delaware, Newark, DE.
- Effland, W.R., and R.V. Pouyat. 1997. The genesis, classification, and mapping of soils in urban areas. Urban Ecosystems 1:217-228.
- Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. 9. ASA, Madison, WI.
- Godefroid, S., D. Monbaliu, and N. Koedam. 2007. The role of soil and microclimatic variables in the distribution patterns of urban wasteland flora in Brussels, Belgium. Landscape and Urban Planning 80:45-55.
- Jim, C.Y. 1998. Urban soil characteristics and limitations for landscape planning in Hong Kong. Landscape and Urban Planning 40:235-249.
- Lorenz, K., and E. Kandeler. 2005. Biochemical characterization of urban soil profiles from Stuttgart, Germany. Soil Biol. Biochem. 37:1373-1385.
- Lowery, B., and J.E. Morrison. 2002. Soil penetrometers and penetrability. In Dane and Topp (ed.) Methods of soil analysis. Part 4. SSSA Book Series 5. ASA, Madison, WI.
- Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961-1010. In D.L. Sparks (ed.) Methods of soil analysis. Part 3. SSSA Book Series 5. ASA, Madison, WI.
- Pouyat, R.V., I.D. Yesilonis, J. Russell-Anelli, and N.K. Neerchal. 2007. Soil chemical and physical properties that differentiate urban land-use and cover types. Soil Sci. Soc. Am. J. 71:1010-1019.
- Ross, D. 1995. Recommended soil tests for determining soil cation exchange capacity. p. 62-69. In J.T. Sims and A. Wolf (ed.) Recommended soil testing procedures for the Northeastern United States. Northeast Regional Bulletin #493. Agricultural Experiment Station, University of Delaware, Newark, DE.
- Schindelbeck, R.R., H.V. van Es, G.S. Abawi, D.W. Wolfe, T.L. Whitlow, B.K. Gugino, O.J. Idowu, and B.N. Moebius-Clune. 2008. Comprehensive assessment of soil quality for landscape and urban management. Landscape and Urban Planning 88:73-80.
- Soil Survey Staff. 1993. Soil survey manual. Agric. Handb. 18. U.S. Gov. Print. Office, Washington, DC.
- Soil Survey Staff. 2005. New York City reconnaissance soil survey. United States Department of Agriculture, Natural Resources Conservation Service, Staten Island, NY.
- U.S. Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, title 430-VI [Online]. Available at <http://soils.usda.gov/technical/handbook/> (verified 16 Sep. 2010).
- Wolf, A.M., and D.B. Beegle. 1995 Recommended soil tests for macronutrients: phosphorus, potassium, calcium, and magnesium. p. 25-34. In J.T. Sims and A. Wolf (ed.) Recommended soil testing procedures for the Northeastern United States. Northeast Regional Bulletin #493. Agricultural Experiment Station, University of Delaware, Newark, DE.