Article

Improved or Unimproved Urban Areas Effect on Soil and Water Quality

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Abstract: Construction in urban areas usually results in compacted soil, which restricts plant growth and infiltration. Nutrients may be lost in storm runoff water and sediment. The purpose of this study was to determine if existing lawns benefit from aeration and surface compost additions without the negative impact of nutrient loss in runoff. Four sets of lawns were compared, with or without compost plus aeration, as a paired comparison. Surface bulk density was significantly reduced in the treated lawns (1.32 versus 1.42 Mg$\cdot$m^{-3}). Visual evaluation of soil structure showed improvement in the treated lawns. Of fifteen measurement dates over four years, four dates showed significantly higher surface soil water contents in the treated lawns compared with the untreated lawns. When compared over time, three of the four treated lawns had significantly higher soil water content than the untreated lawns. Nutrient concentrations in rainfall simulator runoff were not significantly different between treated and control lawns, which showed that compost did not negatively impact water quality. Compost and aeration helped restore soil quality for urban soils of recent construction.

Keywords: soil quality; water quality; urban soil; rainfall simulator

1. Introduction

Construction in urban areas usually results in compacted soil which restricts plant growth and infiltration [1]. Reduced infiltration increases storm runoff and erosion [2] or ponding in low areas. Nutrients may be lost in storm runoff and sediment.

Aeration combined with surface compost additions may improve infiltration. Aeration (removal of small cores of soil) has primarily been used in golf course putting greens to reduce thatch build-up, decrease bulk density, and increase infiltration [3]. Loper et al. [4] and Evanylo et al. [1] observed that compost decreased bulk density and improved plant growth. Visual evaluation of soil structure (VESS) has been used to evaluate soil structure in agricultural soils [5], but not in urban soils.

Compost additions should be enough to aid plant growth, but not so much that excess nutrients are lost in runoff [6,7]. Persyn et al. [8] showed that surface compost blankets reduced sediment loss in runoff. Yard waste compost had higher soluble P in runoff than the control, but sorbed P loss in runoff was not significantly different [8]. Faucett et al. [9] observed significant reductions in runoff, sediment, and nitrate loss for surface compost additions. Franklin et al. [10] measured reduced runoff and total phosphorus loss with broiler litter, but aeration did not have a significant effect. Johnson et al. [11] did not observe any significant increases in total phosphorus or nitrate loss in runoff after compost additions up to 99 m$^3\cdot$Ha^{-1} on bluegrass. Chaganti and Crohn [12] showed that green waste compost had significantly reduced runoff and sediment loss but significantly higher concentrations of ortho phosphate in the runoff.

The purpose of this study was to determine if urban lawns benefit from aeration and surface compost additions without the negative impact of nutrient loss in runoff.

2. Materials and Methods

Four yards were selected, at different stages after construction. Two yards in Ankeny, Iowa, were around two years after construction, and two yards in Ames, Iowa, were more than five years after construction. Yard 1 at Ankeny and yard 1 at Ames had prior compost addition with aeration years before the study was started. Due to activity at the yard 1 Ankeny site, the compost used was from dairy manure with food wastes and sand, sieved with 12 mm chicken wire. For all other sites, a mixture of cow manure and yard waste clipping was used. This compost had 9.3 g·kg^{-1} of total nitrogen, and 384 mg·kg^{-1} of ortho phosphate (Olsen [13]), but analysis of the dairy compost is not known. All compost was applied in the fall of 2012. First, the yards were aerated with 3.8 cm long tines on average 10 cm apart. Then, 1.3 cm depth of compost was applied at the surface and spread using a rake. The treated yards were paired with adjacent untreated yards.

Surface soil water content was monitored with a HydraProbe (Stevens Water Monitoring Systems, Inc., Portland, OR, USA) in both the improved yards as well as paired nearby yards without aeration and compost additions—six measurements in each yard. Some of the HydraProbe data gave spurious data (such as negative water content or log of a negative number during data processing), so mean soil water content per date/yard sometimes had measurements at fewer than six sites.

One year and three years after addition of compost and aeration, a small rainfall simulator [14] was used for the analysis of runoff, and loss of sediment and nutrients in the treated yards and nearby yards without treatment. The infiltrometer ring had an inner diameter of 241 mm; rain was applied at 30 cm·h^{-1}; slopes were small (1%–2%). Soil was dug out to allow for a runoff collection area. Runoff was continued for approximately sixty minutes after steady-state. Because the simulator was small, three to six replicates were measured on each treated yard and a nearby untreated lawn. For each yard, the runoff samples were combined by mixing for analysis of sediment and nutrients. Runoff samples were refrigerated until analysis. In the third year, the water used for infiltration was also analyzed for background nutrient levels. In year three, this extracted soil was examined to give the index from Visual Examination of Soil Structure (VESS: [5]). Observations [5] included aggregate firmness and porosity, roots interaction with aggregates, color, presence of earthworms, and soil texture by feel [15]. In the second year, disk infiltrometers [16], of 230 mm diameter, were used to determine infiltration rates at ponded, and −30 mm head. There were five replicates in each treated yard and the paired yard.

Nitrate plus nitrite nitrogen was measured with a Lachet autoanalyzer using a Cd reduction [17,18]. Total phosphorus was determined using flow injection analysis [19] after acid-persulfate digestion. Runoff samples were dried at 105 °C to determine sediment loss.

After three years, soil samples were collected to determine bulk density, total nitrogen, and organic and inorganic carbon. For each yard, six samples were collected with an incremental sampler [20] of 19 mm inner diameter. The samples were divided into 0–10, 10–20, and 20–30 cm and pooled by depth for each yard. Samples were taken after the first year for bulk density alone, and only to 20 cm depth. After obtaining moist mass, subsamples were oven-dried. Knowing the volume and oven-dried water content, bulk densities were determined. Air-dried samples were sieved (2 mm) before carbon and nitrogen analysis. Total carbon and nitrogen were determined by dry combustion [21] with a Fisons NA1500 Elemental Analyzer. Inorganic carbon [22] was determined by a pressure calcimeter, and organic carbon was determined by subtraction.

Each yard was paired with and compared to the nearby untreated yard. All properties were analyzed by paired comparisons [23] between treated and untreated yards across sites. Soil water differences between each lawn set were also compared over time, pairing by measurement date. Differences were considered significant at p = 0.05.

3. Results

Four out of fifteen measurement dates showed significant increases in soil water content where the compost and aeration were applied (Table 1). Examining each yard pair over time showed that the two Ankeny sites (0.281 > 0.243 $m^3 \cdot m^{-3}$, 0.292 > 0.225 $m^3 \cdot m^{-3}$) and one Ames site (0.298 > 0.276 $m^3 \cdot m^{-3}$) had higher water content in the treated area than the untreated yards.

Table 1. Comparison [1] of surface water (0–6 cm) for improved and control lawns.

Date	Soil Content Water ($m^3 \cdot m^{-3}$)	
	Improved	Control
7/25/13	0.247 [a]	0.216 [a]
8/14/13	0.269 [a]	0.228 [a]
9/5/13	0.183 [a]	0.193 [a]
9/25/13	0.263 [a]	0.214 [b]
4/11/14	0.323 [a]	0.282[a]
5/5/14	0.385 [a]	0.331 [a]
7/8/14	0.326 [a]	0.263[a]
7/30/14	0.244 [a]	0.266[a]
9/2/14	0.332 [a]	0.250 [a]
5/13/15	0.290 [a]	0.204 [b]
5/27/15	0.380 [a]	0.339 [b]
8/7/15	0.265 [a]	0.239 [a]
4/25/16	0.293 [a]	0.258 [b]
5/16/16	0.395 [a]	0.276 [a]
6/27/16	0.265 [a]	0.252 [a]
8/25/16	0.316 [a]	0.268 [a]

[1] Within row treatments with the same superscripts (both [a]) are not significantly different at p = 0.05, with the different superscripts ([a] and [b]) are significantly different.

Bulk densities in the third year were significantly reduced in the 0–10 cm depth in the yards treated with compost and aeration (1.32 $Mg \cdot m^{-3}$) compared with untreated areas (1.42 $Mg \cdot m^{-3}$). There were no significant treatment effects on bulk density for the 10–20 cm or 20–30 cm depths (1.60 and 1.64 $Mg \cdot m^{-3}$) or for samples taken in the first year (1.17 and 1.56 $Mg \cdot m^{-3}$ for 0–10 and 10–20 cm). Others have shown that compost reduces bulk density in urban soils [1,4,24,25].

In the third year, organic (1.23 g/100 g) and inorganic carbon (0.62 g/100 g) as well as total nitrogen (0.10 g/100 g) levels were not significantly affected by the treatments. Compost added to urban areas often increases soil organic carbon [1], at least in the long term [26]. At least eight years would be needed to detect significant management effects on soil carbon [27]. For unmanaged (unfertilized) areas, C-3 grasses decreased total nitrogen and C in soil [28], although C-4 grasses can increase C [29,30]. Spatial variation may require terrain co-variates to detect significant changes in soil C [31].

In the third year, VESS [5] showed significant improvement in the topsoil for compost plus aeration (1.2) compared with the control (2.3). Smaller VESS indicates better soil structure. Anything smaller than 3 is considered adequate soil structure [5], so even the control surface soil was okay. Earthworms were apparent in the surface soils at all sites, but not the subsurface. Most of the subsoils at Ankeny were gleyed, showing poor drainage and poor subsoil structure. Soil texture by feel indicated that most soils were loam or clay loam, but one site in Ames was sandy loam.

In the first year after establishing the treatments, the compost plus aeration yards did not show any significant effect on the infiltration rate (41 $mm \cdot h^{-1}$), runoff rate (211 $mm \cdot h^{-1}$), time to runoff, sediment loss (0.25 $g \cdot L^{-1}$), or P (0.30 $mg \cdot L^{-1}$) or nitrate concentrations (1.17 $mg \cdot L^{-1}$) in runoff compared with untreated areas. Ponded (20 $mm \cdot h^{-1}$) and tension infiltration (1.7 $mm \cdot h^{-1}$) were not significantly affected by the compost and aeration in the second year. In the third year, again, there were no significant treatment differences in the infiltration rate (184 $mm \cdot h^{-1}$), runoff (50 $mm \cdot h^{-1}$), time to runoff, sediment loss (0.26 $g \cdot L^{-1}$) or loss of total phosphorus (0.16 $mg \cdot L^{-1}$) or nitrate (0.1 $mg \cdot L^{-1}$).

Higher nutrient levels in the first year resulted from no blank being analyzed (background nutrient levels in the infiltration water).

Total phosphorus concentrations in runoff were at the low end for loss from grassed areas: 0.3 to 7.1 mg·L^{-1} [30,32]. Sediment concentrations were low and similar to those shown by Logsdon et al. [29]. The addition of compost did not increase P loss compared with the control, which was also shown by Johnson et al. [11].

There were interesting trends in the rainfall simulator study, even though overall results were not significant between treated and control yards. One of the treated sites in Ankeny had longer time to runoff than all the other sites (4.5 vs. 1.7 min in the first year; 5.8 vs. 1.9 min in the third year). That site also had no sediment loss in the third year, whereas all other sites had some sediment loss. Time to runoff was generally lower than most values (2 to 78 min) in the literature [30,32,33].

4. Conclusions

In the third year, surface bulk density and VESS were improved for compost plus aeration over the control. For over one-quarter of the measurement dates, the improved lawns had significantly higher soil water content, but the other measurement dates did not show significant differences in surface soil water content. Subsurface soil still showed the construction-imposed-compaction, especially for the sites in Ankeny, where restricted infiltration resulted in aeration problems. Runoff and sediment rates were not significantly affected by the treatments, but the sediment and nutrient losses were low for all yards. The compost treatments did not negatively affect the nutrient quality of runoff water.

Spatial variability of infiltration [11,34,35], and slow recovery of organic carbon showed that these were non-sensitive tests for soil quality on urban soils. Bulk density and VESS were more useful tests, and would be recommended to detect improved physical soil quality, especially in the short term.

Author Contributions: Sally Logsdon and Pat Sauer conceived the experiments, Sally Logsdon directed conducting the experiments. Pat Sauer found contacts who assisted in located landowners for the experiments. Sally Logsdon wrote the manuscript with input from Pat Sauer.

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