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Utilization of Compost as a Soil Amendment to Increase Soil Health and to Improve Crop Yields

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Abstract

Compost amendments have remarkable potential for improving soil structure, porosity and water holding capacity. Soil health is the ability to function as a living system, to sustain plant and animal productivity, to enhance water and air quality, and to promote plant and animal health. Soil health can be estimated by measuring the total living microbial biomass, retained carbon, odor, and texture. Poor or deteriorating soil health is threatening food security. The potential for compost to reverse these negative trends is transformative if means and methods for large scale composting and compost amendments can be developed. A field-scale compost soil amendment project was implemented in Rapid City, South Dakota. The compost was added to a soil plot at 5 wt% and 10 wt% and the results were compared with an adjacent untreated plot without any compost addition. Measurements of soil health characteristics indicate that compost amendments improve soil health, crop yields, and soil water content. Treating soils with compost has the potential to reverse global deteriorating soil health.

Keywords

Compost, Crop Yields, Soil Health, Food Security

1. Introduction

Addition of compost to soil increases soil porosity, water holding capacity and organic content. These changes are collectively known as the "soil structure". With international and national concern about the world's soil being lost through erosion and the remaining soil experiencing deteriorating soil health, compost amendments may assist significantly in improving overall soil health and increasing food security [1] [2]. There has been a surge in international awareness of the need to maintain and develop healthy soils and to maximize food production, in quality and quantity. Healthier soils created by the incorporation of compost will increase the amount of carbon sequestered which could be a leading method to mitigate global warming. Large-scale composting and incorporating the compost into soils helps to greater sustainability of our soils, to maintain our forests, and to protect our waters [3] [4].

Soil porosity and organic matter content play a critical role in the biological productivity and hydrology of agricultural soils. Pores are of different size, shape, and continuity and these characteristics influence the infiltration, storage and drainage of water, the movement and distribution of gases, and the ease of penetration of soil by growing roots [5].

Soil health is the soil's ability to function as a living system, to enhance water and air quality, and to promote plant and animal health. Soil health can be estimated by measuring the total living microbial biomass, retained carbon, odor, and structure. Soil organisms illustrate cause and effect that link land management and the ultimate productivity and health of the plants and animals [6]. Disease control is also an indicator of soil health and can be viewed as a manifestation of ecosystem stability and health [7].

The health of a soil is dependent on the maintenance of four major functions; carbon transformations; nutrient cycles; soil structure maintenance; and the regulation of pests and diseases [8]. Quantification of soil health is measured by analyzing these four major functions. Soil quality is essential for sustainable agriculture and soil health is expressed in crop quality not quantity [9].

When a soil is healthy it has structural porosity, nutrient availability, and organic content which allow the soil to breathe and absorb water. Healthy soil has a loose texture allowing roots to easily penetrate the soil matrix and access water and nutrients. By understanding the stress that the plant is undergoing, best management practices can be developed to close the gap between the plant's yield and its genetic yield potential, thus supporting worldwide food security [10].

Recent awareness that soil health is vital to food production and the global ecosystems has increased awareness in the status of the soil and how it can be improved [11]. Soil structure and health can be renewed or improved by re-introducing porosity, organic matter, and nutrient availability through no-till farming, conservation agriculture and incorporation of compost [3] [12] [13]. To increase soil organic matter and other nutrients in the soil of cultivated land, the integrated implementation of land management through compost, cover crops, manures, minimum tillage, crop rotation, and liming to decrease soil acidity are suggested [14]. Agricultural waste for soil amendment is limited in developing countries as competition for the use of agricultural waste for use as fuel and feed is dominant. Composted municipal solid waste should also be utilized as a soil amendment [15].

Compost is developed using the natural decomposition process of organic matter, by managing and applying appropriate amounts of moisture, air, and feedstock. Compost is stable and provides humus to the soil [16]. The composting process produces a soil amendment with an acceptable carbon nitrogen ratio, safe levels of pathogens, a relatively balanced pH, and stable in its respiratory rate [17] [18]. The purpose of composting is to change organic waste material into a stable and usable product, called compost that can be amended into soils [19]. Soil amended with compost will improve soil aggregation and the root zone environment [20]. "While there is not a consensus on exactly how to measure soil quality, there is little disagreement that organic matter content gives soils many of their desirable properties" [21]. Soil organic matter is important determinant of available water content because, on a volume basis, it is a significant component. One to 6% organic matter, by weight, is equivalent to approximately 5% to 25% by volume [22]. One of the cheapest forms of conservation is soil amendment with compost, which can cut summer irrigation demands in half [23]. Soil health is a combination of physical, chemical and biological properties that impact the function and productivity of the soil with several of these characteristics directly impacting the economics [24]. Three terms related to the water budget are field capacity (FC), wilting point (WP) and available water (AW) [25]. Compost increases water holding capacity and total porosity [26]. Increased water holding capacity increases the available water content. Compost addition is more effective than tilling by reducing the soil strength and compaction and increasing soil infiltration [26]. Research indicates that water holding capacity is greatly increased by adding organic matter to soil [27]. Research has shown that incorporation of yard waste compost decreased soil bulk density compared to non-tilled treatment, and the compost treatment increased soil carbon, nitrogen contents and plant available water [28]. Use of mulch and soil conditioners has shown to improve efficiency of water use by reducing evaporation, improving water infiltration and storage, and reducing deep drainage [29]. Particle size and particle size distribution, as they contribute to porosity and water retention, has been studied [30]. Research indicates that compost added to a soil stimulates microbial growth and activity, may change species composition in the soil, promotes earthworms, and may suppress plant disease. Greater microbial biomass increases availability of nutrients to plants and promotes formation of soil aggregates and structure [31] [32]. Researchers have studied the control of soil borne plant pathogens with composts [32].

In 2003 the United States Compost Council adopted the Seal of Testing Assurance (STA) [33] to establish standards for determining compost quality. Research was performed to the potential for improving soil health through the use of compost as a soil amendment [34]. The purpose of the research was to determine if irrigation water would be conserved when soils are amended with compost. Increases in soil health parameters were also observed.

2. Methods

A 4756 m^2 field was developed into two 2090 m^2 fields that could be uniformly irrigated. One field was controlled, with no compost (NC) and one field had compost incorporated into the soil. The in-situ soil density used for calculating the addition of compost was 92.4 lb./ft^3 (1480.1 kg/m^3). The only variable was the amount of compost amended into the upper 8-inches (200-mm) of soil. The amendments were determined to be 5% and 10% by weight of the in-situ soil. The treated field was divided with half receiving 10% compost and the half receiving 5% compost. Compost was added to a depth of 8-inches (203 mm). The compost for the 5% plot was 18.6 U.S. tons (16.87 metric ton) and compost for the 10% plot was 37 U.S. tons (33.57 metric ton).

Irrigation occurred when natural precipitation did not maintain field moisture above the wilt point of 20 percent soil moisture. The wilting point is the amount of water per unit weight or per unit bulk volume in the soil, expressed in percentage, that is held so tightly by the soil matrix that roots cannot absorb this water and plant will wilt [35] [36]. The wilting point for a clay loam is estimated at 20% [36].

Data collection included measured precipitation and irrigation, water content at 0" - 8" (0 mm to 203 mm), 8" - 16" (203 mm to 406 mm) and 16" - 24" (406 mm to 610 mm) depths. Surface soil moisture contents at 0 to 8-inch (0 to 203 mm) depth were taken at 45-degree quadrants, at 10-foot (3.05 m) intervals, with seven intervals, 10 ft (3.05 m) to 70 ft (21.34 m) Moisture content readings were also taken for soil depths of 0" - 8" (0 mm to 203 mm), 8" - 16" (203 mm to 406 mm) and 16" - 24" (406 mm to 610 mm) at on-site wells. There were six well nests in the no compost (NC) field and six well nests in the compost field. Locations were at the 45, 90, 135, 225, 270, and 315-degree quadrants at a radius of 30 feet (9.1 m). A portable Hydro Sense II moisture instrument, from Campbell Scientific, Inc. of Logan, Utah, was used for measuring volumetric water content of soil.

Random soil samples were taken and sent to the North Dakota State University Soils Lab. The surface soil was found to be a silty loam. An onsite soil sample was analyzed using the Guideline to texture (soil) by feel, USDA NRCS [37] and the soil was determined to be silt-loam. The microbial activity of the soil was measured using total living microbial biomass, Phospholipid Fatty Acid (PLFA), testing was conducted by Ward Laboratories of Kearney, Nebraska.

3. Materials

The City of Rapid City conducts compost testing to comply with the EPA standards for Class A compost [38]. Class A compost can be applied anywhere and for any plant. The Soil Control Laboratory of Watsonville, California conduct compost quality testing in accordance with the U. S. Compost Council's Testing for Quality Assurance (STA) [33]. The analysis of the compost applied is described in detail in the dissertation of Dr. Wright [34].

The fields were seeded with a reclamation seed mix. The seed mixture went to the no-compost field and the compost field at equal rates of 50 lbs (22.7 kg) each field. Fifty pounds (22.7 kg) of 18-46-0 (Nitrogen-Potassium-Phosphorus) fertilizer was equally applied to each field. All fields received equal machine work.

4. Results

Porosity tests show the 0% compost at 46.5%, the 5% at 50%, and the 10% at

52%, for a difference of a +5.5% porosity in a silty clay loam when amended with compost by 10% by weight. Infiltration tests were conducted in the field using a double ring infiltration system, with the infiltration rates being 10.93 in/h (278 mm/h) for the 0% compost, 16.44 in/h (418 mm/h) for the 5% composted soil, and 38.44 in/h (976 mm/h) for the 10% composted soil. The infiltration rate was increased by 150% when 5% compost was added and increased by 351% when 10% compost was added [35].

In 2018 sampling, the 10% compost soils improved soil carbon by 32%, total living mass by 70% and crop yield by 115%. In 2019 sampling, the 10% compost soils improved soil carbon by 48%, total living mass by 32% and crop yield by 30%. In 2020 sampling, the 10% soils improved soil carbon by 127%, total living mass by 106% and crop yield by 61%. Results are at **Table 1**.

Soil chemistry data suggests that the use of compost is beneficial in providing nitrogen, phosphorous, and potassium to the soil. Results are shown in **Table 2**.

Soil microbial results are summarized in **Table 3**. Soil microbial biomass generally comprises less than 5% of organic matter in soil but performs at least 3 critical functions of soil and the environment. 1) It is a reliable source of carbon, nitrogen, phosphorus, and sulfur; 2) it is an immediate sink of carbon, nitrogen, phosphorus, and sulfur; and 3) and it is an agent of nutrient transformation and pesticide degradation [39]. Microorganisms form symbiotic associations with roots, act as biological agents against plant pathogens, contribute towards soil aggregation and participate in soil formation [39].

The results of crop yield rates are in **Table 4**.

The visual health and vitality of the plants appeared much higher in the 10% soil area when compared to the no compost (NC) or the 5% soil area. In 2018, the no compost (NC) field had an estimated 25% infestation of buffalo bur (*Solanum rostratum*) weeds. The compost fields show a minimal amount of infestation estimated at 1% - 2% by area.

Compost incorporation improved total carbon content, biomass population, soil texture and appearance. Results are shown at **Table 5**.

Table 1. Total carbon by soil type and depth.

Soil Blend	Depth (inches)	Total Carbon % August 2018	OM %* Aug 2018	Total Carbon % August 2019	OM % Aug 2019	Total Carbon % August 2020	OM % Aug 2020
NC No compost	0 - 8	3.5	6.2	2.9	5.0	3.7	6.7
	8 - 16	2.6	5.2	2.5	4.0		
	16 - 24	2.3	4.7	2.4	2.9		
5%	0 - 8	4.0	7.2	4.0	6.2	6.3	9.8
	8 - 16	2.6	4.7	3.2	4.2		
	16 - 24	2.6	4.4	3.1	3.8		
10%	0 - 8	4.6	7.6	4.8	7.4	8.5	14.3
	8 - 16	2.4	4.3	3.8	5.4		
	16 - 24	2.7	4.5	2.7	3.6		

*Soil organic matter (OM) expressed as a percent of total.

Table 2. Soil chemistry by soil type and the top 8 inches (203 mm) depth.

Soil Blend	August 2017	August 2018	August 2019	July 2020
Conductivity ECC m ohms/cm				
NC	0.78	0.45	0.31	0.38
5%	1.1	0.73	0.33	0.51
10%	1.7	0.89	0.51	0.64
Total Nitrogen N ppm				
NC	103	NA	12	37
5%	36	NA	16	89
10%	44	NA	87	207
Total Phosphorous P ppm				
NC	13	10	9	10
5%	24	28	9	56
10%	50	47	31	116
Total Potassium K ppm				
NC	380	320	299	735
5%	390	384	337	1085
10%	670	530	485	1100

Table 3. Biological Soil Analysis (0 - 200 mm) 2 years after amendment.

	NC No Compost			5% Compost			10% Compost		
	2018	2019	2020	2018	2019	2020	2018	2019	2020
Total Bacteria	2644	4367	2594	3500	4716	3678	4224	5178	5601
Total Fungi	736	1031	901	1161	1390	870	1589	1502	1863
Protazoa	105	41	46	109	56	22	182	40	56
Undifferentiated	1546	2516	1794	2227	3066	1194	2563	3744	3516
Total Living Biomass	5031	7955	5335	6997	9228	5764	8558	10,465	11,036

Table 4. Year 2018-2020 crop yield field data based on wet weight.

Field		0% Baseline	5%	10%
Average Yield Difference by Mass	2018	0%	+39%	+115%
	2019	0%	+1%	+30%
	2020	0%	+15%	+61%

Table 5. Average total carbon and living biomass 2018-2020 over the upper 200-mm of soil.

	Total carbon % by weight	Total living mass (PLFA), ng/g	% Increase Total C	Total Biomass
No compost (NC)	3.5%	6107	N/A	N/A
5% compost	4.7%	7329	+34%	+19%
10% compost	6.0%	10,020	+71%	+62%

Adoption of improved tillage and residue management improves soil health. Increasing soil organic matter improves water holding capacity, improves soil structure, increases nutrient exchange, helps soil adjust to resist drastic pH changes, and increases nutrient availability [40].

5. Discussion

Incorporation of compost into agricultural soil has shown a significant benefit in improving the soil in several key aspects of soil health. Increased infiltration rates, higher moisture content, higher total carbon, higher total biomass, and higher yields indicate sizable benefits from the incorporation of compost into soil. Composting organic wastes reduce the tonnage a community landfill, and can reduce the carbon footprint if composted on-site. Utilization of compost as a soil amendment provides a very beneficial use of the compost product beyond simple mulching. In this study, three years of data from a field scale experiment strongly show that all key measures of soil health were increased by soil compost amendments, and that the benefits scale with increasing compost amounts. Key to this study was the mixing of compost into the soil rather than using it as a mulch. This direct incorporation into the soil matrix serves a different purpose than mulching and can be used in connection with mulching for enhanced performance and even better soil health outcomes. Perhaps most impressive were the long-term increases in N/P/K concentrations showing that composting is a viable means to reduce need for agricultural producers and homeowners to supplement with N/P/K fertilizers.

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Conflicts of Interest

The authors declare no conflicts of interest.

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