COMPARING BIOLOGICAL AND STRUCTURAL FEATURES OF SOILS UNDER CONVENTIONAL AND CONSERVATION TILLAGE

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ABSTRACT

The effect of tillage decisions on soil structure is well understood by growers and agricultural researchers. There are, however, biological consequences of tillage operations that have traditionally been less appreciated. The effect of tillage on soil organisms, specifically microorganisms, is an area that has become a focus of research only recently. The effect of tillage on soil organic matter, which includes living microorganisms but additionally encompasses all forms of living and dead plant and animal tissue, has also been underappreciated in many farming operations. Tillage operations significantly affect soil microbial populations and community structure and also reduce organic matter through oxidation. The objective of this research was to investigate the differences between microorganism numbers and soil physical properties and their related functions in different agricultural systems. The agricultural treatments in this study are: conventional tillage vs. conservation tillage and synthetic fertilizers and pesticides vs. organic inputs. We found that microbial respiration and nitrogen mineralization were enhanced in conservation tillage treatments regardless of the fertilizer and pest management sources. Microbial biomass was greatest in the conservation tillage-organic input treatment and was lowest in the conventional tillage-synthetic inputs treatment. Bulk density was slightly lower in the conservation tillage treatments compared to conventionally tilled treatments. Total porosity was very similar for all treatments, but macroporosity was greatest in the conventionally tilled treatments and microporosity was greatest in the conservation tillage treatments. Aggregate stability was greatest for the conservation tillage treatments.

INTRODUCTION

The importance of integrating the biological and physical components of soil in our agricultural management decisions is becoming increasingly apparent. One concept that is still not fully appreciated is the critical role soil organisms have played in soil formation and their current role in soil modification and stabilization. Soil organisms and soil physical properties are highly responsive to tillage regimes in agricultural soils. Tillage has been conclusively shown to exert a powerful influence on the soil ecological community and therebt affects the functional activity of soil microorganisms as well as micro-, meso-, and macroinvertebrates (Doran, 1980; Paul and Clark, 1989). Intensive tillage practices have been shown to result in significantly reduced aggregate stability, which is an important soil structural characteristic as well as a microbially-mediated property (Tisdall and Oades, 1980; Lynch, 1984). Erosion, sedimentation, and damage to soil structure are related problems associated with intensive tillage that can negatively affect both the physical and biological properties of soil and off-site locations.

Tillage systems dramatically influence the microbial population and diversity of a soil by affecting carbon dynamics, such as organic carbon distribution and quality, as well as influencing soil habitat parameters such as pH, temperature, aeration, and water-holding capacity. Tillage systems also play a critical role in determining the structure of a soil by influencing bulk density, pore-size distribution, and aggregate stability. Soil organisms and soil structure are correlated in agricultural systems, such that outside factors having a positive effect on one factor generally have a mutually positive effect on the other (Fig. 1). Soil microorganisms are also known to be sensitive indicators of soil physiochemical changes. It has been shown that microbial populations respond measurably to changes in soils induced by agricultural production practices long before other chemical or physical soil properties show measurable differences (Powlson et al., 1987; Fauci and Dick, 1994).

As a result of regular surface removal of crop biomass, conventionally-tilled crop ecosystems have plant biomass levels similar to that of a desert or tundra, despite having much more favorable growing conditions (Chapin et al., 2002). By increasing the amount of organic matter introduced to the surface of the soil, reduced tillage systems play an important role in affecting soil structure. Organic matter comes from both living and dead sources, including leaves, roots, fauna, and microorganisms. Organic matter can improve the structure of agricultural soil as well as make soils more resistant to structural degradation due to compaction, water logging, and tillage. Roots and mycorrhizal hyphae produce polysaccharide compounds which facilitate organic matter protection through the formation of stable soil aggregates. Cation exchange capacity (CEC) also is affected by organic matter, the effect generally being an increase in CEC with increasing soil organic matter content. Increases in CEC result in greater nutrient retention by soils and increased pH buffering capacity.

The factors of organic matter, biology, and structure act together in cyclical fashion such that each component of the cycle affects, directly and indirectly, each other component. The changes induced by different tillage strategies act to affect this cycle in many ways, making soils more or less suitable for sustainable crop production.

The objective of this research was to characterize and compare the soil microbial and physical properties of vegetable systems that incorporated tillage and production methods in a long-term (9 year) experiment.

MATERIALS AND METHODS

Field History and Design:

The site for this study was located at the Mountain Horticultural Crops Research Station in Fletcher, N.C. The soil type of the field is a Delanco fine-sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult) with 2-7% slopes. The soil is gently sloped, moderately to somewhat- poorly drained and formed from old alluvial deposits. The average length of the growing season is 190 days between April 14 and October 25. Prior to this study being implemented, this field was planted to grain corn for the previous five years and had a pH of between 5.9 and 6.6 with a base saturation between 75 and 100% and a CEC between 4.3 and 6.9 cmol/kg when the study was initiated (Johnson, 1999).

Description:

A long-term vegetable crop experiment was initiated in 1994 to compare two sustainable agriculture practices, 1) conservation tillage vs. conventional tillage and 2) organic fertilizers and pest control vs. chemical fertilizers and pesticides. A vegetable rotation treatment was also implemented on subplots, but this treatment will not be included here. Every combination of treatments, five treatments in all including a control, was replicated 4 times in a completely randomized plot design. Each plot measured 40 feet by 80 feet. There was a distance of at least 40 feet between plots to minimize fertilizer and pesticide drift and pest and pathogen migration between plots. The control plots were established with no inputs to show background values for soil nutrients and pest pressure due to disease, weeds, and insects.

This experiment has been in place for nine years. Based on visible differences in soil physical properties and crop yield among treatments, it is believed by the authors that this was sufficient time to allow the microbial communities to acclimate and equilibrate to representative levels within each plot treatment.

All data presented was collected over a single growing season, in the spring and fall of 2003. The crop planted during this year was staked fresh market tomatoes. A cover crop of wheat and crimson clover had been seeded the previous fall in all plots except the control. In the spring, the winter cover crop was killed with glyphosate (conservation till chemical treatment), tilled under (convention till chemical and organic treatments) or flail chopped (conservation till-organic treatment). The conventionally tilled treatments were disked, bedded, and black plastic applied after plowing. Additionally, the conventional-tilled chemical treatment was fumigated when plastic was applied, usually two weeks prior to planting. The conventionally tilled treatments were disked and bedded after the winter cover was mowed and plowed in. The conservation tillage treatments had 12 inch strips tilled into the plots (strip-tillage) using a Bushhog Ro-till. In the conventionally-tilled organic treatment, rows were bedded and black plastic stretched over beds, just as in the fumigated treatments, but no fumigant was added. All treatments were hand transplanted after tillage, plastic, and fumigation additions.

Synthetic fertilizer and pesticides were applied as needed to the chemical treatments, with 180 lbs N/acre applied each year for each crop and phosphorus, potassium, and limestone added as recommended by soil test results. All chemical herbicide, fungicide and insecticide applications were applied according to standard North Carolina recommendations as determined by the N.C. Agricultural Chemicals Manuals (1995-2003). In the organic treatments no synthetic pesticides were used and fertilizer nutrients were applied as surface banded materials as follows: soybean meal was used as the main fertilizer source (at 180 lbs N/acre rate) and assumed 100% availability. Phosphorus, potassium, and limestone were added when recommended by soil test results and only materials approved by the Organic Materials Review Institute (OMRI) were used. Disease and insects were controlled with materials approved for organic production (OMRI) and weeds were controlled by mowing and hoeing.

Soil samples for microbiological analysis were collected from in-row areas to a depth of 8 inches prior to fumigation in the spring and after the final harvest in the fall. Samples were transported to the lab on ice and were stored at 5 degrees C until all assays were completed. All bioassays were completed within 5 weeks of sampling date. Soil samples taken for physical properties were collected in the fall. Samples for aggregate stability were taken from a depth of 6 inches, air dried, and ground to pass through a 0.3 inch sieve. Bulk density, porosity, and pore size distribution samples were taken using a 3 inch Uhland core sampler (four samples per plot) and were transported and stored at room temperature until analyzed. See Figure 2 for a schematic representation of data collected. We also determined cover crop and vegetable biomass and vegetable crop yields during this study.

Analyses:
Figure 2 describes a conceptual framework for which microbial and physical analyses were performed. This selection of analyses is designed to give broad-ranging indications of soil microbial populations and activity, and nutrient transformations taking place as a result of microbial communities and climatic factors. Tillage-mediated analyses will be evaluated at three different levels: 1) microbial biomass, 2) microbial activity, and 3) soil physical properties. For biomass measurements, we analyzed microbial biomass carbon (MBC), and microbial biomass nitrogen (MBN) using the chloroform fumigation-extraction method. For microbial activity we measured soil respiration with a base trap incubation technique and potentially mineralizable N using salt extractions, both over the course of a 28-day incubation period. For soil physical property changes we analyzed aggregate stability with a wet sieving method, bulk density from intact cores, and porosity, and pore size distribution using a differential pressure saturated hydraulic conductivity apparatus.

RESULTS AND DISCUSSION

Microbial Properties:
Microbial respiration was measured as CO_2 evolution during a 28-day incubation in the spring and fall (Table 1). The conservation till-organic treatment consistently had the greatest soil respiration and the conservation till-synthetic treatment was second-highest for both sampling dates. By the end of the growing season, in the fall, the conventional till-organic and conventional till-chemical treatments had similar, relatively low, respiration rates. The conservation till-organic treatment displayed a relatively large increase in carbon dioxide evolution over the growing season, very similar to the control treatment, indicating that the conservation till-organic treatment produced a soil environment suitable for increased microbial populations over the other treatments. The conservation till-synthetic treatment also showed an increase in respiration over the conventional tilled treatments, but not as great as the conservation till-organic. The reduced values for CO_2 evolution in the two conventionally-tilled treatments indicates a relative decline in the microbial activity, probably due to the reduction in soil organic matter in these treatments over the 9 years of this experiment as cover crop residues were available earlier in the season and were eventually depleted by the second sampling date.

Potentially mineralizable N was also measured among treatments during a 28 day incubation study (Figure 3). Soils were removed from the respiration study after 28 days (with no additional organic amendments) and then extracted with 0.5M K_2SO_4 and analyzed for available NO_3-N and NH_4-N. At the beginning of the season (spring sampling) the two conservation-tilled plots and the conventional till-organic treatments had similar N mineralization values and the conventional till-synthetic and control treatments had somewhat lower values. By the fall sampling date, the conservation till-organic treatment had increased the pounds of N mineralized per acre by about 21 pounds, theoretically representing a net gain in N availability to plants. The other four treatments had varying degrees of negative net N mineralization over the course of the growing season. The greatest decrease in pounds of N mineralized was in the conventional till-organic treatment; in this treatment there was a decrease of about 20 pounds of N per acre. This may be the result of increased immobilization of previously plant-available mineral N or very rapid mineralization of the organic materials early in the season (it was a very wet spring and summer) resulting in the majority of available N being removed from the system by NO_3 leaching or plant uptake by the fall sampling date. This data indicates that tillage plays an important role in the mineralization of organic N sources over the course of the growing season. More research must be conducted to determine the exact fate of the N in the organic systems. The two chemical treatments show similar modest declines (ranging from about 5 to about 9 pounds per acre) in N mineralization over the growing season, indicating that synthetic fertilizers are not as strongly affected by microbial processes as are organic N sources. It should be noted, however, that the absolute values of available N which were salt-extractable were greater in the conservation tilled treatment than in the conventionally tilled treatment when chemical fertilizers and pesticides were applied.

Tables 2 and 3 summarize the results of the microbial biomass C and N (MBC and MBN) analyses, respectively. As would be expected, the relative patterns of change among treatments for the spring and fall sampling dates is the same for both analyses. In the conservation till-organic treatment, the MBC value increased modestly while the MBN value decreased by 23 pounds per acre. This reduction in MBN correlates to the increase in potentially mineralizable N of 21 pounds per acre. In the conservation till-chemical plots, the MBC increased about 137 pounds of C per acre while the MBN values remained essentially the same at the beginning and end of the growing season. The two conventionally tilled treatments demonstrated a reduction in MBC and MBN from the spring to fall. The MBC values in the conventional till-chemical plots decreased by 271 pounds/acre while the MBN decreased by 8 pounds/acre. The control plot exhibited the greatest increases in both MBC and MBN of all the treatments.

Physical Properties:
Similar bulk densities were measured across all tillage and production practice treatments in the top three inches of soil, although plowed soils (including the control) appeared to have higher bulk densities (Figure 4). The control treatment had the greatest bulk density, possibly because they are plowed every year and are not seeded with a cover crop. These plots remain fallow after harvest and are generally overgrown with native grass species during both summer and winter seasons. It may be the combination of these factors which make the soil bulk density relatively high and the MBC and MBN values relatively high as well. Figure 5 depicts the pore size distribution and total porosity of the treatments. The total porosity remains similar across all treatments, but macroporosity is slightly greater in the conventionally tilled treatment soils while microporosity is slightly higher in the conservation tillage treatment soils. The control treatment soil had the lowest macroporosity and the second greatest microporosity. It's combination of low total porosity combined with the high percentage of those which were micropores contribute to our understanding of the high bulk density of the control plots shown in Figure 4. Table 4 describes the soil aggregate stability which was measured as percent water-stable aggregates in the bulk soil and then converted to a single value described by the geometric mean diameter of the water stable aggregates. Soils from the conservation till-organic treatment gave the greatest average diameter for the water stable aggregates, meaning it had the greatest aggregate stability. The control treatment produced the second highest measurement for aggregate stability. These results correlate with the values for MBC and MBN, reinforcing the idea that soil aggregate stability is a microbially-mediated property. These results are not surprising since the visual effects of the treatments were obvious while the wet sieving was being performed during this analysis. Those treatments which were later shown to have fewer water stable aggregates (the conventionally tilled treatments) produced a very turbid water-soil solution, so dense it was difficult to see through. The conservation tilled treatments, on the other hand produced much less turbid solutions during the wet sieving process.

CONCLUSIONS

The cycle portrayed in Figure 1 is clearly being affected by the treatments imposed (tillage and chemical inputs) in the experiment reported here. Respiration levels were greatest in the conservation till-organic treatments followed by the conservation till-chemical treatment. The relatively lower values determined for the conventionally tilled treatments indicates a lower microbial activity under the plowed tillage regime. Potentially mineralizable N (PMN) analysis revealed that the conservation till-organic treatment was the only treatment with a net positive mineralization value between the spring and fall sampling dates. The greatest reduction in PMN over the course of the growing season was found in the conventional till-organic treatment. This indicated that tillage affects N mineralization from organic N sources. The PMN values in treatments fertilized with synthetic fertilizers and using chemical pesticides did not change very much, reinforcing that N from synthetic sources are not as dependent upon microbial processes for transformation into plant-available forms as are organic fertilizers. MBN values in the conservation till-organic treatments were found to decrease to a similar degree that PMN values increased over the growing season. This indicates that the N budget was strongly influenced by microbially-mediated mineralization processes in this system. Other treatments showed trends for MBC and MBN values similar to the trends determined for the respiration measurements.

Physical properties were also influenced by the experimental, but not to the same degree as were microbial properties. This corresponds to the results of other studies indicating that microbial activities are strong indicators of soil biophysical properties. Bulk density values in the top 3 inches of soil were similar among treatments. Conservation tilled plots were slightly less dense than conventionally tilled plots after 9 years of treatment impact. Total porosity was also very similar among treatments, but pore size distribution revealed that there were more macropores in conventionally tilled soils and more micropores in conservation tilled soils. Macropores are not as valuable to crop growth from a moisture-holding perspective because they are too large to retain water against gravitational force; micropores, however, have a greater water-holding capacity due to capillary forces in the smaller diameter pores. Aggregate stability was found to be greatest in the conservation till-organic treatment.

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Table 1. Cumulative respiration measurements of CO_2 over a 28 day incubation period in spring and fall (standard deviations in parentheses)

Treatment	Spring lb CO_2/1000 lb soil	Fall lb CO_2/1000 lb soil
cons/org	0.38 (0.06)	0.57 (0.18)
cons/syn	0.34 (0.12)	0.38 (0.09)
conv/org	0.27 (0.04)	0.17 (0.07)
conv/syn	0.20 (0.07)	0.16 (0.04)
control	0.15 (0.03)	0.37 (0.13)

Table 2. Microbial biomass C and N measurements in spring and fall (standard deviations in parentheses)

Treatment	Spring MBC lb C/acre	Fall MBC lb C/acre	Spring MBN lb N/acre	Fall MBN lb N/acre
cons/org	1355 (214)	1406 (240)	98.2 (31.4)	75.2 (5.2)
cons/syn	855 (122)	992 (214)	40.8 (17.1)	41.3 (7.3)
conv/org	1072 (387)	767 (178)	47.8 (10.0)	36.0 (5.4)
conv/syn	531 (197)	260 (95)	19.4 (13.4)	11.4 (8.0)
control	656 (248)	1138 (291)	36.3 (10.4)	53.9 (17.1)

Table 3. Geometric Mean Diameter (GMD) of Water Stable Aggregates

Treatment	GMD (mm)	Std Dev
cons/org	1.80	0.12
cons/syn	1.12	0.37
conv/org	0.98	0.57
conv/syn	0.96	0.11
control	1.48	0.47

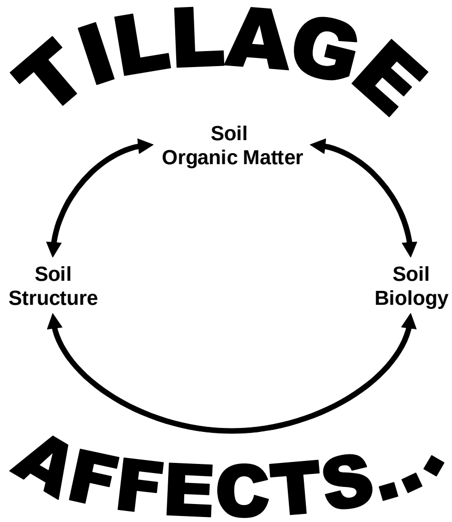

Figure 1. Tillage affects all components of the organic matter-biology-structure cycle. Each component, in turn, can affect the rest of the cycle.

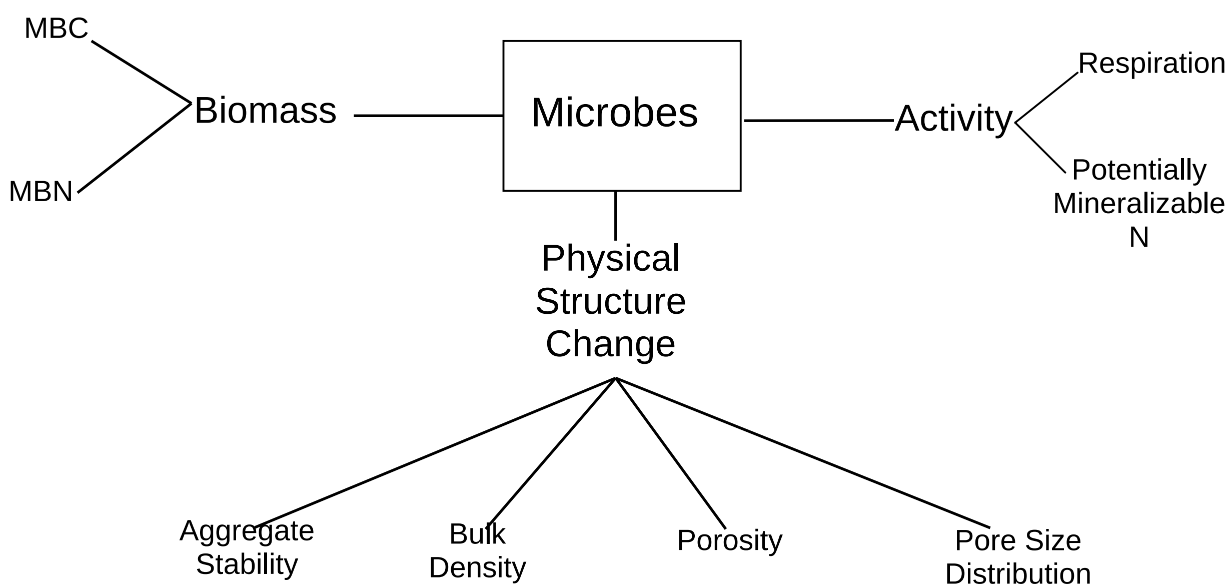

Figure 2. Conceptual diagram of measurements (MBC=Microbial Biomass C; MBN=Microbial Biomass N)

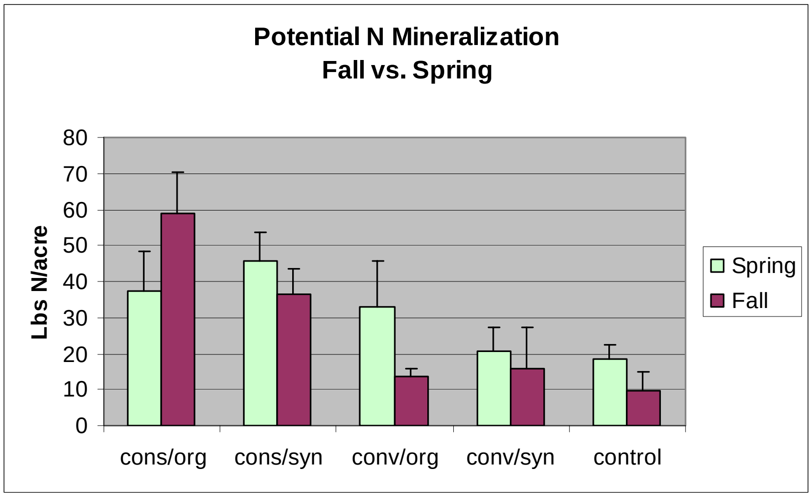

Figure 3. Potentially mineralizable N measurements over a 28 day incubation period in spring and fall

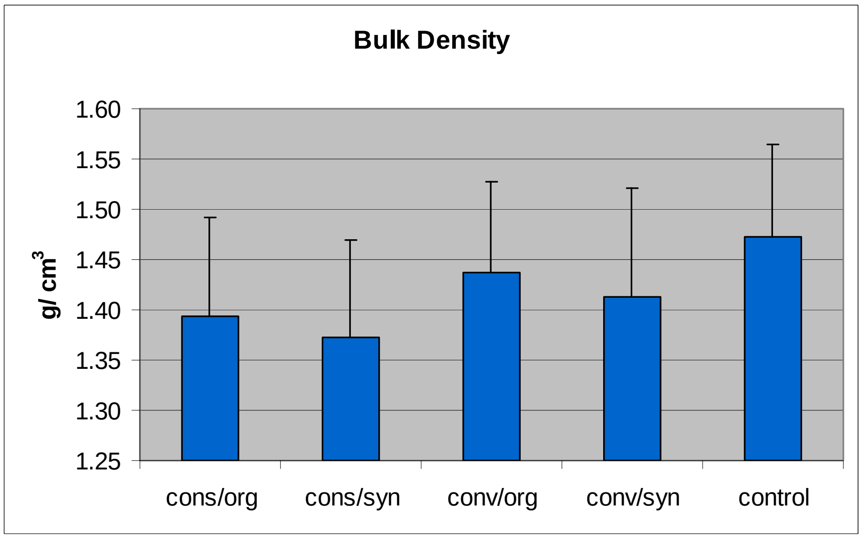

Figure 4. Bulk density measurements of treatments

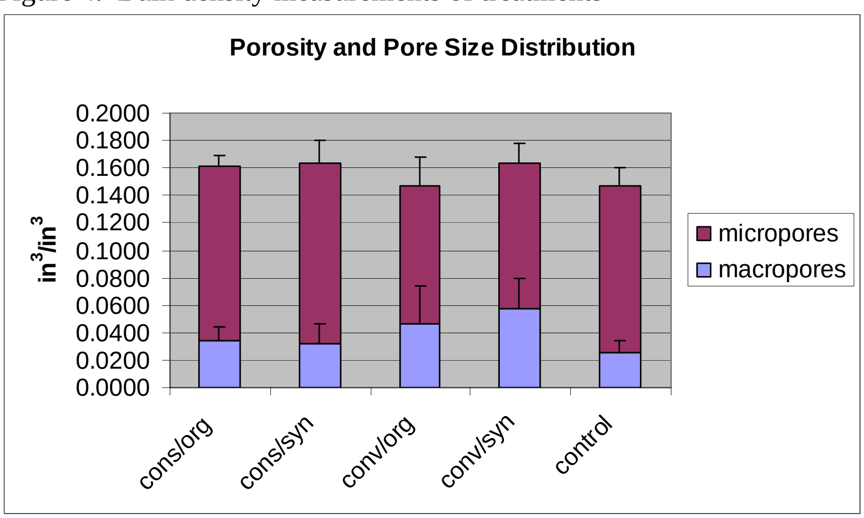

Figure 5. Porosity and pore size distribution of treatments