SOIL HEALTH NEXUS

Manure Land Application and Soil Health Indicators

2016 Manure and Soil Health Working Group Report

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Project Summary

This project aimed to correlate important soil health variables and land application of manure data collected in Missouri. The collaborating team included agricultural engineers, soil scientists, and personnel from the University of Missouri Soil Health Assessment Center. The team assembled and analyzed data of soil health related variables and manure land application details collected under the Missouri Cover Crop Cost-Share Program. The manure related information was only added to the required information collection in early 2016, thus only a partial year of data is included in this report. Over 1700 samples were collected, and 1000 samples are included in this report. No significant difference was found between the fields with and without manure application for total organic carbon, active carbon, pH, potentially mineralizable nitrogen, bulk density, and water stable aggregates; a significant difference was found only for phosphorus. The lack of correlation is mostly likely because only a small portion of the state-wide samples were associated with manure land application, and the samples were highly variable in tillage, soil type, crop and manure type, and application rate and methods, and consistent, multi-year data from similar fields is limited. However, when the effects of manure land application was compared within counties, the manure applications increased the active carbon contents (p<0.01) for two of the top three counties where manure application data was collected. The manure application also significantly increased (p<0.05) organic carbon, phosphorus, potentially mineralizable nitrogen, and water stable aggregate values for Stoddard county.

In order to better examine the effects of manure land application on soil characteristics, another set of data was included in this report. This dataset was collected from controlled experimental field plots with consistent tillage and repeated crop and fertilizer treatments. When comparing the plots that received full fertilizer, no fertilizer, and manure application, the effects of the manure land application clearly affected several key variables. The manure application resulted

in higher soil organic carbon, active carbon, phosphorus, and water stable aggregates, and lower bulk density. These findings confirm that the benefits of manure application in increasing soil organic materials and improving soil aggregate ability can be seen at least from fields that were consistently treated. The findings regarding manure use and soil health indicators are important and should be shared with stakeholders. While considering measurable economic and environmental impacts of nutrient and manure management, especially for increasing the carbon content in the crop fields, manure land application can be one of the recommended practices.

Introductions and Objectives

A growing number of farmers and producers are using additional soil management practices to improve the productivity and function of their soil. When it comes to improving soil management, there has been a significant effort in promoting certain management practices such as low or no tillage, cover crop, and adding or increasing organic matter content in the soil.

A state-wide effort to encourage adoption of cover crops to improve water quality and soil health is under-way in Missouri. The Missouri N340 Cover Crop Cost-Share Program (DNR, 2016) provides incentives to operators who implement specific cover crop management. The program presents a unique opportunity for systematic evaluation of soil health indicators, crop rotation and yield, and manure application. Participants are required to submit such information. To date, over 1700 soil samples have been submitted to the University of Missouri Soil Health Assessment Center (https://cafnr.missouri.edu/soil-health/), Figure 1.

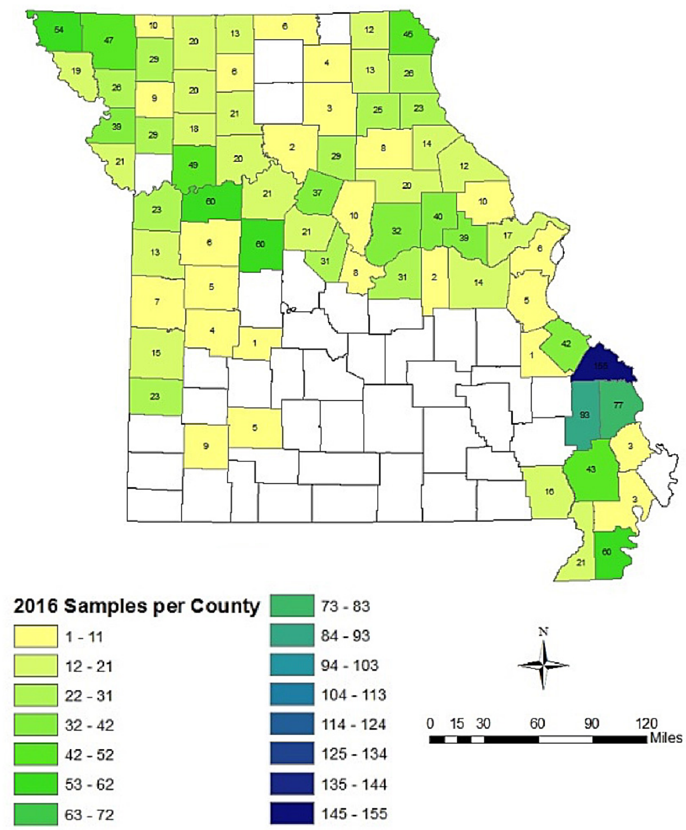

Figure 1. Number of samples collected under the 2016 Missouri Department of Natural Resources Cover Crop Cost-Share Program.

In contrast to cover crop and no-till management, efficient use of livestock and poultry manure to increase soil productivity and resiliency to extreme growing conditions, has not received as much attention. There remains a knowledge gap preventing the recommendation of future research, demonstration, and policy in efficient use of manure relating to soil health and productivity. The objective of this effort was to leverage existing and ongoing programs/projects in Missouri, and to assemble and analyze soil health indicators and manure application data.

Approach & Methods

State-Wide Soil Sample Analysis

A graduate student, under the direction of Dr. Lim and Ms. Brandt, analyzed the data of soil health related variables, and manure application details collected by the 2016-2017 Missouri Cover Crop Cost-Share Program. The main dataset analyzed was 1000 results of the soil health and manure application data. Critical land application of manure data were also being collected for this cost-share program, which included information such as manure type, tons/acre, and method applied. The manure related information was only added to the required information collection sheet in early 2016.

In addition to the more typical soil nutrient (nitrogen, phosphorus, and potassium) values, many key soil health indicators included in the program were soil aggregate stability, total organic carbon, active carbon, exchangeable cations, bulk density, and water stable aggregates (WSA). The soil samples were shipped to the Missouri Soil Health Laboratory for the analysis, following standard methods reported in the USDA NRCS Soil Survey Laboratory Methods Manual (USDA, 2004). Some of the important management information collected from the various fields included field location (county), crop rotation, tillage use, sampling use, etc. The group assembled and analyzed the data, and correlated the soil health indicators and manure application.

An additional research dataset was also compared with the cover crop and manure data. The research data was collected from a historic experiment field, Sanborn Field. The experimental field has been used to research soil properties, fertilizer uses, crop rotation, and recovery of exhausted soils. Recent research activities also involve the University of Missouri Soil Health Assessment Center personnel and evaluations of more detailed soil health indicators.

Experimental Field Plot Sample Analysis

The experimental field plots were located on the University of Missouri campus in Columbia, MO, and were part of the Sanborn Field plots. The plots were established as early as 1888, and were designed to assess the benefits of rotating crops and application of manure on crop production (J. Miles and R. Brown, 2011). The Sanborn Field had 44 individual plots, each measured 30.55 m x 9.42 m. The soil is primarily silt loam, which is in an area known as the central clay-pan till plains. The majority of the plots were managed in ongoing historic monoculture or rotation crop system. On plots with no additions of manure, no herbicides were used and weed control was through cultivation. Organic carbon for the soil samples were measured with a LECO CR-12 carbon analyzer, in line with the 2016 cover crop soil sampling program. A wide range of cropping systems were conducted at Sanborn Field, ranging from continuous corn, continuous soybean, continuous wheat, continuous Timothy, to three-year rotation of corn-wheat-red clover, and four-year rotation of corn-soybean-wheat-red clover. The fertilizer treatment included full fertility, full fertility minus nitrogen, full fertility minus phosphorus, 6 tons manure/acre-year, red clover as green manure, and no fertility. All plots included in this report were conventionally tilled. Four sets of soil samples were collected and analyzed for the complete soil characteristics to date. The sampling was conducted in May and September of 2014, and April and August of 2016. Because there were so many treatments and such a long history, the results included in this report focus on the overall full fertility, manure application, and no fertility, and especially their comparisons.

Statistical Analysis

The experimental data was organized and presented using a spreadsheet developed by Microsoft (Redmond, Washington), Excel 2016 (v16.0), which was included in Office 2016. The statistical analysis of significant differences between two treatments (in this case, with and without manure land applications) were determined using Analysis of variance (ANOVA) test function in the Excel program. The ANOVA is a collection of statistical models used to analyze the differences among group means and their associated procedures. If the calculated p-value was below the threshold ($p<0.05$), then the null hypothesis that the two mean values did not differ significantly was rejected.

Results and Discussion

Over 1700 samples were collected under the Missouri Cover Crop Cost-Share Program, and as of August 2017, 1000 samples were complete and analyzed for this report. Among these, 78 samples were reported to have applied manure fertilizer, which was a 7.8% ratio. For the 1000 samples, they were submitted from 71 counties. There were 29 counties indicated to have land applied manure, which included cattle, chicken, poultry and swine manure, Table 1.

Total sample	Soil-manure	Soil+manure	Cattle manure	Poultry manure	Swine manure	Not indicated
1000	922	78	28	39	9	2

Table 1. *Summary of sample size and type of manure applied collected under the Missouri Cover Crop Cost-Share Program.*

Figure 2 depicts the average total organic carbon values overall, and soil samples with (n=78) and without manure (n=922) applications. Although not statistically different, the soil samples with manure application are 9.4% higher in total organic carbon than soil without manure. Total organic carbon is an important indicator of soil health because the organic contents has been shown to affect biological, chemical, and physical soil properties (J. Miles and R. Brown, 2011). Total organic carbon and microbes help the soil filter, buffer, and transform inputs such as herbicides. The average active carbon values were 485, 517, and 482 mg C/kg soil for the overall, and soil samples with and without manure applications respectively, Table 2. Similar to the organic carbon, the active carbon values of the manure treated fields did not differ significantly from those that did not have manure application, but were 7.4% higher. Unfortunately only a small portion (78 out of 1000 samples) of the state-wide samples were associated with manure land application, and considering the variability in soil type, crop and manure source, and application rate and methods, more data would be needed to systematically compare and contrast the soil samples that received and did not receive manure. In addition, since this was the first time such data was collected, the dataset lacks consistent, multi-year data from similar fields.

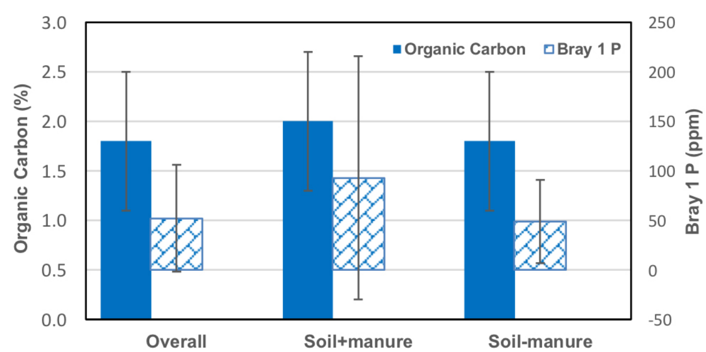

Figure 2. *Organic carbon and phosphorus contents of the state-wide soil samples, and with and without manure application.*

	N	Organic carbon (%)	Active carbon (mg C/kg soil)	pH Water	Bray 1 P (ppm)	Mineralizable Nitrogen (ppm)	Bulk density (g/cm^3)	Water stable aggregates (%)
Overall	1000	1.81	484.6	6.47	52.4	78.2	1.21	30.2
Soil + manure	78	1.97	517.4	6.58	92.9**	81.4	1.22	29.7
Soil - manure	922	1.80	481.8	6.46	49.0	77.9	1.21	30.3

*Significant different p<0.05, **Significant different p<0.01.

***Table 2.** Summary of key soil variables for the state-wide soil samples.*

Most plants prefer a soil pH between 6.0 and 7.0. The average pH values of the overall and soil samples with and without manure application were within this range. Soil pH affects the solubility of plant nutrients and the nutrient holding capacity or cation exchange capacity (CEC) of the soil.
The Bray 1 Phosphorus (B1P) test results are an estimate of available P levels for plants. Interestingly, the average phosphorus of soil samples with manure application was 92.9 ppm, which was almost twice the average value of the soil without manure application (49.0 ppm), indicating a correlation between manure application and the amount of phosphorus in many manure fertilizers. Too much phosphorus in the field can cause plant nutrient imbalances, and more importantly, contribute to high nutrient loss and potential environmental issues. However, the variance of phosphorus in soil samples with manure application is 122.6 ppm, Figure 2, suggesting a wide range of values in the samples. Potentially Mineralizable Nitrogen (PMN) is also a measure of soil biological activity and efficiency. The average potentially mineralizable nitrogen value for soil with manure application was 81.4 ppm, which is 4.5% higher than the samples from fields that did not have manure application.

Bulk density (BD) is an indicator of soil compaction and the soil functions of regulating water, producing biomass, and providing support for plants and structures. On average, the overall samples and soils with and without manure application are identical, averaging 1.21 to 1.22 g/cm^3. Water stable aggregates is an indicator of how soil particles bound together resist breaking apart, even during wet soil conditions. The mean water stable aggregates was 29.68% for the soil samples that had manure application, which is 0.6% lower than soil without manure application which averaged 30.28%. These values seem confounding since the soils that received manure application (and showed slightly higher carbon contents) did not have higher aggregate property. Potential causes include additional soil disturbance due to mechanical incorporation tillage, differences between soil types across the state, lack of multi-year sampling and data, and relatively low soil samples with manure application (n=78 out of 1000). More effort would be needed to compare these critical variables within similar soil types, manure application, application methods, and long-term yield and samples. Most of the variables indicated a general trend where they were affected by the manure application, except for the bulk density and water stable aggregates.

	N	Organic carbon (%)	Active carbon (mg C/kg soil)	pH Water	Bray 1 P (ppm)	Mineralizable Nitrogen (ppm)	Bulk density (g/cm^3)	Water stable aggregates (%)
No manure	922	1.80	481.8	6.46	49.0	77.9	1.21	30.3
Cattle	28	1.92	529.7	6.54	143.8	89.6	1.19	32.9
Poultry	39	1.90	504.5	6.54	65.2	75.1	1.24	25.2
Swine	9	2.33	558.3	6.70	62.8	94.1	1.17	46.0

Table 3. *Summary of key soil variables for the state-wide soil samples with different types of manure land applications.*

Comparison of Manure from Different Species

The key soil variables were also organized according to the type of manure applied, Table 3. There were three major types of manure reported: cattle, poultry (chicken and turkey), and swine. Two samples did not specify manure type. It is interesting to note the relatively high phosphorus value of 144 ppm for the soil samples with cattle manure, which is almost three fold higher than the state-wide no manure samples, and more than twice the level of the soils with poultry and swine manure application. When compared with the overall and no-manure samples, the different manure types showed a trend that generally differs from the samples without manure application, with the exception of the bulk density. The other exception is the water stable aggregates value for the poultry manure, which was actually 16.83% lower than the no manure samples, while the cattle and swine manure application increased the water stable aggregates values by 8.60% and 51.82%, respectively, Figure 3. This indicates that the cattle and swine manure were in general able to increase soil carbon contents and aggregate stability. Some of the important factors, such as manure application method (broadcast, sprayed, and injected), incorporation vs. tillage, and tanker vs. drag-hose, can affect many relevant variables such as the nutrient loss, soil density, and water stable aggregates. The different soil characteristics between poultry and other manure application suggests that more samples and multi-year samples collected from identical fields are needed to better correlate the factors.

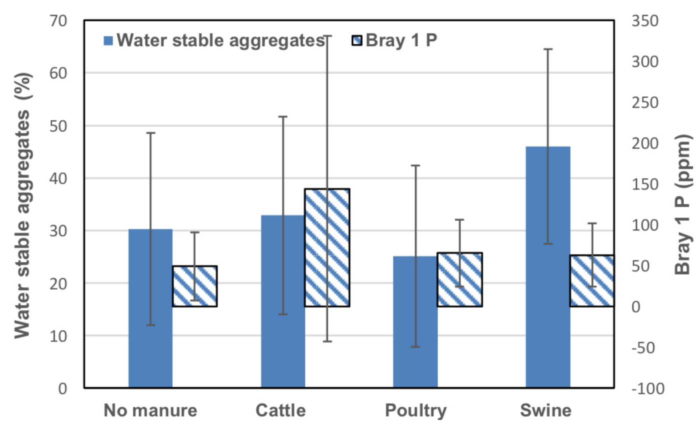

Figure 3. *Water stable aggregates and phosphorus content of soil samples applied with no manure and different types of manure.*

Comparison of Samples within County

A total of 1000 samples were included in this report, which were submitted from 71 counties during the 2016 period. The 78 soil samples reported to have applied manure were submitted from 29 counties, and the ratio is 40.85%. The top three counties with manure fertilizer were Pettis (15 samples, all were poultry manure), Moniteau (10 samples, all were poultry manure), and Stoddard (7 samples, 6 cattle and 1 poultry manure), Table 4. This dataset allows a more comprehensive comparison of the soil samples with and without manure application, that the sample size of soil with manure application is at least half the numbers of those without manure application. Also, in contrast to comparing the state-wide samples with and without manure application, Table 2, the within-county comparisons seem to allow more homogeneous by narrowing data to smaller regions with similar soils.

	N	Organic carbon (%)	Active carbon (mg C/kg soil)	pH Water	Bray 1 P (ppm)	Mineralizable Nitrogen (ppm)	Bulk density (g/cm^3)	Water stable aggregates (%)
Pettis+manure	15	1.94	530.1	6.45	56.9	74.5	1.25	24.9
Pettis-manure	29	1.91	522.0	6.56	47.1	81.4	1.24	24.8
Moniteau+manure	10	2.03	539.3**	6.72	60.1	75.7	1.19	24.9
Moniteau-manure	21	1.87	450.9	5.92	46.3	81.9	1.25	34.6
Stoddard+manure	7	2.36**	651.4**	6.01	344.2**	107.5**	1.23	31.0*
Stoddard-manure	12	0.93	247.1	6.19	52.6	38.8	1.08	22.8

*Significant different p<0.05 within the county, **Significant different p<0.01 within the county.

***Table 4.** Summary of soils characteristics for samples with and without manure application for the top three counties.*

In general, the manure applications increased the soil carbon contents ($p<0.01$ for total organic carbon in Stoddard country, and for active carbon in Moniteau and Stoddard counties). Also, in general, phosphorus values were affected by the manure application, while the other variables were not as consistently affected. For Stoddard county, which is located at the Southeast corner of Missouri and known for its sandy soils, the land application of manure clearly increased the carbon contents, phosphorus, potentially mineralizable nitrogen, and water stable aggregates values ($p<0.05$ or $p<0.01$, Table 4 and Figure 4). The mineralizable nitrogen is also a factor of soil health; the samples were incubated at 40ºC under water for seven days and analyzed for ammonium. This variable can be indicative of the amount of nitrogen mineralized over a growing season. These findings confirm, first that the sandy soils contain less nutrients and are less dense than the other soils, and second that the impact of manure application can be easily observed as well. The higher phosphorus level also poses a risk to polluting water bodies, especially when the soil moisture content, pH, and weather condition favors phosphorus loss from the soil.

These findings provide an interesting comparison to the Sanborn field data regarding organic carbon and active carbon. It was reported that after initiation of crop residue return to the fields, manure only treatments nearly returned to 1915 organic contents in the surface soil after 38 years, and the increase was a result of the nutrients from the manure in concert with the residues (J. Miles and R. Brown, 2011). The authors also concluded that greater active carbon was observed with manure and higher input management systems, and the active carbon had a wide seasonal flux as a function of temperature and moisture fluxes on microbial activity within the soil. Unfortunately, there are no details regarding the amount of residue that remained in the fields, and comparison of non-cover crop soil samples collected under the Missouri Cover Crop Cost-Share Program. Such data could provide more systematic comparisons and findings regarding the different critical management practices.

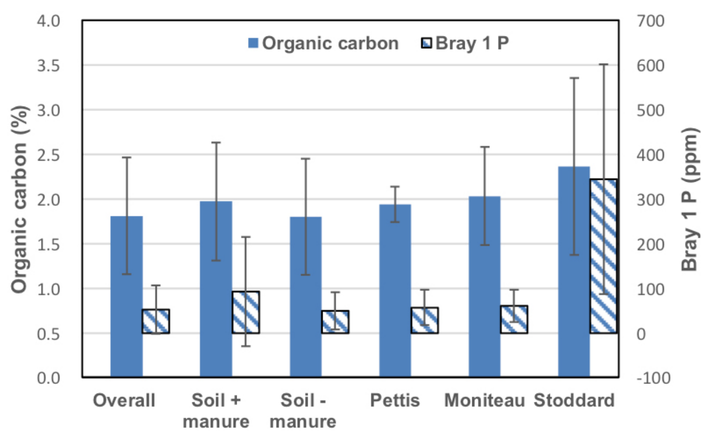

***Figure 4.** Comparisons of soil organic carbon and phosphorus contents, for state-wide and top three county data.*

Comparison of Manure Form and Application Method

The manure application information was further categorized and compared by forms of manure. For the 78 manure applications, 63 were reported as solid manure, four were liquid manure, and 11 were not reported, Table 5. Although there were only three species reported in this research, and it is common to assume the poultry and cattle manure were more likely in solid form, only data that clearly indicated the form were included to reduce ambiguity. In general, there were some differences between the two forms of manure sources, ranging from 4.6% to 11.1%, however, the number of samples were again relatively small and collected from various counties, especially for the liquid manure samples (n=4).

	n	Organic carbon (%)	Active carbon (mg C/kg soil)	pH Water	Bray 1 P (ppm)	Mineralizable Nitrogen (ppm)	Bulk density (g/cm^3)	Water stable aggregates (%)
Solid	63	2.05	533.0	6.59	89.9	83.8	1.24	31.6
Liquid	4	1.87	496.1	6.30	101.1	92.5	1.12	34.3

Table 5. *Summary of key soil variables for the liquid and solid manure land application.*

The survey included questions regarding manure application method. The majority of the farms reported to have used either spread or broadcast (n=28 each), and the rest were grazing and (center) pivot, and only two indicated using injection, Table 6. This confirms that due to the relatively small number of samples the effect of manure application could not be systematically compared and concluded.

Application method							
Method	Spread	Broadcast	Surface	Grazing	Pivot	Injected	Unknown
Number	28	28	3	3	2	2	12

Table 6. *Summary of different manure application method.*

Comparison of State-Wide and Experimental Plot Samples

The more uniform soil type and repeated experimental field plots provide a more controlled and homogenous comparison for the research of manure land application. The state-wide soil dataset shows only minor differences between the soil samples with and without manure application for the organic carbon contents, but the Sanborn experimental field plot data shows more differences between the treatments of full-fertilizer, manure application, and no fertilizer, Figure 5. Due to the fact that the Sanborn field plots were of similar soil type, and more importantly, have been receiving the same fertilizer treatments and management program on the same plots for at least 50 years, the organic carbon of soil with manure (M) is higher ($p<0.01$) than full fertility (FF) and no fertility (NF), Figure 5. This experimental field plot agrees with the within-county comparisons, Table 4, that the manure application was able to increase the soil carbon contents.

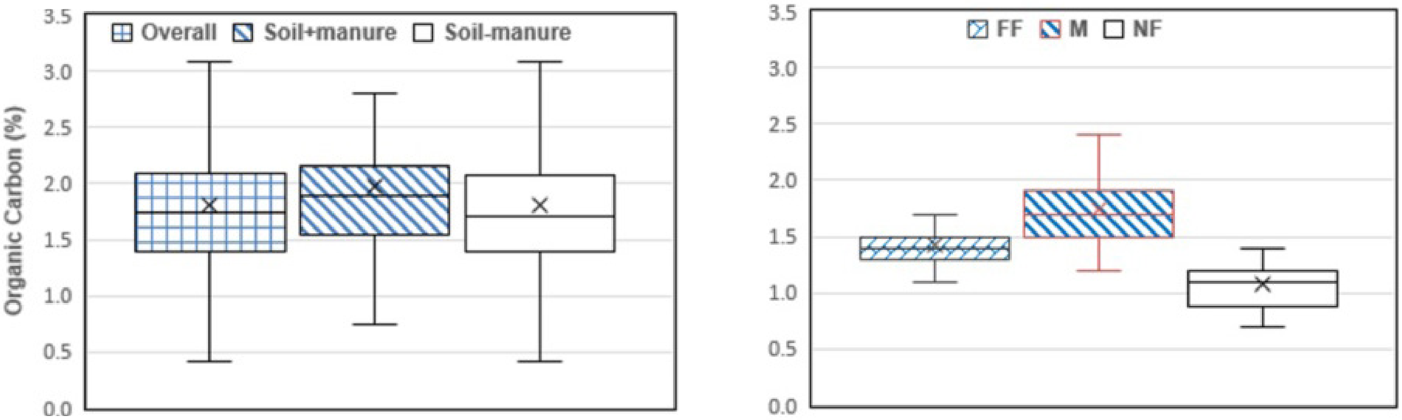

Figure 5. *Comparisons of organic carbon contents for the state-wide and Sanborn field plot soil samples, the plots depict median (solid line), mean (x), quartile box, and minimum/maximum values. . The state-wide samples (left) were state-wide average (overall), fields treated with manure (Soil+manure), and fields did not have manure application (Soil-manure). The field plot treatments (right) were full fertility (FF), manure (M), and no fertility (NF).*

For the experimental plots, the mean phosphorus values were 56.2, 36.7, and 6.8 ppm for the plots treated with full-fertility (FF), manure (M), and no fertility (NF), respectively, Figure 6. The plots that had no fertilizer applied had the lowest phosphorus value, while the manure application had higher phosphorus contents ($p<0.01$) than those that were receiving fertilizer at agronomic rate. In fact, the phosphorus difference was the only one that showed statistical differences between the state-wide comparisons for the soil samples with and without manure application.

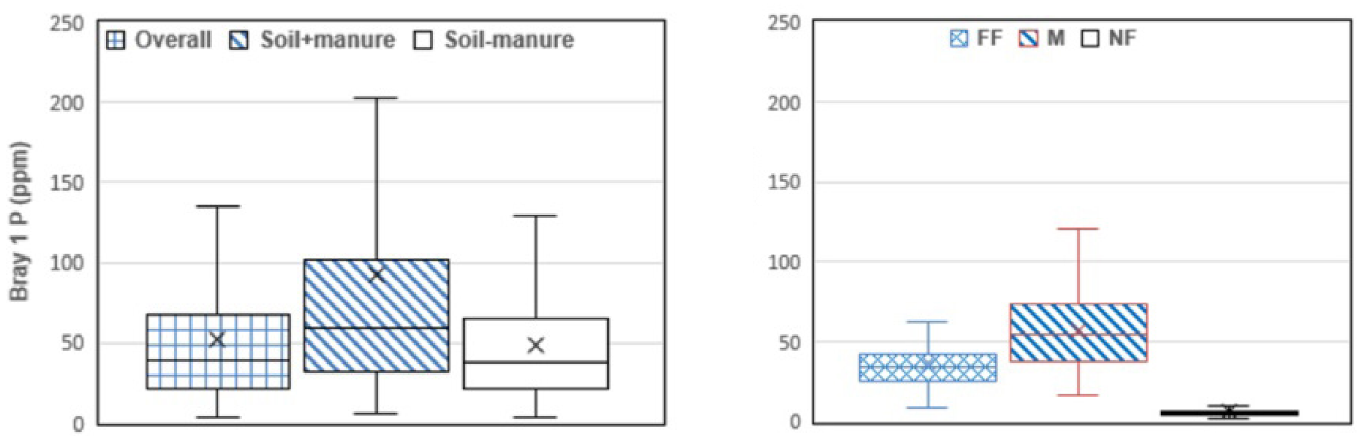

Figure 6. *Comparisons of phosphorus content for the state-wide and Sanborn field plot soil samples, the plots depict median (solid line), mean (x), quartile box, and minimum/maximum values. The state-wide samples (left) were state-wide average (overall), fields treated with manure (Soil+manure), and fields did not have manure application (Soil-manure). The field plot treatments (right) were full fertility (FF), manure (M), and no fertility (NF).*

The mean bulk density values for the state-wide soil samples with and without manure application are identical, averaged 1.22 and 1.21 g/cm^3 respectively, Figure 7. However, when comparing the effects of manure application on bulk density, the plots that had manure application showed the lowest density value ($p<0.01$), followed by full-fertility and no fertility treatments, and the average values were 1.33, 1.35, and 1.40 g/cm^3 respectively. Although the differences between the three treatments were relatively low, the manure application has shown to reduce the overall soil density, which helps to improve the soil aeration, and ability to regulate water and provide support for plants and structures.

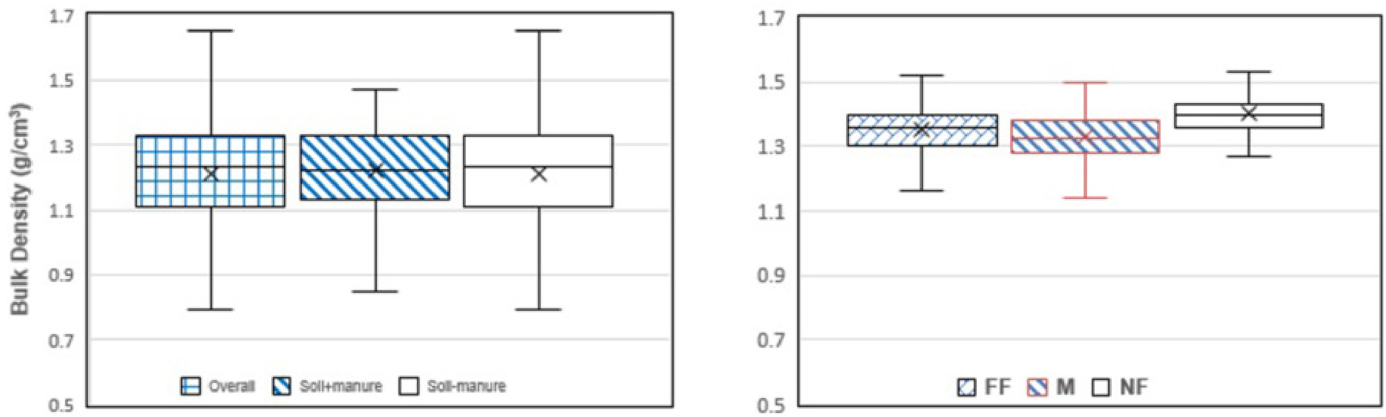

Figure 7. *Bulk density of state-wide and Sanborn field soil samples, the plots depict median (solid line), mean (x), quartile box, and minimum/maximum values. The state-wide samples (left) were state-wide average (overall), fields treated with manure (Soil+manure), and fields did not have manure application (Soil-manure). The field plot treatments (right) were full fertility (FF), manure (M), and no fertility (NF).*

An interesting finding observed in the Missouri Cover Crop Cost-Share program soil analysis is that the overall water stable aggregates value for soil with manure application was 0.6% lower than those without manure application, although it was not statistically different. Furthermore, even when comparing the two treatments within the top three counties with most manure application, only one county (Stoddard) showed a statistical difference in the water stable aggregates result, while the water stable aggregates of soil samples with manure was 9.7% lower ($p>0.05$) than those without manure in Moniteau county. This is rather confusing yet important given the importance of the water stable aggregates characteristics. Although soil aggregate ability has been measured by many ways, it has been widely accepted that better aggregate stability can lead to reduced erosion, and increased soil biological activity, infiltration, and water holding capacity. The average water stable aggregates values for the experimental field plots were 17.7%, 25.3%, and 14.8% for the plots treated with full fertility (FF), manure, and no fertility (NF), respectively, Figure 8. This at least confirms under more controlled and repeated experiment settings, that the application of manure has at least increased the water stable aggregates by 7.6% and 10.8% when compared with full-fertility and no fertility treatment.

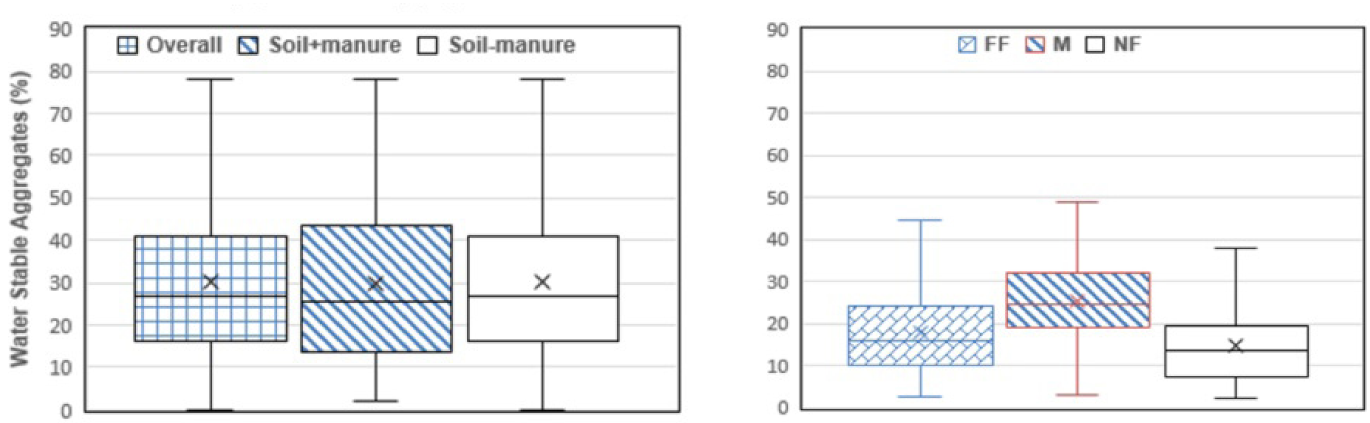

Figure 8. *Water stable aggregates of state-wide and Sanborn field soil samples, the plots depict median (solid line), mean (x), quartile box, and minimum/maximum values. The state-wide samples (left) were state-wide average (overall), fields treated with manure (Soil+manure), and fields did not have manure application (Soil-manure). The field plot treatments (right) were full fertility (FF), manure (M), and no fertility (NF).*

Conclusions

Based on the 1000 soil samples analyzed under the Missouri Cover Crop Cost-Share Program and the University of Missouri Sanborn Field experimental plots, this study examined the overall effects of manure land application on soil characteristics, especially those that have implications in soil health. In addition to the typical soil nutrient (nitrogen and phosphorus) variables, many key soil health indicators were included in the program such as total organic carbon, active carbon, exchangeable cations, bulk density, and water stable aggregates. Some of the important management information collected from the program included field location, crop rotation, tillage use, and if there was previous cover crop use, etc. Manure land application information included manure type, application rate, and method applied.

When comparing the state-wide soil analysis results, only the phosphorus value was affected ($p<0.01$) by the manure application, while the other variables were not as consistently affected. However, when the soil analysis was compared within county for the top three most manure application counties, more significant differences were noticed. For Stoddard county, which is known for its sandy soils, the land application of manure significantly increased ($p<0.05$ or smaller) the carbon contents, phosphorus, nitrogen, and water stable aggregates values. The results also confirm that the sandy soils contain less nutrients, are less dense, and the impact of manure application can be easily observed.

The more controlled experimental field plot data indicated a more obvious trend that the manure application affected the key soil characteristics. When comparing the plots that received full fertilizer, no fertilizer, and manure application, the manure application resulted in higher soil organic carbon, active carbon, phosphorus, and water stable aggregate, and lowered the bulk density. These findings confirm that the benefits of manure application, in adding soil organic materials and improving soil aggregate stability, can be easily seen from fields that were consistently treated and tilled. The findings regarding manure use and soil health indicators are important for management of the soil and can contribute to the many factors that need to be considered for increasing food production on a limited land base.

Acknowledgement

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