Effect of Long-term Beef Manure Application on Soil Test Phosphorus, Organic Carbon and Winter Wheat Yield

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ABSTRACT

In this study, 24 years (1990-2013) of data from a long-term experiment, in Stillwater, Oklahoma (OK) were used to determine the effect of beef manure on soil test phosphorus (STP), soil organic carbon (SOC) and winter wheat (Triticum aestivum L.) yield. Beef manure was applied every four years at a rate of 269 kg nitrogen (N) ha^{-1} while inorganic fertilizers were applied annually at 67 kg N ha^{-1}, 14.6 kg phosphorus (P) ha^{-1}, and 27.8 kg potassium (K) ha^{-1} for N, P and K, respectively. Averaged across years, application of beef manure and inorganic P maintained STP above 38 mg kg^{-1} of Mehlich-3 extractable P, a level that is far beyond crop requirements. A more rapid decline in SOC was observed in the check plot compared to the manure treated plot. This study shows that application of animal manure is a viable option to maintaining SOC levels while also optimizing grain yield.

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Keywords

manure application, soil organic matter, soil test phosphorus

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INTRODUCTION

In a bid to sustain food production and feed a rising world population, application of external inputs to supplement the already mined native nutrient sources are inevitable (Tillman, 1999; Edmonds et al., 2009). However, the type, nature and the amount of fertilizer applied could raise agronomic, economic and environmental concerns. According to the United States (US) Environmental Protection Agency (EPA), nutrient pollution is one of the most widespread and costly environmental problems in the US (EPA, 2014). Le et al. (2012) noted that inorganic nutrient sources are notably more damaging to agricultural ecosystems compared to their organic counterparts. Over application of inorganic phosphorus (P) would lead to build up in the soil to a level that can cause environmental pollution (Sims et al., 1998; Tillman, 1999; Jianbo et al., 2011; Le et al., 2012) through run-off and erosion. Carpenter et al. (1998) reported a linear increase in P discharged to surface waters with increasing soil P. Excessive discharge of P in surface waters cause dramatic changes in aquatic life, such as imbalances in the population of fish, water plants, and other aquatic organisms, as a result of excessive algal bloom or eutrophication (Syers et al., 2008). Sharpley (1995) noted that in some areas where intensive crop and livestock production is practiced, P has accumulated in the soil to such extent that additional sorption of P by the soil has become extremely limited. Phosphorus buildup in soil over time is due to higher levels of P in manure compared to P removed with the crop (Zhang et al., 2004) and the immobile characteristics of P in the soil (Schulte and Kelling, 1992). Whalen and Chang (2001) reported a difference of 1.2 to 3.8 mg P ha^{-1} in total P between non-irrigated manure treated and control plots. This work showed that over 16 years of manure application at a rate of 90 Mg ha^{-1} yr^{-1} soil total P increased from 13 to 16 Mg P ha^{-1}, an increase of 23%. While evaluating several long-term experiments, Hooda et al. (2001) found an increase of 300 mg P ha^{-1} between the check and a P treatment of triple super phosphate (TSP) and manure at 50 kg ha^{-1} over 28 years of application. Parham et al. (2002) noted however, that application of manure over a long period increases microbial activity and therefore P movement through the soil. To avoid accumulation of P in the soil, it is therefore important to know the level of P fertilizer required by plants (Sharpley et al., 1994). Many authors have shown the agronomic and environmental benefits of manure application to soil (Lupwayi et al., 2014; Dunjana et al., 2012; Eghball, 2002; Gao and Chang 1996). Haynes and Naidu (1998) noted that the use of manure has many beneficial impacts such as increased water holding capacity, porosity, infiltration capacity, and decreased bulk density and surface crusting. The use of organic fertilizer has also been shown to stimulate soil biological activity (Marinari et al., 2000). Gao and Chang (1996) reported increased N, total organic carbon (TOC), and increased cation exchange capacity (CEC) with increasing rates of animal manure application. There is also evidence of manure effecting soil pH. Lupwayi et al. (2014) proposed manure as a substitute for lime to correct soil pH in the Alberta Peace River Region in Canada. Consistent with this study, a study evaluating the effect of manure and compost on physical and chemical properties of soil showed an increase in soil pH after four years of application compared to a decrease in soil pH with inorganic fertilizer (Eghball, 2002).Various publications have associated the use of organic amendments with an increase in the amount of soil organic carbon (SOC) (Majumder et al., 2008; Manna et al., 2007; Murage et al., 2000; Bronson et al., 1997; Singh et al., 1997). In a study conducted in Kenya

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with small scale producers, farms with a higher production were found to contain higher levels of SOC and microbial biomass C, as compared to unproductive farms where lower levels of manure were applied (Murage et al., 2000). Dunjana et al. (2012) found a significant increase in SOC in sandy soils when manure was applied. Work by Manna et al. (2007) showed that nitrogen, phosphorus and potassium (NPK) combined with farmyard manure was able to maintain the highest level of SOC throughout the years included in the study. In agreement with these findings, Majumder et al. (2008) reported a 26.7% increase in SOC over the control treatment (no fertilizer) with the use of NPK combined with farmyard manure. Soil organic carbon has been defined as C occurring in soil organic matter (Milne, 2009). The microbial fraction of total SOC has been used as an indicator of changes in soil organic matter (Powlsen et al. 1987). Soil organic matter, which is arguably, the most significant indicator of soil quality (Reeves, 1997), can be depleted in a continuous cropping system even with addition of other soil amendments. However, the rate and extent of decline depends on management practices employed (Reicosky et al., 1995). The objective of this study was to determine the effect of long-term beef manure application on soil test P (STP), SOC, and the yield of winter wheat.

MATERIALS AND METHODS

The Magruder experiment (known as the Magruder Plots), at Stillwater, OK located on a Kirkland silt loam (fine, mixed, thermic Udertic Paleustolls), was initiated as a long-term continuous winter wheat (Triticum aestivum L.) experiment in 1892 by Alexander C. Magruder (Girma et al., 2007). The manure treatment was initiated in 1899 while inorganic fertilizer treatments were initiated in 1929. Results presented in this paper include data from 1990 – 2013.

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The six treatments included in this long–term experiment are manure, P, NP, NPK, NPK plus lime (NPKL) and an unfertilized control plot (Check). Plots are 30 m long and 5 m wide. Beef manure was applied every 4 years at 269 kg N ha^{-1} while the chemical fertilizer treatments received an annual application prior to planting. Nitrogen was applied as urea at a rate of 67 kg N ha^{-1}, while P was applied at 14.6 kg P ha^{-1}, and K was applied at 27.8 kg K ha^{-1}. At the time of establishment of this long-term experiment, there was no robust use of statistical methods in agricultural experiments. As a result, replications were not included in the experimental design. However, a study of this nature (long-term) could potentially provide a basis for understanding the effect of management practices on the physical and chemical changes in the soil. The treatment structure including the application rates for the respective fertilizer sources are summarized in Table 1. Composite soil samples, 15 – 20 cores per plot at 0–15 cm, were taken each year reported in this study. Soil samples from the field were sieved through a 2 mm screen, oven dried and ground to pass through a 1 mm sieve. Mehlich-3 extracts were filtered with 0.45 μm filters and P levels were determined by an inductively coupled plasma spectrometer (ICP-P). For each sample, 2 g of soil was weighed into an Erlenmeyer flask to which 20 ml of Mehlich-3 was added. The flasks were then put in the shaker for 5 minutes and the content emptied into funnels for soil P extraction. Three ml of each sample extract was pipetted into plastic cups. A solution of boric acid was made from which 3 ml was added to each cup, plus 5 ml of color reagent solution. Each year of the study period, plots were harvested with a Massey Ferguson combine and yield data recorded. Soil organic carbon was determined using dry combustion (LECO truspec) (Schepers, 1989). Simple statistics with mean, minimum, range and maximum values for STP, yield and SOC were computed for the study period. The rate of change in SOC in the beef manure and the untreated plots were compared using linear regression. Analysis of variance was performed using Proc GLM in SAS 9.3 (SAS Institute, 2003). Stability analysis was used to compare the environmental yield means of the manure versus the P treated plots.

RESULTS AND DISCUSSION

Soil Test Phosphorus (STP)

The Mehlich-3 extractable soil test phosphorus (STP) for the check, manure and inorganic P treated plots over the study period are reported in Figure 1. There was a significant difference in STP between the check, inorganic P, and manure treatments. Year to year variability was observed for all variables in all treatments. Over the entire period of study STP values in the untreated plot ranged from 2.5 to 11.5 mg kg^{-1}, while that for the inorganic P fertilizer and animal manure treatments ranged from 29.6 to 96.5 and 17.7 to 48.6 mg kg^{-1}, respectively (Table 2). Results for this study were grouped into categories (periods) of six years for simplicity of data presentation (Table 3). There were significant treatment differences for all periods (α=0.05). Overall, the manure plots had lower coefficient of variation (24%) compared to the inorganic P treated plot (31%) and the untreated plot (35%). A slight trend for an increase in STP was observed in the inorganic P fertilizer treated plot, while this was not the case with the manure treated plot (Table 3). In the inorganic P plots STP increased from 43 to 48 mg kg^{-1} between 1990 and 2013, while average STP levels reached 65 mg kg^{-1}during 2002-2007. The STP levels in the manure plot were not significantly different between periods considered in this study (Table 3). Average STP values in the manure plots were around 37 mg kg^{-1} in 1990-1995 and 2008- 2013. This study revealed that, the inorganic P plots had higher levels of STP, on average, 20% more than the manure treatment. The NP, NPK, and NPKL treatments had average STP levels that were 8 to 23% higher than the manure treatments. In an earlier study, Parham et al. (2002) recovered only about 22% of P from the manure plot compared to about 80% of that in the inorganic P fertilizer treatment. In other words, they demonstrated that the inorganic P source resulted in a greater increase in STP compared to the organic P sources. On the contrary, Jongbloed and Lenis (1998) demonstrated that animal manure resulted in more P accumulation in soil compared to inorganic fertilizer P. Zhang et al. (2004) explained that whether or not, animal manure results in more P accumulation, this depends on the quantity and source of manure applied. If the application of animal manure depends on N requirements, then most likely P applied in manure would be beyond crop requirements, and that would explain the P soil build up. According to Zhang et al. (2009), most crops require STP value of 35 mg kg^{-1} to be 100% sufficient in yield. Since 1991, application of animal manure every four years maintained the STP level above 35 mg kg^{-1} for the Mehlich-3 extractable P. Soil test phosphorus levels for the check were significantly lower than other treatments. Compared to the inorganic P fertilizer treatment, STP in the check plots was 85% lower, with an average of 6 mg kg^{-1}. This suggests the need for either inorganic and/or organic P sources in order to avoid yield reductions due to low soil test P.

Soil Organic Carbon

Results showed that there is a declining trend in the level of SOC in both the manure treated and the untreated plots (check) (Figure 2). Over the last 24 years, overall SOC decreased from 10 g kg^{-1} to 3.7 g kg^{-1} considering all plots. Organic carbon content of the untreated check plot declined from about 8.7 to 3.7 g kg^{-1} while the manure treated plot fluctuated above and below 8

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g kg^{-1} with a steady decline over the study period. In all four groupings of the study period, the manure treated plot had the highest level of SOC (Table 3). Figure 2 illustrates that the rate of decline in SOC from the manure treated plot was slightly lower, with a negative slope of 0.13, compared to the untreated plot, with a negative slope of 0.19. A comparison of the slope components of the two equations thus indicates a more rapid decline in SOC for the untreated check plot. The declining trend in SOC over time suggests that continuous crop production could completely deplete SOC which plays a pivotal role in nutrient recycling (Girma et al., 2007). This study demonstrates that application of manure reduces the rate of decline in SOC over time. The beneficial effect of manure application such as improved chemical, physical and/or biological functions of soils are a result of increased organic matter content of the soil (Haynes and Naidu, 1998). Organic matter has been viewed largely as a source of CEC which helps hold and releases positively charged ions (cations) for plant uptake (Salazar et al., 2002). Soils with lower organic matter content therefore, do not have a sustained ability to supply essential nutrients necessary for plant growth. Reduced nutrient uptake as a result of low organic matter would also lower fertilizer use efficiency (Linquist et al., 2007). Results of this study were similar to that of Manna et al. (2007) showing that annual long-term application of organic manure increases SOC. Similarly, Damodar et al. (2000) reported a significant increase in organic carbon with continuous application of manure alone or in combination with inorganic P fertilizer. The comparatively high levels of SOC in the NPKL treatments (Table 3) suggest that improved growing conditions resulted in increased yields and therefore higher levels of carbon from straw accumulation in the soil. The steady decline in SOC is evident in the periods from 1990- 2007. However, in 2008-2013 a slight increase in SOC can be noted. This can be

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explained by the comparatively higher yields in the periods 1996-2001 and 2002-2007, causing carbon accumulation in the following years (Table 3).

Grain Yield Response

Results from this study showed differences in variability in grain yield for the treatments evaluated. Yields in the check plot fluctuated over the study periods with minimum and maximum grain yields of 0.11 and 1.81 Mg ha^{-1}, respectively. The beef manure treated plot produced yields ranging from a minimum of 0.17 Mg ha^{-1} to a maximum of 4.04 Mg ha^{-1}(Table 2). The untreated plot averaged 1.04 Mg ha $^{-1}$ over the period reported in this study while manure treated plots averaged at 2.14 Mg ha $^{-1}$ over the same period. However, the manure treatment yielded 0.37 Mg ha^{-1} (14%) less than the NPKL treatment with the highest average yield (2.51 Mg ha^{-1}) recorded over the study period. Inorganic P fertilizer treated plot, with an average yield of 1.16 Mg ha^{-1}, did not appear different from that of the check plot (with average yield of 1.04 Mg ha^{-1}). For every period considered in this study the difference between the check and the inorganic P treatment was not significant at the 0.05 level. Nonetheless, it should be noted that when this study began, a response to applied P was evident, and that lasted until 1958, when N supply via soil organic matter mineralization had levelled off (Boman et al., 1996). Similarly, the NPK treatment, with an average yield of 2.45 Mg ha^{-1}, did not differ significantly from the NPKL treatment with an average yield of 2.51 Mg ha^{-1}(Table 2). The difference of 0.06 Mg ha^{-1} (2.0%) between these two treatments suggests that addition of lime had little effect on final grain yields. The variability in wheat grain yields for the check plot suggests that changes in the environment played a key role in yield response. Girma et al. (2007) noted that changes in the environment maintain crop yield to some level even when no external soil amendments are added. They further noted that any trend of increase in yield would definitely require addition of external inputs. No significant difference was found between the manure treatment and the NP, NPK, and NPKL treatments for every period in this study (Table 3). This implies that similar yields could be obtained with manure treatment as with inorganic fertilizer. Ghosh et al. (2004) found similar yield levels between inorganic fertilizer alone and combined with organic amendments. Tayebeh et al. (2010) concluded that one can essentially obtain the same yield level with either organic fertilizer or inorganic fertilizer sources. However, the quantity and type of organic fertilizer used play an important role in achieving the same yield response as with the chemical fertilizer (Tayebeh et al., 2010; Morteza et al., 2011). Some studies suggest that the use of a combination of organic and inorganic fertilizers contributes better to achieving the highest crop yield than if individual fertilizer sources were used (Damodar et al., 2000; Tayebeh et al., 2010). This is probably due to improved soil physical and biological properties such as improved soil structure and micro-porosity that can improve crop nutrient uptake. Use of animal manure can be a good option for improving crop production where chemical fertilizers are not available, especially for the resource constrained farmers in developing countries. In 1996-2001, there was a significant difference between the manure and P inorganic treatments, with standard error of the difference (SED) of 0.51 (Table 3). Even though the difference between manure treated and P treated plots was not significant in all of the periods considered, the difference between these treatments ranged from 4 to 26 mg kg^{-1}.

When evaluating the relationship between SOC and yield and STP and yield, no significant linear relationship was found (results not shown).

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Stability analysis, where treatment means are plotted against the yearly (environment) means, showed that yield from the manure plots was more stable than yield in the inorganic P plots. This is indicated by the slope component of manure plots being closer to 1 as compared to the inorganic P treatment, with a slope of 0.58 (Figure 3). This implies that over the 24 years of study the manure plots were more resilient against changes in the environment (Raun et al., 1993; Girma et al., 2007).

CONCLUSIONS

This long-term study shows that continuous crop production reduces organic carbon content of the soil and that the application of animal manure slows down the rate of depletion of SOC thus maintaining biological functions of the soil and therefore crop yield. Much as organic manure could produce the same yield levels as inorganic fertilizer sources, the variability in its quality, which is related to source and/or animal species, will produce varying results. This could necessitate further evaluation of the behavior of manure from different sources in soil. Similar to other studies, this work showed that inorganic P fertilizer can result in an increase in soil test P. However, it is important to note from the present study that beef manure application equally contributed to high levels of soil test P above crop requirements. As was the case in this study, application of organic manure with the primary objective of meeting crop N needs would undoubtedly lead to soil P build up. Never the less, this study has shown that organic manure is a good option for reducing the decline in SOC, while also meeting crop nutrient demand and maintaining yields at adequate levels.

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Table 1. Treatment structure, composition and description for Magruder Plots at Stillwater, OK.

Treatment	Composition	Description	Quantity applied
1	Manure	Beef manure applied every 4 years	269 kg N ha^{-1}
2	-	No nutrient applied	-
3	P	P applied each year	14.6 kg P ha^{-1}
4	NP	N and P applied each year	67 kg N ha^{-1},14.6 kg P ha^{-1}
5	NPK	N, P and K applied each year	67 kg N ha^{-1}, 14.6 kg P ha^{-1}, 27.8 kg K ha^{-1}
6	NPKL	N, P and K applied each year + lime applied when soil pH <5.5	67 kg N ha^{-1}, 14.6 kg P ha^{-1}, 27.8 kg K ha^{-1} +Lime

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Table 2. Simple statistics showing mean, maximum, minimum values and range for Magruder plots at Stillwater, OK. 1990-2013.

Statistics	Manure	Check	P	NP	NPK	NPKL
Grain Yield				(Mg ha^{-1})		
Mean	2.14	1.04	1.16	2.25	2.45	2.51
max	4.04	1.81	2.54	4.05	4.17	4.35
Min	0.17	0.11	0.07	0.17	0.32	0.35
Range	3.87	1.70	2.47	3.88	3.85	4.00
CV, %	46	43	46	46	41	43
STP				(mg kg^{-1})		
Mean	38.82	6.29	49.32	42.25	47.59	42.09
max	48.63	11.49	96.5	68.34	92.27	89.74
Min	17.67	2.53	29.55	24.44	30.59	21.94
Range	30.96	8.96	66.95	43.9	61.68	67.8
CV, %	24	35	31	30	36	43

C.V—coefficient of variation, %

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Table 3: Treatment averages for winter wheat grain yields (Mg ha^{-1}), soil organic C, and soil test phosphorus values (mg kg-1) for the selected time periods at Magruder Stillwater, OK from 1990 to 2013

		Grain Yield Mg ha^{-1}	SOC g kg^{-1}	STP mg kg^{-1}
Source of variation	df		Pr>F	
Period	3	0.0078	<0.0001	<0.0001
Treatment	5	<0.0001	<0.0001	<0.0001
Treatments		Treatment means		
1990-1995				
Manure		1.64	9.59	37.37
Check		0.92	7.92	6.10
P		0.88	7.30	43.19
NP		1.67	8.23	36.69
NPK		2.04	9.01	37.54
NPKL		2.02	9.08	32.26
SED		**0.47**	**0.66**	**6.45**
CV, %		**44**	**11**	**28**
1996-2001				
Manure		2.48	8.39	43.87

Check	1.23	4.69	8.15
P	1.29	5.12	47.60
NP	2.52	6.64	41.27
NPK	2.70	7.06	41.96
NPKL	2.68	8.09	38.41
SED	**0.51**	**1.35**	**3.62**
CV, %	**34**	**29**	**14**
2002-2007			
Manure	2.34	7.13	39.56
Check	1.06	3.69	6.94
P	1.16	4.27	65.89
NP	2.54	5.91	56.94
NPK	2.71	5.84	71.69
NPKL	2.95	6.76	69.97
SED	**0.77**	**0.89**	**15.60**
CV, %	**51**	**22**	**43**
2008-2013			
Manure	2.11	7.21	37.10
Check	0.97	4.32	5.00
P	1.30	5.11	47.78
NP	2.26	6.25	40.70

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NPK	2.35	6.55	48.56
NPKL	2.41	7.14	39.35
SED	**0.73**	**0.40**	**5.76**
CV, %	**55**	**9**	**22**

C.V—coefficient of variation in percent; SED- Standard error of the difference; STP—soil test phosphorus in mg kg^{-1};SOM- Soil Organic Matter in percent (%) and P, N, K and L stand for phosphorus, nitrogen, potassium and lime in their respective combinations

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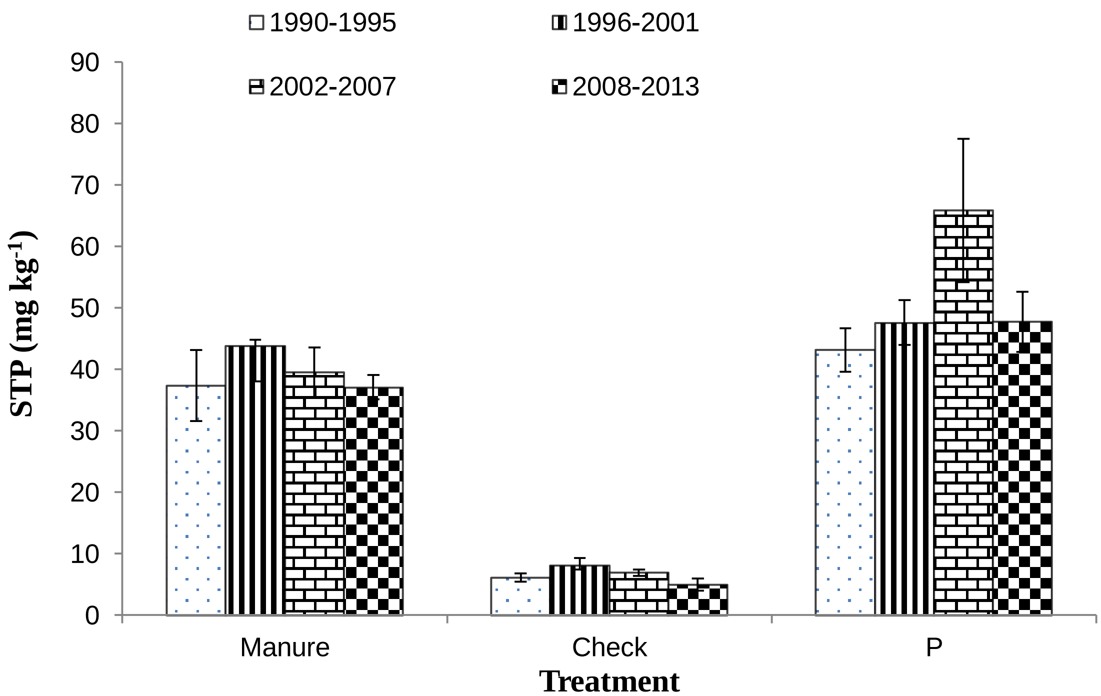

Figure 1. The level of soil test phosphorus (STP) for manure, inorganic P fertilizer and the untreated plots at Magruder, Stillwater, OK.

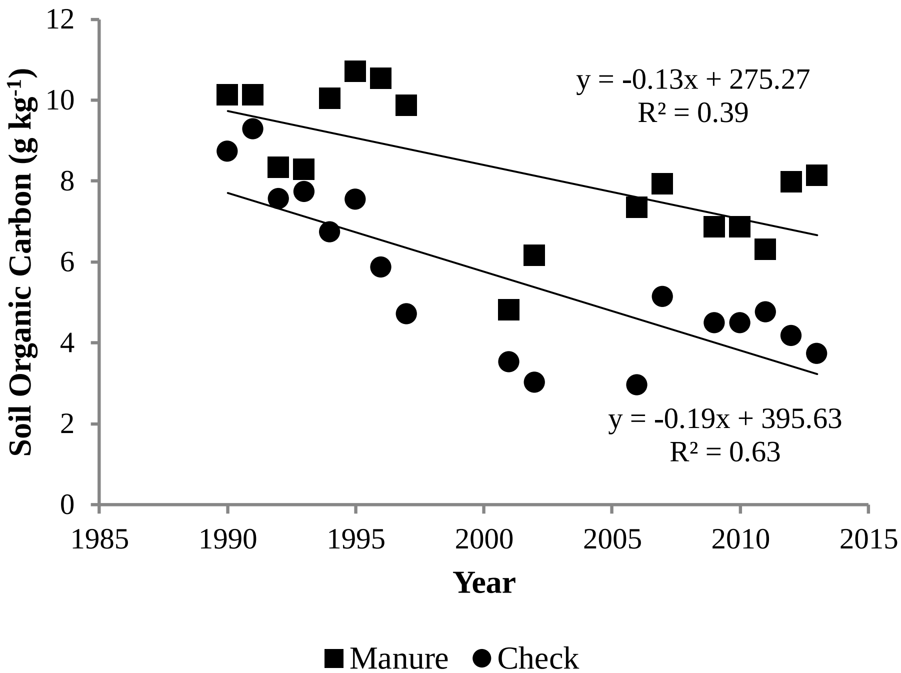

Figure 2. Soil organic matter from 1990 to 2013 for manure and the check (no nutrients applied), Magruder Plots, Stillwater, OK.

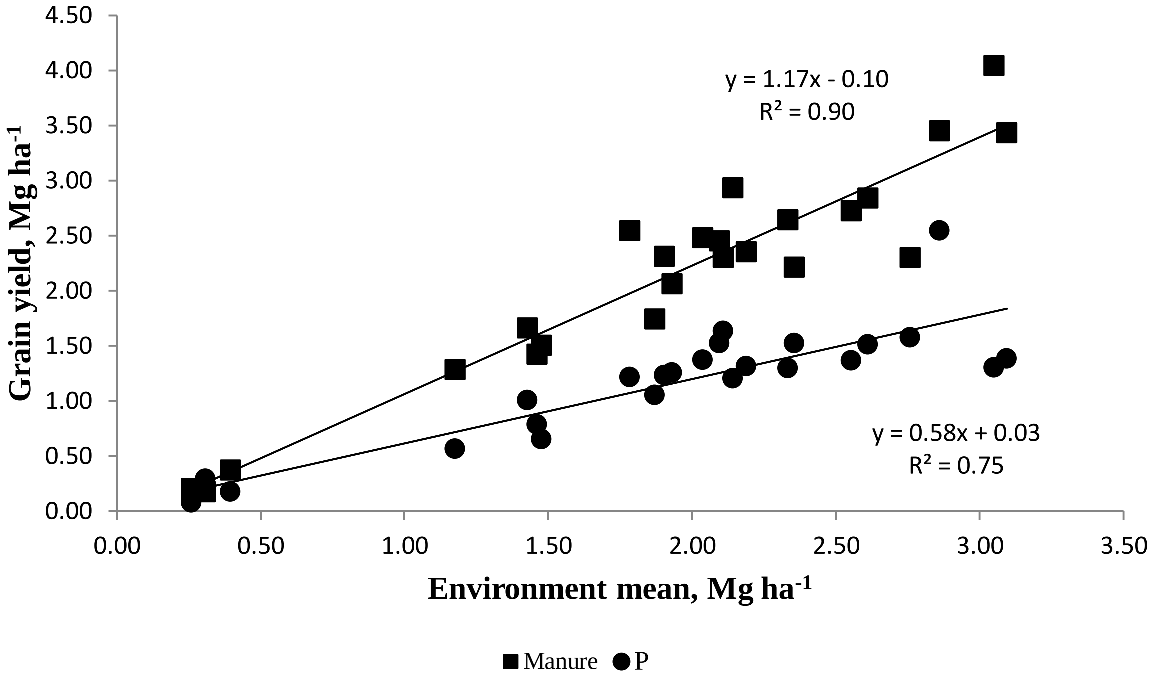

Figure 3. Stability analysis for animal manure treated plots and P treated plots, Magruder Plots, Stillwater, OK. 1990-2013.