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RESEARCH ARTICLE

The effects of manure application on soil aggregation

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Abstract Surface application of manure may increase the risk of phosphorus loss in runoff. Manure application, however, often results in increased soil aggregate stability with reduced runoff and erosion and, therefore, reduced P transport potential. Three field studies were conducted with silt loam or silty clay loam soil in Nebraska to determine how water-stable soil aggregation in the 0- to 25-mm soil depth is affected: (1) by application of raw or composted feedlot manure; (2) by repeated annual manure application; and (3) by the residual effect of composted manure applied five to seven years before sampling. Large macro-aggregates (>2 mm) were increased 200% or more by both manure and compost application within 15 days after application; the effect persisted for the seven months of study with a greater effect due to compost application. Aggregate stability was similar for incorporation and no incorporation of the applied compost or manure. Bray-P1 in large macro-aggregates was 200% more than for the whole soil sample with manure or compost applied, but Bray-P1 in large macro-aggregates was similar to the whole sample in the control. Annual application of swine slurry for several years resulted in a 20% increase in aggregates >250 mm. After four years of no compost following three years of compost application, aggregate size distribution was similar for the compost- compared to the no-compost-applied treatments. Increased macro-aggregate formation and high Bray-P1 in these aggregates may protect against P loss in runoff due to reduced runoff and erosion and protection of P in water-stable large macro-aggregates.

Keywords Aggregate stability · Compost · Eutrophication · Macro-aggregate · Soil porosity

Abbreviations

Ag>2mm	Large soil macro-aggregates
Ag0.25–2mm	Small macro-aggregates
Ag0.053–0.25mm	Soil micro-aggregates
ARDC	Agricultural Research and Development Center
DAA	Days after application of manure or compost
SOM	Soil organic matter
UN-L	University of Nebraska-Lincoln

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Introduction

Runoff-P concentration is typically higher with higher soil P concentration as in fields where much manure has been applied (Sauer et al. 2000; McDowell and Sharpley 2001; Andraski and Bundy 2003; Daverede et al. 2003; Klatt et al. 2003). Dissolved and particulate P loss in runoff can be significant, however, even at agronomically moderate soil test P levels because a large proportion of soil P is non-labile (Eghball and Gilley 1999; Eghball et al. 2002; Wortmann and Walters 2006). Runoff P loss is, therefore, largely dependent on the rate of erosion and runoff.

Feedlot manure is commonly applied to the soil surface with no or shallow incorporation. Runoff P loss was much less after one year compared with one day after surface application of beef feedlot manure (Eghball et al. 2002). Such reductions indicate that soil aggregation is increased by manure application within two weeks after application resulting in less runoff P loss, and that the effect persists for a year or longer.

Manure application is often credited with improving soil physical properties with benefits such as reduced runoff and erosion, and these effects can persist for several years following manure application (Gilley and Risse 2000; Wortmann and Walters 2006). Celik et al. (2004) found that after five years of application of 25 t ha^{-1} yr^{-1} of manure or compost incorporated by moldboard plowing, the mean weighted diameter of water-stable aggregates was 65% greater for the 0 to 30 cm depth than where no manure or compost were applied. Aggregation was similar with compost and manure. They also observed reduced bulk density, increased macro- and micro-porosity, and increased hydraulic conductivity after application of compost or manure. Available soil waterholding capacity was increased by 85 and 56% compared to the control for the 0 to 30 cm depth with compost and manure applied, respectively. Surface application of manure or compost may be most advantageous for improving water infiltration but it results in very high P concentrations at the soil surface. Much of this P may be protected from runoff due to the increased formation of water-stable soil aggregates associated with an increase in organic particulates with manure application (Six et al. 2000). While manure application does not always result in reduced runoff and erosion (Gilley and Eghball 1998), the effect is common enough to be considered as partly offsetting the effect of manure application on runoff P concentration (Angers 1998; Six et al. 2000; Whalen and Chang 2002).

Research was conducted to test the hypotheses that application of raw or composted manure will result in increased macro-aggregate formation in the surface 25 mm of soil and that the effects can persist for several years after application. The objectives of this research were to determine how soil aggregation is affected: (1) during the months following incorporation and surface application of raw and composted feedlot manure; (2) by repeated applications of feedlot solid manure and swine slurry manure; and (3) by composted feedlot manure applied five to seven years before sampling. The distribution of Bray-P1 and soil organic matter (SOM) in large macro-aggregates relative to the whole surface soil sample at 30 days after application was determined. These objectives were addressed using data from three field studies.

Materials and methods

Study 1

Experiments were conducted on two soil types at Havelock Agronomy Farm of the University of Nebraska-Lincoln (UN-L) on the east edge of Lincoln NE (40°51′ N, 96°36′ W). The soil types were upland loess Crete soil (fine, smectitic, mesic Pachic Argiustolls) and alluvial Nodaway soil (fine-silty, mixed, superactive, mesic Cumulic Hapludolls). Each site was tilled with a tandem disk before application of the treatments.

The treatments included three manure treatments and two tillage treatments in a complete factorial with four replications in a randomized complete block design. The manure treatments were: (1) 50 Mg ha^{-1}, d. wt., of composted feedlot manure; (2) 50 Mg ha^{-1}, d. wt., of uncomposted, stockpiled feedlot manure; and (3) the control with neither compost nor manure applied. The amount of P applied with the compost and manure treatments was 610 and 452 kg ha^{-1}, respectively. The tillage treatments were no tillage following application and incorporation with a garden tiller to about 7.5 cm depth. The plot size was 4.5 × 4 m. The treatments were applied on 25 April 2005. The crop was non-irrigated maize (*Zea mays* L.) planted on 10 May 2005.

Soil samples composed of six cores of 70-mm diameter were collected for the 0- to 25-mm depth at 15, 30, 60, 90, 120, and 150 days after application (DAA). All sampling points were determined at the start of the research to avoid sampling of soil disturbed by previous sampling. Wheel tracks formed during planting were avoided during sampling. Bray-P1 (Bray and Kurtz 1945) and soil organic matter content by weight loss on ignition (Nelson and Sommers 1996) were determined for the complete soil and the individual aggregate fractions collected 30 days after application.

The percent of soil in water-stable aggregates was assessed by a wet-sieving method (Cambardella and Elliott 1994). Field-moist soil was gently crumbled, air-dried, and passed through an 8-mm sieve. Material retained on the sieve was discarded, and visible pieces of crop residues and roots were removed. A 100 g d. wt. sub-sample of soil was distributed on a 2-mm sieve of 20-cm diameter and immersed in about 3 cm of water for 5 min. After immersion, samples were wet sieved by dipping the sieves into water 50 times during a 2-min period, done first with the 2-mm sieve, and then sequentially with 0.250-mm and 0.053-mm sieves. Material retained in each sieve was washed separately into a 150-ml beaker and allowed to settle for about 20 min. Supernatant water was carefully poured from the beaker and discarded, while water-stable aggregates were transferred into a pre-weighed aluminum tin, oven dried at 50°C, and weighed. Classes of water-stable aggregates were large macro-aggregates (>2.0 mm, Ag>2 mm), small macro-aggregates (0.250–2.0 mm, Ag0.25–2mm), and micro-aggregates (0.053–0.250, Ag0.053–0.25mm) expressed as g 100 g^{-1} of dry soil. The three aggregate classes were totaled to give the percent of soil mass in water-stable aggregates.

Analyses of variance were conducted using Statistix 8 (Analytical Software, 2003). Means were compared with the ANOVA-protected LSD (0.05) method. The analysis of variance was conducted with manure and tillage treatments as main plot effects, and with sampling time as a subplot effect in a split-plot analysis. Differences were considered significant at $P < 0.05$.

Study 2

This study was conducted on two soil types at the UN-L Northeast Research and Extension Center-Haskell Agricultural Laboratory near Concord NE (42°23′ N, 96°57′ W). The upland site was on a sloping hillside with a Moody-Leisy complex silt loam (fine-loamy, mixed mesic Udic Haplustoll and fine-loamy, mixed mesic Udic Argiustoll; 6–11% slope) soil and the bottomland site was on a Maskell loam (fine-loamy, mixed mesic Cumulic Haplustoll soil; 2–6% slope). The treatments were: beef feedlot manure applied at a mean rate of 46 Mg ha^{-1} yr^{-1} d. wt. with incorporation after 24 h; swine slurry manure broadcast and incorporated after 24 h at 2.7 Mg ha^{-1} yr^{-1} dry weight; and no manure applied. The experimental design was a randomized complete block with three replications. The manure was applied each year from 1999 to 2003. Composite soil samples were collected in the fall of 2003 for the 0- to 25-mm depth. The analysis of aggregate size distribution was as above. Analyses of variance were conducted using Statistix 8 (Analytical Software, 2003). Differences were considered significant at $P < 0.05$.

Study 3

Research was conducted at the UN-L Agriculture Research and Development Center (ARDC) near Ithaca NE (41°10′ N, 96°28′ W) to determine the residual effect of applied compost on soil aggregation. A total of 200 Mg ha^{-1} composted feedlot manure was applied in three applications between 1998 and 2002 (Wortmann and Walters 2006). The study had three treatments: compost from low P manure; compost from high P manure; and no compost. The experimental design was a randomized complete block with three replications. Composite soil samples were collected in the fall of 2003 for the 0- to 25-mm depth. The analysis of aggregate size distribution was as above. Analyses of variance were conducted using Statistix 8 (Analytical Software, 2003). Differences were considered significant at $P < 0.05$.

Results

Study 1

The interaction effect of soil type by DAA was significant for all aggregate size fractions and total aggregates, as was the DAA main effect (Table 1; Fig. 1). However, the differences due to soil type were inconsistent over time. Aggregation was greater with the alluvial soil on some sampling dates but less or not different on others compared with the loess soil. The significant effects of the soil type × DAA interaction and DAA on soil aggregation may have been due to sampling conditions rather than to treatment effects; soil water content was observed to be higher for the 120-day sample than at other sampling times and soil in macro-aggregates was more, especially for the Crete soil site, for this sampling date than for other dates.

The DAA × tillage × manure and the DAA × tillage interactions were not significant for all aggregate size fractions (Table 1). The soil type × tillage × manure interaction was significant for Ag0.25–2mm and nearly so for Ag0.053–0.25mm ($P = 0.06$) but not for Ag > 2 mm and total aggregates (Fig. 2). Ag0.053–0.25mm were reduced while Ag0.25–2mm were increased with compost and manure application for both soil types. These effects were less pronounced with incorporation than with surface application, especially for the alluvial soil. The reduction in Ag0.053–0.25mm and increase in Ag0.25–2mm compared with the control were greater with manure than with compost with incorporation for the Crete loess soil and with no incorporation for the Nodaway alluvial soil.

Total amount of soil in aggregates was not affected by manure treatments. However, the main effect of the manure treatments was a greater reduction in Ag0.053–0.25mm and a greater increase in Ag0.25–2mm with manure than with compost application as compared with the control, while Ag > 2 mm were increased more with compost (300%) than with manure (200%) application (Table 2).

Table 1 ANOVA results for trials conducted on two sites at UN-L Havelock Agronomy Laboratory in 2005

Source of variation	df	Soil aggregates, g 100 g^{-1} soil			
		> 2 mm	0.25–2 mm	0.053–0.25 mm	Total
Site (S)	1				
Rep/site	6				
Tillage (T)	1	NS[a]	NS	NS	NS
Manure (M)	2	***	***	***	NS
T × M	2	NS	NS	NS	NS
T × S	1	NS	NS	NS	NS
M × S	2	NS	NS	NS	NS
T × M × S	2	NS	*	0.06	NS
Error a	30				
DAA (D)	5	***	***	***	***
S × D	5	**	***	***	***
T × D	5	NS	NS	NS	NS
M × D	10	0.07	NS	NS	NS
T × M × D	10	NS	NS	0.06	NS
T × D × S	5	**	***	***	***
M × D × S	10	NS	NS	NS	NS
T × M × D × S	10	NS	NS	NS	NS
Error b/CV	180	62.5	18.6	17.2	6.7

[a] NS, *, **, ***: not significant or significant at $P < 0.05$, 0.01, and 0.001, respectively

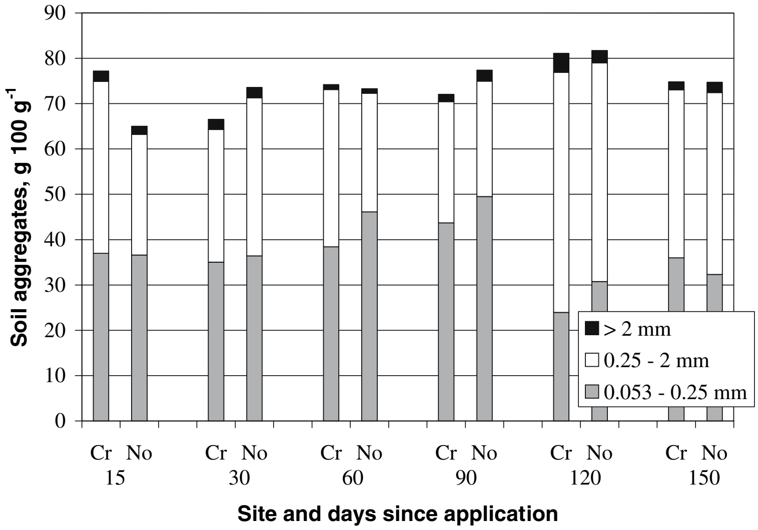

Fig. 1 Variation in soil aggregation as affected by the site by days after application interaction on upland loess Crete, Cr, and bottomland alluvial Nodaway, No, soil at UN-L Havelock Agronomy Laboratory in 2005, The standard errors of the mean for the site by days after application interaction were 0.27, 1.33, 1.30, and 1.02 for the > 2 mm, 0.25–2 mm, and 0.053–0.25 mm water-stable aggregate size fractions, and the total of aggregates, respectively

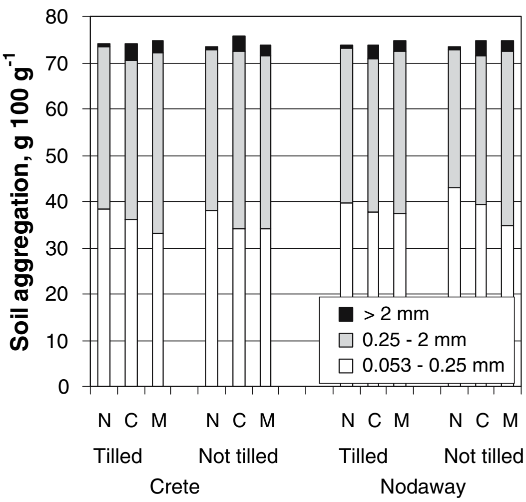

Fig. 2 Mean effect of the soil × tillage × manure application interaction on soil aggregation on two soil types at UN-L Havelock Agronomy Laboratory in 2005, N, C, and M designate no compost or manure applied, composted feedlot manure applied, and stockpiled feedlot manure applied. Crete and Nodaway soils are upland loess soil and bottomland alluvial soil, respectively. The standard error of the means for the soil by tillage by manure application interaction were 0.29, 1.32, 1.27, and 0.90 for the >2 mm, 0.25–2 mm, and 0.053–0.25 mm water-stable aggregate size fractions, and total aggregates, respectively

Tillage and interaction effects were not significant for Bray-P1 at 30 DAA. However, the manure treatment effects generally were highly significant (Table 3). Bray-P1 was highest with compost applied and lowest with the control. However, Bray-P1 concentration in Ag > 2 mm was about three times as high compared with the complete soil sample for the manure and compost treatments. Although Ag > 2 mm accounted for a small fraction of the soil, 13 and 8% of soil Bray-P1 was in Ag > 2 mm for compost and manure applied, respectively, while less than 1% of Bray-P1 was in Ag > 2 mm for the control.

Manure and compost application resulted in a great increase in Ag > 2 mm with high SOM concentration at the 0- to 25-mm soil depth. The concentration of SOM was increased in Ag0.25–2mm (8%) and in the whole soil (6%) with compost- and manure-applied compared with the control. Mean SOM was 87, 31, 28, and 32 g kg^{-1} for Ag > 2 mm, Ag0.25–2mm, Ag0.053–0.25mm, and the whole soil, respectively. The relatively high SOM in Ag > 2 mm for the control as well as the compost- and manure-applied treatments indicates the importance of presence of organic material to the formation of large macro-aggregates, probably due to consolidation of micro-aggregates (Six et al. 2000).

Study 2

The treatment by site interaction was not significant. Aggregate size distribution was affected by manure application, but the total amount of soil in aggregates > 0.053 mm was not affected (Table 4). Macro-aggregates were increased while Ag0.053–0.25mm

Table 2 Mean effects of manure application treatments on soil aggregation in trials conducted on two sites at UN-L Havelock Agronomy Laboratory in 2005

Treatments[a]	Aggregate size			
	>2 mm	0.25–2 mm	0.053–0.25 mm	<0.053 mm
	g 100 g^{-1}			
Manure	2.4 a[b]	37.3 a	34.9 c	25.4 a
Compost	3.2 b	34.5 b	36.8 b	25.4 a
Control	0.8 c	33.2 b	39.8 a	26.2 a

[a] Tillage and interaction effects were not significant

[b] Values with different letters in columns are statistically different ($P < 0.05$)

Table 3 Mean effects of manure treatments for two soil types at 30 days after manure and compost application on Bray-P1 in the 0- to 2.5-cm soil depth at UN-L Havelock Agronomy Laboratory in 2005

Treatments [a]	Aggregate size			
	>2 mm	0.25–2 mm	0.053–0.25 mm	<0.053 mm
	Bray-P1, mg kg^{-1} [b]			
Manure	326.9 b[c]	110.5 b	82.4 b	28.3 b
Compost	753.9 a	182.8 a	107.5 a	81.4 a
Control	32.4 c	49.9 c	51.7 c	5.3 c

[a] Tillage and interaction effects were not significant

[b] Bray-P1 in the complete soil sample for the 0- to 2.5-cm depth was 106.1, 208.5, and 42.7 mg kg^{-1} for the manure, compost and control treatments, respectively

[c] Values with different letters in columns are statistically different ($P < 0.05$)

Table 4 The effect of types of applied manure on water-stable soil aggregate size at Haskell Agricultural Laboratory in 2004

Treatments	Aggregate size		
	>0.25 mm	0.053 to 0.25 mm	<0.053 mm
	g 100 g^{-1}		
Swine manure	42.5 a[A]	40.3 b	20.2 a
Beef manure	40.1 ab	45.2 ab	16.3 a
No manure	35.0 b	48.5 a	18.5 a

[A] Values with different letters in columns are statistically different ($P < 0.05$)

were decreased with manure application, with the greatest effect due to swine manure application.

Study 3

The residual effect of compost applied five to seven years before sampling on aggregate size distribution was not significant (Table 5). The residual effect of compost application on total soil in aggregates >0.053 mm was not significant.

Discussion

Generally the effect of manure application was to increase macro-aggregates relative to Ag0.053–0.25mm without an effect on the total amount of soil

Table 5 The residual effect of composted manure (4 years after application) on soil aggregate properties at the Agricultural Research and Development Center in 2004

Treatments	Aggregate size		
	>0.25 mm	0.053 to 0.25 mm g 100 g^{-1}	<0.053 mm
High P compost	44.7	37.9	17.4
Low P compost	45.9	35.4	18.7
No compost	41.1	38.5	20.4
Significance	NS[a]	NS	NS

[a] NS: differences are not statistically significant at $P < 0.05$

in aggregates >0.053 mm. These effects were consistent across soil types with the soil by treatment interaction accounting for little of the total variation due to treatment effects at the Havelock and Haskell sites. The results generally agree with the finding of Sommerfeldt and Chang (1985), that larger aggregates were increased while smaller aggregates were decreased due to manure application, probably due to increased consolidation of micro-aggregates into macro-aggregates (Six et al. 2004).

The manure × DAA interaction effect was not significant and the effect of manure or compost application on aggregation occurred soon after application with a significant increase in Ag > 2 mm at 15 DAA. The greatest increase was for compost with a 240% increase in Ag > 2 mm compared with no manure or compost applied, and this increase persisted for the 7-month duration of the Havelock study. Bray-P1 in Ag > 2 mm was much more than in the rest of the soil sample with compost or manure applied. Whalen and Chang (2002), however, found that the increase in soil P with long-term manure application was greater in the 0.5 to 2.0 mm size than in larger or smaller dry-sieved aggregate sizes. The increase in water-stable soil macro-aggregates with high Bray-P1 within a short time after application of compost or manure may be important to reducing P loss in runoff due to increased infiltration, less soil dispersion due to the impact of rain drops, and protection of applied P in macro-aggregates.

Composted feedlot manure application resulted in more Ag > 2 mm but less Ag0.25–2mm macro-aggregates than raw feedlot manure. The effect of applied compost on soil aggregation was not significant four years after the last application at the ARDC site. In a related study, however, runoff at this site continued to be less with the compost-applied treatments compared to the no-compost control until five years after the last application (Wortmann and Walters 2007). This site was disk tilled every year; the compost effect on soil aggregation may have persisted longer with no-till (Six et al. 1999; Wright and Hons 2005). A much greater residual effect of applied compost was reported by Celik et al. (2004).

Conclusion

Manure and compost application results in a significant increase in water-stable large macro-aggregates within 15 days after application, probably due in part to consolidation of smaller aggregates. The newly formed large macro-aggregates were much higher in Bray-P1 than the rest of the soil and than in the large macro-aggregates of soil where compost and manure were not applied. The macro-aggregation was more with compost than with raw feedlot manure and swine slurry manure had a similar effect as solid feedlot manure. The effect of manure or compost application persisted through one cropping season but was not detectable at four years after application in a cropping system that was tilled annually. While manure or compost application may increase the risk of P runoff, the risk is likely to be greatest during the days after application as the resulting increase in large water-stable soil macro-aggregates with a high P concentration should reduce the risk of P runoff. Studies involving simulated rainfall conducted shortly after manure application may over-estimate manure application effects on the risk of P runoff. Manure application should be avoided at times of high probability of a runoff event within days of application.

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