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LONG-TERM APPLICATION OF POULTRY LITTER TO IMPROVE SOIL AGGREGATE STABILITY UNDER COOL AND WARM SEASON GRASSES

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ABSTRACT

Farming practices such as organic and inorganic amendment and soil type can affect aggregation under forage species. We determined the effect of nitrogen rate and soil-litter history on short-term response of aggregate stability under tall fescue (*Festuca arundinaceae* Schreb.), annual ryegrass (*Lolium multiflorum* Lam.) and bermudagrass (*Cynodon dactylon* L.). Nitrogen was applied as ammonium nitrate (NH_4NO_3) at rates 0, 160, 320 kg total N ha^{-1} in split applications (80 and 160 kg N ha^{-1}) to tall fescue, annual ryegrass and bermudagrass grown in 2000g of a litter-amended and unamended Bude silt loam (Fine-silty, mixed, active, thermic Aquic Fragiudults) and to bermudagrass in a litter-amended and unamended Ruston sandy loam (Fine-loamy, siliceous, semiactive, thermic Typic Paleudults) in a greenhouse pot experiment. Aggregate stability was measured as water stable macro-aggregate (> 250 µm) and micro-aggregate (125-250 µm) using a wet sieving apparatus. The litter-amended soils produced more dry matter yield per unit of N and had more stable aggregates in comparison to their unamended counterparts. Increasing rate of N decreased aggregate stability in the litter-amended Bude under annual ryegrass and bermudagrass, possibly due to the rapid drying of the soil that resulted from the increase in yield. The results of these studies indicate that the effect of soil type, forage species and fertility management on soil aggregate stability may vary base on environmental condition. Field studies are required to understand the effect of management practices on aggregate stability.

Keywords: aggregate stability, poultry litter, nitrogen fertilizer, dry matter yield

INTRODUCTION

Farming practices that improve and maintain soil aggregate stability are important to sustain productivity and reduce phosphorous (P) loss on litter-amended soils. In Mississippi, monoculture of warm season grasses such as bermudagrass (*Cynodon dactylon* L.) and bahiagrass (*Paspalum notatum*) dominate pastures (Lemus and Weirich, 2009). During winter months, to sustain livestock production, farmers either feed hay harvested from warm season grasses or over-seed summer pastures with a cool season crop such as wheat (*Triticum astivum,* rye (*Secale cereale*), or annual ryegrass (*Lolium multiflorum* Lam.) to meet animal feed requirements. Producers may apply poultry litter as a source of nutrients to enhance forage productivity, but an upward trend in soil test P has been reported in soils from hay and pastures in Mississippi due to continuous application of poultry litter to the same land (Read et al., 2009).

Aggregate stability indicates the soil's capacity to resist the destructive actions of wetting, impact of raindrops and cultivation (Wuddivira and Camps-Roach, 2007). The presence or absence of stable aggregates at the surface of a soil has a direct effect on the soil water status, nutrient dynamics, crust formation and excessive runoff during rainfall events (Allison, 1973; Amézketa, 1999; Bronick and Lal 2005). In southern coastal plain soils Levy and Miller (1997) found a direct relationship between aggregate stability and infiltration rate. Likewise, Vanderford (1962) reported that soils of the Mississippi silty upland and southern coastal plain are usually highly erodible and are prone to compaction due to their medium to coarse texture top soil.

Generally, the development of macro-aggregates (> 250 µm) is primarily dependent on soil management practices such as crop rotation, fertilizer amendment (organic or inorganic) and tillage. The more stable micro-aggregates (< 250µm) are generally not affected by management and could be an intrinsic characteristics of soils (Tisdall and Oades, 1980). Several investigators have reported that surface application of manure may be most advantageous for improving soil aggregate stability (Angers and N' Dayegamiye, 1991; Evers, 1998; Aoyama et al., 1999; Rasool et al., 2007; Wortmann and Shapiro, 2008). Whalen and Chang (2002) showed that despite the benefits of increase aggregate stability from applying manure to cultivated soils, long-term application of manure can increase dispersion of dry sieved macro-aggregates due to increase monovalent cations and foreign soil mixed with the manure.

Tisdall and Oades (1982) suggested that macro-aggregates (> 250µm) are from the binding of micro-aggregates (< 250µm) by roots and mycorrhizal hyphae. Therefore, the rate of change of macro-aggregate stability can be influenced by the grass species present (Haynes and

Beare, 1996). Haynes and Francis (1993) reported aggregate stability (estimated as MWD) after 32 months followed the order perennial ryegrass (*Lolium perenne*) > annual ryegrass (*Lolium multiflorum* L.) > perennial white clover (*Trifolium repens*) = barley (*Hordeum vulgare*) and a similar sequence applies to increase in root mass. Likewise, Milne and Haynes (2004) reported higher aggregate stability under permanent Kikuyu (native) pasture in comparison to annual ryegrass in South Africa.

Previous studies have presented conflicting results concerning the influence of N fertilization on aggregate stability. Latif et al. (1992) observed a decrease in aggregate stability with increasing rates of N fertilizer in maize intercropped with legumes. Haynes and Beare (1996) reported that NPK fertilization can increase aggregate stability by increasing crop yield and crop residue input to the soil. Meanwhile, Biederbeck et al. (1996) reported no effect on aggregate stability after ten years of urea and anhydrous ammonia application to wheat, barley and canola (*Brassica campestris* L). Likewise, Aoyama et al. (1999) also found that application of NPK fertilizer to crops including corn (*Zea mays* L.), barley, wheat, beetroot (*Beta vulgaris*) and canola did not affect soil aggregate stability. Haynes and Naidu (1998) reported that application of NH_4^+ containing or forming fertilizers can have an adverse effect on soil aggregation under low temperature, low moisture and low pH; conditions where nitrification is inhibited. These results suggest that the effect of crop by management on aggregate stability is specific to the environmental condition under which the crop is grown.

Knowledge of the effects of N fertilizer application to litter-amended soils on aggregate stability is essential for increasing infiltration and reducing runoff. Therefore, the objective of this study was to determine the effects of nitrogen fertilizer rates and history of poultry litter application on aggregate stability in the short term of soils planted to Bermuda grass, annual ryegrass and tall fescue (*Festuca arundinaceae* Schreb.).

MATERIALS AND METHODS

I. Cool season grass responses

A greenhouse experiment was conducted at the R. Rodney Foil Plant Science Research Facility, Mississippi State University to determine soil aggregate stability [macro-aggregate stability (> 250 µm) and micro-aggregate stability (125-250 µm)] in a series of treatments. The experiment was arranged as a factorial with two soil litter-histories (litter-amended Bude silt loam (Fine-silty, mixed, active, thermic AquicFragiudult) and an unamended Bude silt loam), two forage crops (‘Jackson’ annual ryegrass and ‘MaxQ’ tall fescue, and three rates of N fertilization (0, 160, 320 kg total N ha^{-1}). The experimental design was a randomized complete block with four replications.

The litter-amended Bude was collected from a “Sumrall 007” hybrid bermudagrass pasture with a 10+ year history of poultry litter fertilization and the unamended Bude from a bahiagrass pasture. These soils which were from Lincoln County Mississippi were collected from the surface (0-15 cm), air-dried, sieved (< 2-mm), and a sub-sample analyzed for Mehlich III phosphorus and other chemical parameters (Table 1).

Table 1. Surface soil (0-15 cm) properties of litter-amended and unamended Bude silt loam and Ruston sandy loam used in this study at Mississippi State, MS.

Soil Parameters	Bude Silt Loam		Ruston Sandy Loam[†]	
	Litter-amended	Unamended	Litter-amended	Unamended
Physical				
Soil texture (%)				
Sand	28	10	73	66
Silt	63	78	22	30
Clay	9	12	5	4
Aggregate size (%)				
>250 µm	53	46	49	36
>125 µm	62	57	55	36
125-250 µm	9	11	6	0
Chemical				
pH	6.2	5.8	5.0	5.0
N (%)	0.4	0.2	0.1	0.1
C (%)	2.8	2.3	1.0	0.6
Ca (mgkg^{-1})	4447	1448	397	108
Mg (mgkg^{-1})	646	340	79	41
K (mgkg^{-1})	1060	333	209	69[‡]
P (mgkg^{-1})	1180	20	122	32

[‡] Fertilized with K base on soil test recommendation

[†] Limed with Ca $(OH)_2$ from pH of 5.0 to 6.0

Soil P, K, Ca, and Mg were determined via emission spectroscopy on a Thermo Jarrell Ash IRIS Advantage HX Inductively Coupled Plasma (ICP) Radial Spectrometer (Thermo Instrument Systems, Inc., Waltham, MA). Soil pH was determined in 1:2 soil:water slurries with a pH meter and glass electrode. Soil texture was determined by the method of Olmstead et al. (1930). Total C and N were determined by dry combustion using a Vario El III elemental analyzer (Tecnologia Internacional Aplicado, San Jose, Costa Rica).

Ryegrass was seeded on 12 October 2007 at the rate of 22 kg ha^{-1} (40 mg seed pot^{-1}) and tall fescue at 15 kg ha^{-1} (26 mg seed pot^{-1}) (calculated base on the area of the pot) in plastic pots (152 mm diameter) filled with 2000 g of soil. Plants were grown for 124 days in the greenhouse and soil moisture in each pot was increased to field capacity every two days based on weighing. Field capacity was determined after watering using Klocke and Fischbach (1998) estimating soil moisture by appearance and feel procedure.

Pots were allowed 52 days to establish before applying N. Nitrogen fertilizations of 80 and 160 kg N ha^{-1} were applied 52 and 94 days after planting. Biomass yield were collected 94 and 124 days after planting were weighed before and after oven drying at 65ºC for 48 hours, and then dry weight were obtained. Biomass yield taken 94 and 124 days after planting were combined to obtain total yield.

II. Bermuda grass responses

In this research a factorial arrangement of treatments with the four soils to include the two soils used previously (litter-amended Bude and unamended Bude) and a litter-amended Ruston sandy loam (Fine-loamy, siliceous, semiactive, thermic Typic Paleudults) and an unamended Ruston sandy loam, and three N fertilizations (0, 160 and 320 kg total N ha^{-1}). The experimental design was a randomized complete block with four replications.

The litter-amended Ruston sandy loam and the unamended Ruston sandy loam were collected from bahia grass pastures in Wayne County Mississippi. The litter-amended Ruston sandy loam had a 5 year history of poultry litter fertilization.

Bermuda grass "common" was seeded at the rate 20 kg ha^{-1} (34 mg seed pot^{-1}) (calculated base on the area of the pot) on 12 May 2008. Pots were allowed 49 days to establish before applying N. Nitrogen fertilizer (80 and 160) was applied 49 and 79 days after planting. Biomass yield were collected 79 and 111 days after planting (in July and September) and were weighed before and after oven drying at 65ºC for 48 hours, and then dry weight were obtained. Biomass yield taken in 79 and 111 days after planting were combined to obtain total yield.

Water Stable Aggregates Determination

Percentage water stable aggregates was determined based on the principle that unstable aggregates will break down more easily than stable aggregates when immersed in water using an Eijkelkamp Wet-Sieving apparatus after the method of Wuddivira and Camps-Roach (2007). After the final harvest, the soil was removed from pots and the core was cut vertically into two vertical halves. One half of the core was broken and sieved through and the 1-2 mm aggregates were collected. A sub-sample of aggregates was air-dried for 48 hr. The aggregate stability of the 1-2 mm size fraction was determined by wet sieving. A single sieve apparatus with a stroke of 1.3 cm and a frequency of 34 cycle minute^{-1} was used.

Four grams of air-dried aggregates on sieves were immersed in de-ionized water in cans (45 mm x 6.0 mm diameter) for 5 minutes and then the sieving was initiated for 3 minutes. The unstable aggregates pass through the sieve and were collected in a water filled can. After this fixed time (3 min), the cans were removed and replaced by cans with solution of 2 g NaOH per liter of distilled water. Aggregates remaining on the sieve were then sieved for 5 minutes in the NaOH solution, after which a rubber tipped rod, was rubbed across the screen. The sieving finished when all material passed through the screen except sand grains and plant roots. The pair of cans was placed in an oven at 110 °C for 24 hrs. Aggregate stability was calculated as the mass of stable aggregates ($M_{s)}$ divided by the total aggregate (stable + unstable (M_u)) mass, and expressed as the percentage of water stable aggregates (WSA) (sand-free basis) (Wuddivira and Camps-Roach, 2007).

$$WSA = [(M_s/ (M_s + M_u)] \times 100 \qquad (1)$$

Aggregate stability was measured on sieve size 250 μm and on sieve of 125 μm. The percentage of stable micro-aggregates (125-250 μm) was determined by subtracting the amount of measured macro-aggregates (> 250 μm) from micro-aggregates (>125 μm) in each pot.

$$WSA_{(125\text{-}250\mu m)} = WSA_{(125)} - WSA_{(250)} \qquad (2)$$

Where $WSA_{(125)}$ is the amount of water stable aggregates measured on the 125 μm sieve size and $WSA_{(250)}$ is the amount of stable aggregates measured on the 250 μm sieve size.

Statistical Analysis

Data collected from the experiments were subjected to a covariate analysis of variance using PROC GLIMMIX and regression analysis using PROC REG (SAS Institute, 2009). Means separation was done using Fisher's protected least significant difference (LSD) at a significance level of 0.05.

RESULTS AND DISCUSSION

I. Forage Production

A. Cool season grass responses

Total dry matter yield was similar for tall fescue (2100 kgha^{-1}) and annual ryegrass (2230 kgha^{-1}) in the study. The responsiveness of annual ryegrass to N fertilizer (Evers, 2002) and tall fescue to clipping (Cherney et al., 2002) was considered the reason for the similarity. The interaction between soils and N rates was significant ($P < 0.05$) with mean yields of 1290 and 730, 3950 and 1710, and 6250 and 1750 kgha^{-1} for the litter-amended and unamended Bude at 0, 160 and 320 kgNha^{-1} respectively. This means that dry matter yield changed depending on the litter-history and rate of N applied to cool season grasses. The linear relationship for the litter-amended and unamended Bude is shown in Fig.1.

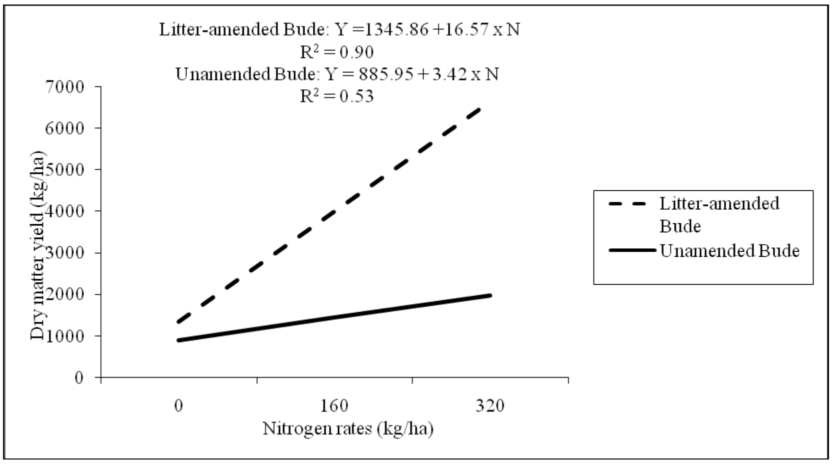

Figure 1. Effects of nitrogen fertilizer rates on the cool season grasses [annual ryegrass (*Lolium multiflorum* L.) and tall fescue (*Festuca arundinacea* L.)] total dry matter yield in a litter-amended and unamended Bude silt loam.

Table 2. Tests for significant statistical effects for cool season grasses [annual ryegrass (*Lolium multiflorum* L.) and tall fescue (*Festuca arundinacea* L.)] total dry matter yield and water stable aggregate.

Source of variation	Total Dry Matter ($kg\ ha^{-1}$)	Water Stable Aggregates %	
		Macro-aggregates (>250µm)	Micro-aggregates (125-250 µm)
	P-value		
Block			
Litter-history (LH)	<0.0001	0.3770	0.0258
Grass Species (GS)	0.4421	0.2415	0.0034
Nitrogen Rates (N)	<0.0001	0.0190	0.8726
LH x GS	0.7009	0.2964	0.0862
LH x N	<0.0001	0.0564	0.5363
N x GS	0.3175	0.9008	0.6280
LH x N x GS	0.4646	0.5901	0.9163

The results showed a strong linear relationship between cool season total dry matter yield and N rate on the litter-amended Bude (r^2 = 0.90). In contrast, a weak linear relationship on the unamended Bude (r^2 = 0.67) was observed. Their positional differences reflect differences in total dry matter yield. Cool season grasses total dry matter yield on the litter-amended Bude more than double that on the unamended Bude. The greater dry matter yield observed, suggests that plants on the litter-amended Bude produced more dry matter yield per unit of N fertilizer in comparison to the unamended Bude. Greater availability of P and K to plants grown in litter-amended Bude was attributed to the reason for the higher productivity. Similar results were reported by Brink and Casler (2009) that N response can be affected by the soil P and K levels. In their study, they also observed a linear increase in total dry matter yield for soft-leaf tall fescue, meadow tall fescue and orchardgrass (*Dactylis glomerata* L.) with increasing rate of N fertilizer (0, 70, 140, 210 and 280 kg total N ha^{-1}) grown in two locations in Wisconsin 2005 and 2006.

B. Bermudagrass responses

This study compared a Bude silt loam and a Ruston sandy loam with different history of litter application. The result showed that soils x litter history x N rates ($P < 0.05$) interact to significantly affect bermudagrass total dry matter yield (Table 3).

Table 3. Tests for significant statistical effects for bemudagrass (*Cynodon Dactylon* L.) total dry matter yield and water stable aggregates.

Source of variation	Total Dry Matter (kg ha^{-1})	Water Stable Aggregates %	
		Macro-aggregates (>250μm)	Micro-aggregates (125-250 μm)
	P-value		
Block			
Soils	<0.0001	<0.0001	0.0295
Litter History (LH)	<0.0001	0.0010	0.0554
Nitrogen Rates (N)	<0.0001	0.3853	0.9275
Soils x LH	<0.0001	0.0244	0.8591
Soils x N	0.2150	0.9805	0.7399
N x LH	0.0002	0.1907	0.3448
Soils x N x LH	0.0069	0.0025	0.5971

Mean yields for the litter-amended and unamended Bude at 0, 160 and 320 kg N ha^{-1} were 9430 and 3100, 17300 and 6460, and 21300 and 5800, respectively. While, the mean yields for the litter-amended and unamended Ruston at 0,160 and 320 kg N ha^{-1} were 4180 and 1840, 9140 and 5320, and 10710 and 6620, respectively. The significant interaction of soils x litter history x N rates may have been due to the differences in soil properties. Results for the Bude soils are shown in Fig. 2, and results for Ruston soils are shown in Fig. 3.

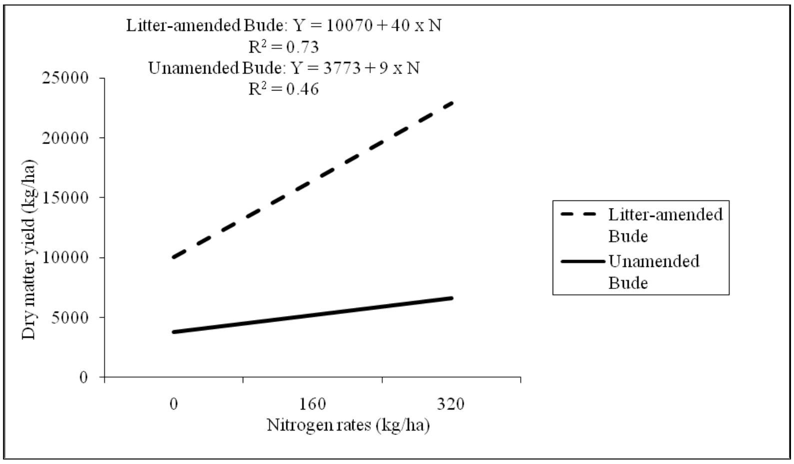

Figure 2. Effects of nitrogen fertilizer rates on total dry matter yield of bermudagrass (*Cynodon Dactylon* L.) in a litter-amended and unamended Bude silt loam

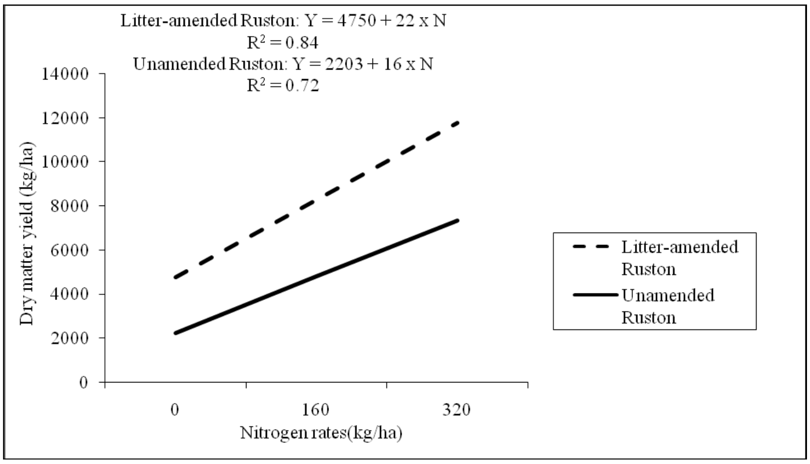

Figure 3. Effects of nitrogen fertilizer rates on total dry matter yield of bermudagrass (*Cynodon Dactylon* L.) in a litter-amended and unamended Ruston sandy loam.

A strong linear relationship was also observed between total dry matter yield and N rates on the litter-amended Bude with a 10+ year history of litter application (r^2 = 0.73) and a weak linear relationship on the unamended Bude (r^2 = 0.46). Moreover, a strong linear relationship was also found on litter-amended Ruston (r^2 = 0.84) with a 5-year history of litter application and unamended Ruston (r^2 = 0.74). Their positional differences suggest differences in total dry matter yield. Dry matter yield from the litter-amended Bude was more than three times greater than the unamended Bude, while dry matter yield from the litter-amended Ruston was about two times that of the unamended Ruston. Similar to in cool season experiments, more available P and K in litter-amended soils was the reason for the greater yield observed. The greater yield and the linear relationship observed for the different soil-litter histories demonstrate that plants on the litter-amended soils produced more dry matter yield per unit of N in comparison to their unamended counterparts.

The linear response observed with increasing rate of N is in agreement with the findings of Wilkinson and Langdale (1974) and Adeli et al. (2006). Wilkinson and Langdale (1974) found soil type having only a minor effect on the linear response of bermudagrass yield to N fertilizer up to 560 kg N ha^{-1}. Likewise, Adeli et al. (2006), reported that broiler litter rates of 0, 4.6, 9.2, and 13.8 $Mgha^{-1}$ equivalent of approximately 0, 175, 350, and 525 kg total N ha^{-1} yr^{-1} was applied to bermudagrass on Ruston, Leeper and Marrieta soils increased yield up to 350 kg total N ha^{-1} yr^{-1} regardless of soil type.

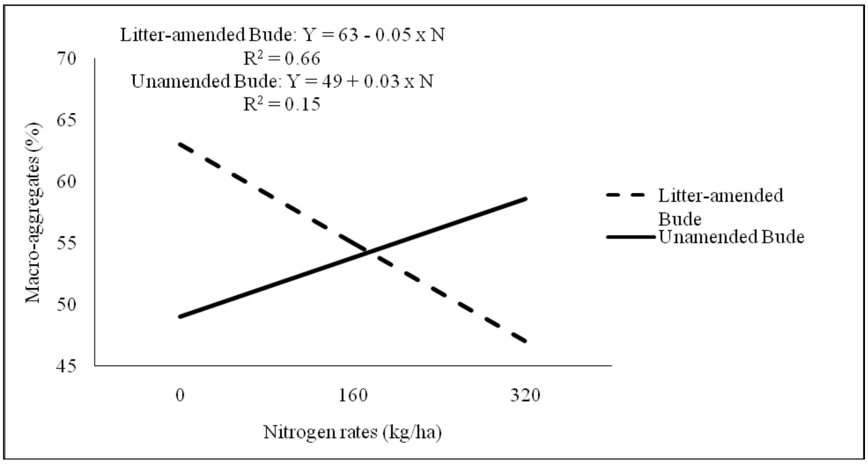

Figure 4. Effects of nitrogen fertilizer rates on water stable macro-aggregates in a litter-amended and unamended Bude silt loam under bermudagrass (*Cynodon Dactylon* L.).

II. Aggregate Stability

A. Cool season grass responses

In all treatments, the soils had more than 50% of their weight in water stable aggregates (> 125 µm) with the majority in macro-aggregates (> 250 µm). The litter-history x grass species x N rates interaction (P > 0.05) was not significant for water stable aggregates (125-250 µm and >250 µm) but, the litter-history and grass species main effects were significant (P < 0.05) for water stable micro-aggregates (125-250 μm) and N rates main effect ($P < 0.05$) for water stable macro-aggregates (>250 μm) (Table 2). Micro-aggregates were greater in the litter-amended Bude (14%) in comparison to the unamended Bude (12%). This finding agrees with that of Whalen and Chang (2002) that long-term application of manure increase the amount of micro-aggregates in a soil.

The amount of water stable micro-aggregates stability was greater under annual ryegrass (14%) than under tall fescue (11%). We hypothesized that the contribution of the large extensive root system of annual ryegrass (Tisdal, 1980; Haynes and Beare, 1997) and smaller root mass of tall fescue (Karki, 2008) may have contributed to the dynamics of aggregation in the Bude soils. Not enough data was provided by this study to explain the reason for the differences and similarities observed for micro-aggregates under annual ryegrass and tall fescue in the litter-amended and unamended Bude in detail. We need to investigate how root production and microbial activity differ in the litter-amended and unamended Bude to better understand aggregation under annual ryegrass and tall fescue.

Application of nitrogen fertilizer was shown to significantly affect macro-aggregates (Table 2.2). There was a linear reduction ($P = 0.0357$) in macro-aggregate stability associated with increase an increase in N fertilizer rate on the Bude soils. Regression equation ($Y = 55 - 0.02 \times N$, $r^2 = 0.10$) showed that for each unit of N added to the soil the amount of water stable macro-aggregates in the Bude soils decreased by 0.02%.

Soil aggregation is a complex soil process that is a result of interaction of internal physical, chemical and biological properties influenced by external factors, such as environment, plant species and management. Therefore, it may be difficult to identify a specific reason for the effect of N on WSA_{250} without measurements of other factors such as soil moisture, soil N concentration and root mass to name a few. However, in other studies, N fertilizer has been reported to directly and indirectly result in a decrease the amount of macro-aggregates. Haynes and Naidu (1998) reported that when the monovalent NH_4^+ ion accumulates in soils in large amounts from applications of NH_4^+ containing or forming fertilizers it can become a dominant exchangeable cation and, like Na^+, it can have an adverse effect on soil aggregation. This is not common in most application of NH_4^+, particularly in the field, because too small a proportion of the soil volume is affected for too short a time (Haynes and Naidu 1998). However, Latif et al. (1992) and Biederbeck et al. (1996) plot studies also reported a decrease in WSA_{250} with high rates of N fertilizer. The decrease in WSA_{250} in Biederbeck et al. (1996) study may be attributed to the low pH of the soil used, as low pH environment provides a favorable condition for accumulation of NH_4^+ (Haynes,1986). While, Latif et al. (1992) found that N fertilizer decreased WSA_{250} under maize plots intercropped with legumes and increased WSA under maize only plots. The decrease in WSA_{250} in Latif et al. (1992) study was attributed to the effect of N on root exudates which are known to affect aggregation. It is clear, that N fertilizer can influence WSA_{250} directly through accumulation of NH_4^+, or indirectly through increase in biomass and microbial community. Therefore, it is fair to speculate that the effect of NH_4^+ in our study could be attributed to the small surface area that was exposed to NH_4^+. Further studies are needed to support such speculation.

In addition, another possible reason for the decrease in WSA_{250} observed could be a result of the effect of the increase biomass from the N application on the drying of the soil. Other studies have also reported decrease in macro-aggregate stability due to rewetting of soils at different moisture content. Denef et al. (2002) reported that rewetting a moist soil tends to result in less breaking of the aggregates in comparison to rewetting a dry soil. Singers et al. (1992) reported that rewetting a dry soil can cause air pressure to build up inside aggregates, resulting in breaking of the aggregates and an increase in micro-aggregates. Again, the wetting and drying cycle in these soils may not be the only factor as there are a number of other factors that could have resulted in these effects. Studies of this nature may yield better results under field condition or with the use of more precise soil moisture monitoring method under greenhouse condition.

B. Bermuda grass responses

In all treatments, the soils had more than 50% of their weight in water stable macro-aggregates. The significant interaction effect of soils x litter history x N rates ($P < 0.05$) on the stable macro-aggregates (>250 μm) was mainly due to the soil type (Table 3). Greater amount of stable macro-aggregates was observed in the Ruston sandy loam (70%) in comparison to the Bude silt loam (55%). Likewise, Reid and Goss (1981) also observed greater amount of stable macro-aggregates in a Sutton sandy loam than a Hamble silt loam under annual ryegrass. Lebron and Suarez (1992) found variation in aggregate stability within and among three soil types (Ebro Basin, Ramona, and Clarence). The reason for the greater amount of stable macro-aggregates in the Ruston in this study may also be due to the effect of lime ($Ca(OH)_2$) added to soil to raise the pH at the start of the experiment.

Litter application history affected macro-aggregates on the Ruston soil. Stable macro-aggregates were greater in the litter-amended Ruston (76%) than in the unamended Ruston (64%). The greater amount of stable macro-aggregates in the litter-amended Ruston in comparison to unamended Ruston is in agreement with the findings of several studies that organic amendments increase the amount of stable macro-aggregates in the soil (Anger and N'Dayegamiye, 1991; Aoyama et al., 1999; Rasool et al., 2007; Wortmann and Shapiro, 2008).

There was a linear reduction ($P = 0.0013$) in macro-aggregate stability with an increase N rate in the litter-amended Bude. The regression equation ($Y = 63 - 0.05 \times N$, $r^2 = 0.66$) showed that macro-aggregate stability decreased by 0.05% for each unit of N applied (Fig. 2.4). No significant ($P = 0.2105$) relationship was observed on the unamended Bude ($Y = 49 + 0.03 \times N$, $r^2 = 0.15$). The reason for the reduction could also be attributed to the soil moisture content at rewetting. The strong linear relationship observed for Bermuda grass may be due to greater biomass yield. This is because more biomass is likely to result in drier soil condition at rewetting. Reduced stability of soil macro-aggregates with added N in the litter-amended Bude is in agreement with the finding of Latif et al. (1992). They found a linear reduction in macro-aggregate stability with applied N at rate of 0, 70 and 140 kg N ha^{-1} as broadcast urea in May under maize intercropped with legume in samples taken in May and September.

It is clear, that the magnitude and direction of the change in soil stable aggregates can be influenced by soil properties, such as clay mineralogy, oxide content, soil moisture, texture, initial amount of stable macro-aggregates and OM content (Haynes and Swift, 1990; Caron et al., 1992; Singers et al., 1992). The greater initial amount of stable macro-aggregates, clay content and available nutrients in the litter-amended Bude may be the reason it was most susceptible to degradation of the aggregates. Likewise, the decrease in stable macro-aggregates in the litter-amended Bude may be due to the effect of plant growth affecting the soil moisture content at rewetting. This finding agrees with Wagner et al. (2007) that soil moisture content can be influenced by the plant growth causing drying of the soil.

Greater amount of stable micro-aggregates were observed in the Bude silt loam (12.8%) than the Ruston sandy loam (9.8%). While, similar amount of stable micro-aggregates were observed in each soil between the litter-amended and the unamended. Micro-aggregates were found to increase for the soils decreasing in macro-aggregates with N rate. This finding was consistent with the hierarchical theories of aggregation, that macro-aggregates are form by the binding of micro-aggregates (Tisdall and Oades, 1982; Oades and Waters, 1991) and macro-aggregates break into micro-aggregates rather than primary particles (Puget et al., 2000; Legout et al., 2004). Micro-aggregates were not affected directly or indirectly by the N application.

CONCLUSIONS

The benefits of increase yields, available nutrients and structural stability from poultry litter application were demonstrated in this research. It is possible that minimal amount of N fertilizer and no additional P and K are needed to maximize yield on the litter-amended soils in comparison to their unamended counterpart.

The greatest decrease in stable macro-aggregates was observed in the litter-amended Bude. The decrease in stable macro-aggregates in the litter-amended Bude was due to repeated wetting of a dry soil. The dry condition at rewetting was due to the effect of an increase in biomass yield from the added N fertilizer affecting the soil moisture content at rewetting. Micro-aggregates were not affected directly or indirectly by N application, but did increase when macro-aggregates decrease.

Soil structural stability can be greatly influenced by management, climatic and biological factors interacting on soil properties. The results of these experiments demonstrate the challenges of replicating the interaction of these factors in a controlled environment. Interpretations of results on the effect of N on aggregate stability obtain under these conditions may not be relevant for field situation without taking into consideration the conditions under which the data was obtained. Furthermore, these results indicate that the effect of soil type, forage species and fertility management on soil aggregate stability was dependent on the soil moisture content at rewetting.

Future studies evaluating the effect of N application on aggregate stability should be conducted under field conditions. Consideration should be given to the time of sampling after N application and frequency of the sampling throughout the growing season to obtain more detail results.

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