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Soil Organic Matter Fractions and Aggregate Distribution In Response to Tall Fescue Stands

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Abstract: The study was conducted to evaluate the influences of tall fescue management on soil organic matter fractions and macro- and microaggregate distribution. Soil samples were collected from four paired adjacent fields consisting of five years of tall fescue mono and poly stands in Western Kentucky. Soil samples from 0 to 15 cm and 15 to 30 cm soil depths were analyzed for soil organic C and N, particulate organic matter C (POM-C) and N (POM-N), macro- and micro aggregate distribution and C-associated with macro- and micro- aggregates. Significant effects were observed between stands for all the properties, except total C, microaggregates and C-associated with microaggregates. Sampling depth significantly influenced total C and N in both stands. Particulate organic matter C and N and C-associated with macroaggregates and the amount of macroaggregates were strongly affected by tall fescue management. This confirmed the hypothesis that early changes in soil properties were reflected in labile C and N fractions and soil structure. Tall fescue mixture stands had 44% higher POM-C, 50% higher POM-N, 26% more macroaggregates and 33% more C-associated with macroaggregates compared to the tall fescue mono stands at the soil surface of 0 to 15 cm.

Key words: Aggregation, forage, Particulate Organic Matter (POM), Soil Organic Matter (SOM), tall fescue

INTRODUCTION

Tall fescue is a preferred forage due to its adaptability to a wide range of soil and climatic conditions and it plays an important role in soil conservation and carbon sequestration (Ball *et al.*, 2002; Franzluebbers and Stuedemann, 2008; Lacefield and Evans, 2009). Tall fescue is recognized as the most crucial perennial cool-season grass in the United States. It withstands grazing pressure by cattle, persisting better than other cool-season perennial forages, particularly during hot and dry conditions (Franzluebbers and Stuedemann, 2008). Common tall fescue management in Kentucky consists of tall fescue mono stands and poly stands (tall fescue plus clover and other grasses). In general, the tall fescue poly stands perform better than tall fescue mono stands in terms of forage production and quality and reducing the cost of fertilizer. However, comparing the impacts of tall fescue mono and poly stands on soil ecosystems has not been addressed.

Soil Organic Matter (SOM) is the most important indicator for soil quality improvement because it regulates water movement and water holding capacity, provides nutrients for

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plants and controls soil structural stability by affecting the quantity of macro- and micro-aggregates (Handayani *et al.*, 2008). Particulate organic matter is considered an intermediately available fraction of organic C and N and more sensitive to the land management changes compared to total soil organic matter (Cambardella and Elliott, 1992; Parton *et al.*, 1987). Particulate organic matter C (POM-C) and N (POM-N) can be major fractions of organic matter in the topsoil under pastures (Franzluebbers *et al.*, 2000; Wander *et al.*, 1998). Plant residues and roots produce particulate organic matter, which becomes a direct source of nutrients supporting living soil microorganisms (Gale and Cambardella, 2000).

Grassland soils are noted for their high levels of organic matter and high structural stability (van Veen and Paul, 1981). However, the physical location (e.g., aggregates) of the organic matter in soil and how this will be influenced by grass management is not well understood. Aggregation is a key to maintaining soil structure stability and an effective means of controlling erosion (Angers, 1992; Cambardella and Elliot, 1992). Soil aggregation is usually determined by a wet sieving method (Kemper and Rosenau, 1984). Soil aggregation has been conceptualized as a hierarchical system of primary particles forming microaggregates (<0.25 mm), which then become the foundation for formation of macroaggregates (>0.25 mm) of varying sizes (Tisdall and Oades, 1982). The formation of macro- and micro-aggregates is a dynamic process involving soil physical, chemical and biological process (Juma, 1993; Monreal *et al.*, 1995). Microaggregates are cemented by persistent, aromatic humic material in association with amorphous Fe and Al and polyvalent metals. The binding agents holding together macroaggregates can be transient or temporary (Tisdall and Oades, 1982). Variations in pasture management that may influence soil aggregation include grass species, grazing pressure and stand age (Canqui *et al.*, 2005). Conversion from cultivated land into grassland increases soil organic matter and aggregation (Angers, 1992; Drury *et al.*, 1991). Introducing other grasses and legumes into tall fescue stands can help improve forage quality and efficiency of forage growth available for livestock production, as well as reducing the need for N fertilizer. However, relatively little is known about the effect of tall fescue versus tall fescue mixture stands on soil organic matter and structure. The objective of this study was to determine the influences of tall fescue management and sampling depth on soil organic matter fractions and aggregate distribution.

MATERIALS AND METHODS

Sampling Procedures

Paired fields were identified at four sites in Calloway and Graves Counties, Kentucky, USA. Each site included one field managed in tall fescue and one with tall fescue plus clovers and other grasses such as timothy (*Phleum pretense* L.), orchard grass (*Dactylis glomerata* L.) and crabgrass (*Digitaria* species). In the tall fescue poly stands, each vegetation covers 15 to 20% of the overall field. Each field has been in its current management for at least five years. Surface soils at all sites have silt loam texture (12 to 15% clay, 66 to 68% silt and 18 to 20% sand), pH 5.95 to 6.33 and bulk density 1.13 to 1.15 g cm⁻³ with slope of 0 to 5%. Generally, surface soils have a fragipan that hinders the growth of roots and leads to the formation of a seasonal high water table within 46 to 61 cm of the surface (Frye *et al.*, 1982).

Soil samples from each field were collected from depth intervals of 0 to 15 cm and 15 to 30 cm during Spring 2007. Within each field, six areas of 100 m² were selected for similarity and uniformity of topography, soil order and soil textural class. Four subsamples

were composited at each depth in each of the six selected areas per field. The composited soil samples were air dried at room temperature for seven days and gently crushed and sieved to pass through 0.50 mm to avoid the root residues. Visible organic matter was removed prior to analysis.

Soil and Data Analysis

Organic C was determined by the Loss of Ignition (LOI) method (Lal *et al.*, 2001). Particulate organic matter was determined by physical fractionation. Twenty-five grams of air-dried soil was dispersed with 100 mL of 5 g L⁻¹ of sodium hexametaphosphate. The soil solution mixture was shaken for 1 h at high speed on an end-to-end shaker and poured over a 0.053 mm sieve with several deionized water rinses. The soil remaining on the sieve was back washed into a pre-weighed aluminum dish then dried at 60°C for 24 h, ground and analyzed for C and N (Cambardella and Elliot, 1992).

Aggregate size distribution was determined using wet sieving with screen diameters of 0.25 and 0.50 mm. The range of micro-aggregates and macro-aggregates is between 0.053 to 0.25 mm and 0.25 to 0.50 mm, respectively. Soils were submerged in water on the largest screen for 5 min before sieving commenced. Soils were sieved under water by gently moving the sieve 3 cm vertically 50 times over period of 2 min through water contained in a shallow pan. Material remaining on the sieve was transferred to an aluminum container and dried at 60°C in a forced-air oven then weighed and measured for C (Elliot and Cambardella, 1991). Soil analyses in the laboratory were conducted in three replications. All the data was subjected to the analysis of variance (ANOVA) at the 5% of level of significance.

RESULTS

Total Organic Carbon and Nitrogen Content in Soils

In general, there was a small difference of total C in soils between tall fescue mono and poly stands. Total C in the surface soil (0 to 15 cm soil depth) increased from 25.10 g kg⁻¹ in the tall fescue mono stands to 29.99 g kg⁻¹ in the tall fescue poly stands (Table 1). At the soil depth of 15 to 30 cm, tall fescue mono and poly stands provide 18.80 and 19.20 g kg⁻¹ of total C in soils, respectively (Table 1). The difference between the two stands was not significant, but there was a significant effect of sampling depth on the total C at both stands ($p < 0.05$). The lowest amount of total C in soils occurred in the tall fescue mono stands. Unlike total C in soils, there was a numerical increase in total N when the soils were under tall fescue poly stands. Total N content in soils increased 26 and 45% from tall fescue mono to poly stands at the depth interval of 0 to 15 cm and 15 to 30 cm, respectively (Table 2). Tall fescue poly stands have the highest content of total N in soils.

Table 1: Physical fractionation of soil organic matter for C under tall fescue stands. POM-C is particulate organic matter C

Fields	Total soil C ------(g kg ⁻¹)-----	POM-C	POM-C/TC (%)
Depth 0-15 cm			
Tall fescue	25.10a	2.24a	8.90a
Tall fescue mixture ¹	29.99a	4.02b	13.40b
Depth 15-30 cm			
Tall fescue	18.90a	1.92a	10.00a
Tall fescue mixture ¹	19.20a	3.56b	18.54b

Values within columns at the same depth followed by the same letter(s) are not significantly different ($p \leq 0.05$). ¹Indicates tall fescue mixture stands (tall fescue plus clover, orchard grass, timothy and crabgrass)

Table 2: Physical fractionation of soil organic matter for N under tall fescue stands. POM-N indicates particulate organic matter N

Fields	Total N ------(g kg ⁻¹)-----	POM-N	POM-N/TN (%)	C/N ratio
Depth 0-15 cm				
Tall fescue	1.49a	0.48a	32.21a	16.84a
Tall fescue mixture ¹	2.00b	0.96b	48.00b	14.99a
Depth 15-30 cm				
Tall fescue	1.12a	0.38a	33.92a	16.88a
Tall fescue mixture ¹	2.05b	0.78b	38.05b	9.37b

Values within columns at the same depth followed by the same letter(s) are not significantly different ($p \leq 0.05$). ¹Indicates tall fescue mixture stands (tall fescue plus clover, orchard grass, timothy and crabgrass)

Table 3: Aggregate size distribution under tall fescue stands

Fields	Macroaggregates -----% of total soil-----	Microaggregates	Ratio ²
Depth 0-15 cm			
Tall fescue	28a	21a	1.09a
Tall fescue mixture ¹	38b	20a	1.90b
Depth 15-30 cm			
Tall fescue	23a	26a	1.08a
Tall fescue mixture ¹	33b	22a	1.50b

Values within columns at the same depth followed by the same letter are not significantly different ($p \leq 0.05$). ¹Indicates tall fescue mixture stands (tall fescue plus clovers, orchard grass, timothy and crabgrass). ²Ratio of macroaggregates/microaggregates

Labile Soil Organic Matter (SOM) Fractions

Particulate organic matter C (POM-C) and N (POM-N) in soils were generally highest in tall fescue poly stands (Table 1 and 2). POM-C contents in the tall fescue mono stands were 44 and 46% lower than tall fescue poly stands at the depth interval of 0 to 15 cm and 15 to 30 cm, respectively. In addition, POM-N contents in the tall fescue mono stands were 50 and 51% lower compared to tall fescue poly stands at the depth interval of 0 to 15 cm and 15 to 30 cm, respectively. The difference in POM-C and POM-N was higher between stands (44-51%) compared to between sampling depth (11-21%). There was no significant effect of sampling depth on the POM-C and POM-N for both stands (Table 1 and 2). The C/N ratios were lower in tall fescue poly stands than tall fescue mono stands, indicating that materials in the mixture stands have been subjected to progressively longer periods of decomposition. In this study, POM-C, POM-N and total N appear to be the most sensitive indicators for comparing the impact of tall fescue mono and mixture stands. The greater POM-C and POM-N levels suggests increased potential C and N availability for soil heterotrophs in tall fescue poly stands compared to tall fescue mono stands.

Aggregate Distribution and Carbon Associated with Aggregate Size Classes

In general, there was a significantly smaller proportion of soil in macroaggregates (0.25-0.50 mm) in tall fescue mono stands compared to tall fescue poly stands (Table 3). The differences in macroaggregates between both stands were 26 to 30% at the depth interval of 0 to 30 cm. There was no significant effect of sampling depth in both stands on macroaggregates and microaggregates. Microaggregate content was relatively similar in both stands. Higher ratios of macro-/microaggregates indicated better aggregate stability in tall fescue poly stands compared to tall fescue mono stands.

Carbon content was greater for each aggregate in tall fescue poly stands than tall fescue mono stands, ranging from 11.40 to 31.30 g kg⁻¹ (Table 4). The greatest significant difference ($p < 0.05$) in C content between tall fescue stands was in macroaggregates at the 0 to 15 cm soil depth (21.10 to 31.30%) compared to microaggregates (11.40 to 14.30%) (Table 4).

Table 4: Soil C fractions associated with aggregate size under tall fescue stands

Fields	C in Macroaggregates	C in Microaggregates
	-----(g kg^{-1})-----	
Depth 0-15 cm		
Tall fescue	2.11a	1.14a
Tall fescue mixture ¹	3.13b	1.43a
Depth 15-30 cm		
Tall fescue	1.83a	1.47a
Tall fescue mixture ¹	1.99a	1.53a

Values within columns at the same depth followed by the same letter are not significantly different ($p \leq 0.05$). ¹Indicates tall fescue mixture stands (tall fescue plus clover, orchard grass, timothy and crabgrass)

DISCUSSION

Total Organic Carbon and Nitrogen Content in Soils

Introduction of other grasses in tall fescue stands did not cause significant changes in concentration of soil organic C in topsoil. However, other grasses and legumes influenced the level of total soil N and particulate organic matter C and N. This agrees with other studies comparing a range of grass species and management (Canqui *et al.*, 2005; Franzluebbers *et al.*, 2000; Handayani *et al.*, 2008; Li *et al.*, 2007). Other studies have shown that different grass species and varieties can change N accumulation in soil, probably due to variations in plant morphology and biomass (Clement and Williams, 1967). Planting forage in arable land increases organic matter content within five years (Angers, 1992). Introducing legumes in tall fescue stands seems to increase the level of total N by 26 to 45% (Table 2).

At the study site, no residue retention was observed 5 years after planting which led to less soil organic C and N retention in the early stage of establishment. Similar results were observed by Pankhurst *et al.* (2002) and Nicole *et al.* (2003). In the present study, the amount of C inputs from residues in both stands could not make significant changes to soil total C. However, the addition of N through N_2 fixation by legumes significantly increased total N in soils of tall fescue poly stands. This study also indicated that the recovery times for soil C could be much longer, depending on how depleted soil C became after grass establishment. Many studies have suggested that land management practices may have wide-ranging impacts on soil C. Soil C may also be affected by climate, soil texture, nutrient status and time since the land management was initiated (Franzluebbers and Arshad, 1997; De Koning *et al.*, 2003).

Labile Soil Organic Matter Fractions

Labile fractions of SOM are important, because they are a part of nutrient cycling (Hu *et al.*, 1997). Particulate organic matter C (POM-C) and N (POM-N) have suggested as labile fractions of SOM and as indicators of impacts from management practices (e.g., tillage, crop rotation, vegetation, fertilization) on soil (Ghani *et al.*, 2003; Handayani, 2004). The ranges of POM-C and POM-N values were 1.92 to 4.02 g kg^{-1} and 0.28 to 0.96 g kg^{-1} , respectively. These values are in the range as reported by Gupta *et al.* (1994) (POM-C: 2.8 to 5.10 g kg^{-1} , POM-N: 0.13 to 0.29 g kg^{-1}) and Franzluebbers *et al.* (1999) (POM-C: 3 to 12 g kg^{-1}), but lower than that observed by Koutika *et al.* (2001) (POM-C: 15 to 22 g kg^{-1}) and higher than that reported by Oedraogo *et al.* (2006) (POM-N: 0.11 to 0.27 g kg^{-1}).

In both fields, about 9 to 19% of total organic C and 32 to 48% of total organic N was comprised of particulate organic matter. These values are considered low compared to the results from Feller *et al.* (1996) in West African sandy soil (47-51%). Garwood *et al.* (1972) found that particulate organic matter under various grasses accounted for about 10% of the

total soil organic C and this variation was related to root biomass. Under long-term pastures in the Southern Piedmont USA, organic C accumulation was partitioned 57% into particulate organic C (Franzuebbers and Stuedemann, 2002). It has been suggested that the POM fraction is preferentially lost when grasslands or forests are cultivated but increased when cropped soils are converted to grasslands (Cambardella and Elliot, 1992). It is important to note that the increase of POM can be transitory; therefore, the tall fescue poly stands should be maintained for a long period to increase the slow and passive pools of SOM. This result is supported by many works that have found the sensitivity of the proportion of POM in SOM to soil management practices (Carter *et al.*, 2003; Handayani, 2004; Liang *et al.*, 2003).

Generally, the composition of particulate organic matter consists mainly of root fragments (Cambardella and Elliot, 1992; Garwood *et al.*, 1972). Thus, different levels of POM-C and POM-N between two fields in this study would suggest differences in root biomass were a major factor in soil aggregation (Tisdall, 1991). According to Handayani *et al.* (2008), root turnover improves POM content in soils even with low aboveground biomass amounts. The common root biomass of tall fescue mono stands was in the range of 620 to 669 g DM m⁻² and tall fescue mixed with clover (50-50) was about 700 g DM m⁻² (unpublished data). Introducing legumes in tall fescue stands likely promotes more decomposition and root regeneration due to additional N, which may increase root contributions to particulate organic matter (Barrios *et al.*, 1996). It is likely that in tall fescue poly stands, plant organic inputs are higher because plant density and root biomass are higher on those sites. Earlier studies have shown that mixed plants and weeds produced 3 to 5 times more biomass than mono vegetation (grass only or trees only), mainly because below-ground biomass inputs are higher (Handayani *et al.*, 2002).

Aggregate Distribution and Carbon Associated with Aggregate Size Classes

Grass establishment with tall fescue and tall fescue mixture did not significantly affect the distribution of microaggregates, but it significantly influenced macroaggregates (Table 3). The smaller percentage of macroaggregates in tall fescue mono stands, compared to the tall fescue mixture stands, is a result of the breakdown of soil structure from extensive periods of cultivation or tillage practices prior to plant establishment. This breakdown in macroaggregates was reflected in the microaggregate amounts in tall fescue mono stands. In both fields, there is a larger proportion of macroaggregates compared to microaggregates, except in tall fescue mono stands at the depth 15 to 30 cm. Nassiri and Elgersma (2002) reported that there was a significant relationship between above-ground biomass production and macro aggregate formation, but the relationship did not exist for micro aggregate formation. Plant roots, fungal hypha and microbial polysaccharides are major components of macro aggregate formation. Microbial community diversity and time are the major components of micro aggregate formation. Micro aggregate formation becomes dominant when plant and microbial communities become less productive and more diverse (Handayani *et al.*, 2008). In this study, the significance of macro aggregate formation in tall fescue mixture stands may be due to the influence of mixed fine dense roots from legumes and other grasses in the soil systems that entangled soil particles, released exudates, formed associations with different microorganisms in the rhizosphere and influenced dry-wet cycles in the rhizosphere, which all increased water stable aggregate formation. In this study, tall fescue mono stands has less fine roots and root exudates as indicated by lower root biomass (640 g DM m⁻²) than tall fescue mixture stands (700 g DM m⁻²) resulting in lower amount of macroaggregates (unpublished data). The reduction of macroaggregates in soils under cropping systems has been clearly documented by previous works (Tisdall and

Oades, 1980; Cambardella and Elliot, 1992). Long-term cultivation decreased the length and mass of fine roots and SOM resulting in a reduction of macroaggregates.

Tisdall and Oades (1980) observed that after few years, grassland provided more roots, hypha and soil organic matter and caused an increase in macro aggregation. Data shows that C in microaggregates was relatively unaffected (Table 4). The soil structure model indicates that macroaggregates are composed of an assemblage of microaggregates (Tisdall and Oades, 1982). Carbon associated with macroaggregates increased with more grasses and legumes in the tall fescue stands, but the proportion of small aggregates decreased. Tisdall and Oades (1980) found that organic matter content associated with 0.020 to 0.250 mm size aggregates was considerably less than that of aggregates greater than 0.250 mm in soils from a wide array of cropping histories, including native grasslands. Previous studies indicate that roots and hypha may be responsible for building macroaggregates together (Oades, 1984; Tisdall and Oades, 1982). Organic C is important in controlling soil stabilization (Chaney and Swift, 1984; Tisdall and Oades, 1982). Dormaar (1984) reported that organic matter associated with macroaggregates is more readily mineralized than organic matter associated with microaggregates. Thus, the C in macroaggregates is more likely to be labile and less processed than C associated with microaggregates (Tisdall and Oades, 1980). Previous studies indicated that the increase of total organic matter following three years of forage establishment indicates better soil structure because organic matter is likely to be humified binding agents for soil aggregation (Canqui *et al.*, 2005; Chaney and Swift, 1984; Clement and Williams, 1967; Handayani *et al.*, 2008). In addition, long-term forages reduce the susceptibility of aggregates to slaking (Clement and Williams, 1967). This study suggests that introduction of legumes and other grasses in tall fescue stands may result in an initial increase in soil structural stability, providing a lag in time before microaggregates begins to significantly decrease. Results from earlier study (Handayani *et al.*, 2008) indicated that the higher macroaggregates, the faster the rate of soil structural improvement. This finding would be compatible with the faster rate of soil stability with higher organic matter content (Angers, 1992). However, further research is necessary to evaluate this observation.

CONCLUSION

Following 5 years of grass establishment, tall fescue poly stands provided a significant increase in total N, POM-C, POM-N, macroaggregates and C associated with macroaggregates. This study suggests that physical fractionation of the soil and SOM clearly showed the effect of tall fescue management on the quality and quantity of SOM. Organic matter associated with particulate organic fraction and macroaggregates appeared to be more sensitive to the changes in tall fescue stands compared to total C in bulk soil. Therefore, C accumulation associated with macroaggregates was more pronounced than C gained observed in the bulk soil and microaggregates. If one of the forage management goals is to improve C sequestration, then the increase of soil C, C stabilization and aggregation development on a long-term scale has to be monitored over a few decades. Therefore, information on change over time in SOM fractions and aggregate distribution will be important to assessing forage management success.

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