WATER–STABLE AGGREGATES AND SOIL ORGANIC MATTER UNDER ITALIAN RYEGRASS AND TALL FESCUE ECOSYSTEMS IN WESTERN KENTUCKY

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SUMMARY

The objective of this study was to determine the effects of Italian ryegrass systems on water-stable aggregate and soil organic matter compared to tall fescue and tall fescue - legume mixture systems. The results show that growth of cool-season grasses and legumes caused significant differences in the amount of macro-aggregate, micro-aggregate, soil organic C, N and C/N ratio. In conclusion, introduction of Italian ryegrass in western Kentucky has shown to reduce soil aggregate stability, organic C and total N, compared to tall fescue and tall fescue mixture systems.

Keywords: Aggregation, Carbon, Nitrogen, Ryegrass, Tall fescue

INTRODUCTION

Most soils in western Kentucky have undergone moderate erosion and degradation as a result of historic tillage systems and seedbed preparation during cropping (Frye et al., 1982). Soil erosion removes the lighter particles from topsoil, such as organic matter, up to 12% (Murdock and Frye, 2003). Extreme losses of soil organic carbon occurred as high as 50% in the topsoil because of accelerated decomposition due to tillage practices and erosion (Frye et al., 1982). However, long-term forage systems have been shown to improve soil aggregation and organic matter (Franzluebbers et al., 2000). In addition, grasses can act as a cover crop and be easily accommodated into different crop rotations or pastures, without the use of extensive tillage (Franzluebbers and Stuedemann, 2008). A previous study in Bernheim Forest, Kentucky shows soil restoration using grass species improved particulate organic matter and aggregation by providing continuous roots and grass residues (Handayani et al., 2008). Forage ecosystems also provide low-cost feed, conserve soil and water resources, and capable of storing a large amount of soil organic C and total organic N (Franzluebbers and Stuedemann, 2005). Grassland soils are noted for their high levels of organic matter and high structural stability (van Veen and Paul, 1981).

Forage systems in Kentucky are commonly based on perennial and annual cool-season forages, such as tall fescue (*Festuca arundinacea* Schreb.) and Italian ryegrass (*Lolium multiflorum* Lam.), respectively (Lacefield et al., 2003a). These systems have an abundance of biomass in the spring and most falls but are not productive in mid to late summer. Tall fescue is deep-rooted, long-lived bunchgrass with short rhizomes (Ball et al., 2002). Common tall fescue management in Kentucky consists of tall fescue stands and tall fescue - legume mixture stands (i.e. tall fescue plus white clovers). Overall, tall fescue mixture stands perform better in terms of forage production, quality and reduce the fertilizer cost (Lacefield et al., 2003a). Italian ryegrass can

In M.S. Reiter (ed.) A multidisciplinary approach to conservation. Proc. 31st Southern Conservation Agric. Systems Conf., Melfa, VA. 20-23 July 2009. Extension Publ. 2910-1417. Dep. Crop and Soil Environ. Sci., Eastern Shore Agric. Res. Ext. Cntr., Virginia Polytechnic Inst. and State Univ., Painter, VA. Available at: http://pubs.ext.vt.edu/2910/2910-1417/2910-1407.html.

grow more than three feet in height as the seed heads mature (Lacefield et al., 2003b). It has greater overall productivity than most other cool-season grasses during its growing period (Lacefield et al., 2003b). Tall fescue and Italian ryegrass are preferred due to their high adaptability under a wide range of soil and climatic conditions, and play an important role in soil conservation and carbon sequestration (Ball et al., 2002; Franzluebbers and Stuedemann, 2008; Lacefield and Evans, 2009). However, basic physical information on how forage species, especially annual and perennial grasses, affect on soil is limited. Such understanding is important for conserving soil and water resources, as well as improving the sustainability of forage-based enterprises.

Water-stable aggregate is a key to maintaining soil structure stability and is considered an effective means of controlling erosion (Angers, 1992; Cambardella and Elliot, 1992). Soil aggregation also influences gas exchange between the soil and atmosphere, soil water movement, plant root development, and microbial development (Jastrow, et al., 1998). It is usually determined by a wet sieving method (Kemper and Rosenau, 1984). Aggregates physically protect soil organic matter from microbial decomposition, resulting in reduced organic matter turnover rates and a steady release of plant available nutrients (Six et al., 1998). Soil aggregation has been conceptualized as a hierarchical system of primary particles forming micro-aggregates (<0.25 mm), which then become the foundation for formation of macro-aggregates (>0.25 mm) of varying sizes (Tisdall and Oades, 1982). Within stable macro-aggregates, micro-aggregates will develop the binding of complex organic matter, silt, and clay. The micro-aggregate is stable and provides a mechanism for long-term C storage.

Soil organic matter is the most important indicator for soil quality improvement because it regulates water movement and water holding capacity, provides nutrients for plants, and controls soil structural stability by affecting the quantity of macro- and micro-aggregates (Handayani et al., 2008). Variations in forage management that may influence soil aggregation and organic matter include grass species, forage composition, grazing pressure, and stand age (Blanco-Canqui et al., 2005).

Italian ryegrass provides the most productive forage component, because of its fast growth in most counties in western Kentucky (Henning, 2009) and considered the best traffic tolerance (Minner and Valverde, 2009). Commonly, Italian ryegrass is planted after harvesting corn during fall. Introducing legumes into tall fescue pasture can help improve forage quality and efficiency of forage growth available for livestock production, as well as reduce the N fertilizer needed (Strohmeier, 2003). Both forages are an important agricultural commodity in Kentucky, but little is known about the effect of forage species composition on soil structure and organic matter. Therefore, the objective of this study was to determine the effects of Italian ryegrass systems on water-stable aggregate and soil organic matter compared to tall fescue and tall fescue - legume mixture systems

MATERIALS AND METHODS

Sampling Procedure

Three adjacent fields were identified at four sites of moderately well drained soils in western Kentucky. Four sites were selected to give a reasonable coverage of our area of inference (western KY; Table 1). Each site included one field managed in tall fescue, one with tall fescue plus clover and one with Italian ryegrass stands. In the tall fescue mixture systems, tall fescue and white clover (*Trifolium repens* L.) contribute 60% and 40%, respectively. Each field has been in its current management for at least five years but no more than 6 years. Surface soils at all sites had silt loam texture (12-16% clay, 65-68% silt, and 17-20% sand), pH 5.85 - 6.43, and bulk density 1.10 - 1.15 g/cm^3 with slope of 0 to 8%.

Soil samples from each field were collected from depth intervals of 0 to 15 cm during Spring 2007. Within each field, five areas of 100 m^2 were selected for similarity and uniformity of topography, soil order, and soil textural class. Four subsamples were composited in each of the five 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 2 mm. Visible organic matter was removed prior to analyses.

Soil and Data Analyses

Aggregate size distribution was determined using wet sieving with screen diameters of 2.00 mm, 0.25 mm and 0.053 mm. The range of micro-aggregates and macro-aggregates is between 0.25 to 0.053 mm and 2 to 0.25 mm, respectively. Soils were submersed in water on the largest screen for 5 minutes 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 collected from each sieve (0.25 – 2 mm, 0.053 – 0.25 mm, and < 0.053 mm) was dried at 60^{o}C until a constant weight was achieved, then weighed (Elliot and Cambardella, 1991). Sand corrections were determined for a subset of samples according to Denef et al. (2000). Organic C was determined by the loss of ignition method (LOI) (Lal et al., 2001). Dry combustion (Leco CHN Analyzer) was employed to determine total N. All soil analyses in the laboratory were conducted in three replications.

The effects of forage system on soil properties were analyzed by ANOVA. Mean separations were computed using Duncan's multiple range test. Results were considered significantly different at the $p < 0.05$ level.

RESULTS AND DISCUSSION

Table 2 presents results on aggregate size distribution under three forage systems. The distribution of soil aggregates among the different size fractions was significantly influenced by forage system except for the amount of fractions < 0.053 mm. The amount of macro-aggregates (0.25 – 2 mm) decreased in the following order of; tall fescue = tall fescue plus clover > Italian ryegrass. The results in Table 2 indicate that 24% of the soil dry weight was present as macro-aggregates under Italian ryegrass, and 28% under tall fescue and tall fescue plus clover stand. The amount of micro-aggregates (< 0.25 mm) decreased in the following order of; Italian ryegrass > tall fescue = tall fescue plus clover. These results indicate that 28% of the soil dry weight was present as micro-aggregates under Italian ryegrass, 23% under tall fescue, and 24% under tall fescue plus clover stand. These results support the hypothesis that perennial grass with continuous input of organic matter from plant biomass without involving tillage would produce the highest level of macro-aggregates. On the other hand, annual grass, such as Italian ryegrass, decreases the amount of macro-aggregates due to corn cultivation each year. Haynes (1993) observed that 5-yr of C3 grass pasture could provide more soil organic matter and increase aggregate stability. Plant roots, fungal hyphae and excretion of microbial polysaccharides are major factors controlling macro-aggregate formation. Plant and microbial diversity and time are major components of micro-aggregate formation. As plant become less productive, micro-aggregate becomes dominant (Visser et al., 1983). In general, total aboveground production for the Italian ryegrass system (3-5 ton/ha/yr) were higher than tall fescue system (2-4 ton/ha/yr) (Lacefield et al., 2003a,b). In addition, Tufekcioglu et al (1999) reported that cool-season grass had significantly greater dead fine root biomass than any other grass type. However, annual pasture involving conventional tillage results in a substantial loss of soil organic matter and soil degradation by reducing aggregate stability (Milne and Haynes, 2004). The reduction of macro-aggregates in soils under cropped system has been clearly documented (Green et al., 2005; Tufeckcioglu et al., 1999). Long-term cropping decreased the length and mass of fine roots, and soil organic matter resulting in a reduction of macro-aggregates (Tisdall and Oades, 1980; Cambardella and Elliot, 1992).

Soil organic matter pools (C and N) were significantly affected by forage system (Table 3). The amount of C and N followed the order of; tall fescue plus clover > tall fescue > Italian ryegrass. The results in Table 2 indicate that perennial grass cultivation using tall fescue and tall fescue mixture stands increased 26% to 38% of C and 25% to 46% of N, respectively compared to annual or Italian ryegrass stand. These results were consistent with other reports (Li et al., 2007; Wright et al., 2004). Li et al. (2007) observed that annual pasture cultivation had substantially decreased total organic C and N at depths ranging from 0-30 cm compared with permanent pasture cultivation. In this study, continuous root productions from perennial grass of tall fescue and tall fescue mixture stands are able to maintain the level of organic C and N in the soil surface. On the other hand, conventional tillage was involved in Italian ryegrass system each year for corn production, thus it caused soil organic matter depletion. Lal (2002) concluded that conventional tillage can deplete soil organic matter by following processes: (1) accelerated mineralization, (2) leaching and translocation as dissolved or particulate organic matter and (3) accelerated erosion. Other studies have also shown that different grass species can cause differences in N accumulation in soil due to variations in plant morphology and biomass (Clements and Williams, 1967). Generally, the amount of lignin and carbohydrates in plant roots, and the C/N ratios, interact to control decomposition of root material in soil (Angers, 1992; Alvarez et al., 1998). Alvarez et al. (1998) found that soils under bermuda grass plus ryegrass had less N availability compared with soils under bermuda grass plus clover stands.

Higher C/N ratio was found in Italian ryegrass and tall fescue stands compared to tall fescue mixture stands. The results from C/N ratios support the hypothesis that clover provides additional N into the ecosystem, thus tall fescue mixture had the lowest C/N ratios. However, other studies showed that introduction of clover to pastures, compared with ryegrass, decreased soil organic C and N sequestration at high-grazing activity, but not at low-grazing activity (Wright et al., 2004). Alvarez et al. (1998) demonstrated that ryegrass had higher C/N ratios than clover stands which caused limited N availability.

CONCLUSIONS

Growth of cool-season annual and perennial grasses during a 5- and 6-yr period in a silt loam caused differences in the amount of macro-aggregate, micro-aggregate, soil organic C, N and C/N ratio. The amount of macro-aggregates increased in the following order for the different forage system; Italian ryegrass < tall fescue = tall fescue plus clover. The amount of micro-aggregates decreased in the following order for the different forage system; Italian ryegrass > tall fescue = tall fescue plus clover. Tall fescue mixture stand provides the highest soil organic C and N, but the lowest C/N ratio. In summary, introduction of Italian ryegrass in western Kentucky has shown to reduce soil aggregate stability and soil organic matter pools compared to tall fescue and tall fescue – legume mixture systems.

ACKNOWLEDGMENTS

We are grateful to many students for their help enabling us to collect the soil samples. This research was supported by Murray State University Committee on Institutional Studies and Research under Contract no. 10-220310. Additional support was provided by the USDA-ARS Forage Animal Production Unit (FAPRU) under Agreement no. 3049022644. Mention of trade names is for information purposes only and does not imply endorsement by the Kentucky Agricultural Experiment Station or USDA. We also thank to Dr. Frank J. Sikora from the University of Kentucky for helping with the soil analyses.

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Table 1. General site description.

Site	Soil texture	Soil order	Slope (%)	Age (yr)
I	silt loam	Alfisols	0-5	5
2	silt loam	Alfisols	0-7	6
3	silt loam	Alfisols	0-8	6
4	silt loam	Alfisols	0-5	5

Table 2. Aggregate size distribution after wet sieving under three different forage systems. Values are expressed as percentages of dry weight of soil and on a sand-free basis in each size fraction.

Forage System	Size fraction (μm)		
	250-2000	53-250	<53
	% dry weight of soil		
Italian ryegrass	23.52a	27.82b	48.66a
Tall fescue	27.85b	22.56a	49.59a
Tall fescue + clover	28.82b	23.82a	47.36a

†Values within columns followed by the same letter are not significantly different ($p < 0.05$) according to Duncan's multiple-range test.

Table 3. Soil organic C, N and C/N ratio under three different forage systems.

Forage System	Soil Organic Matter		
	C	N	C/N
	$g\ kg^{-1}$		
Italian ryegrass	1.86a	0.15a	12.40a
Tall fescue	2.51b	0.20b	12.55a
Tall fescue + clover	2.99b	0.28c	10.68b

†Values within columns followed by the same letter are not significantly different ($p < 0.05$) according to Duncan's multiple-range test.