Aggregate stability of Alfisols root zone upon turfgrass treatment

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ARTICLE INFO	ABSTRACT
	Soil degradation mostly occurs on land where a lack of surface coverage results in soil-aggregate destruction due to heavy rainfall. Turfgrass is an ornamental plant and covers the soil surface and, thus, potentially improves soil-aggregate stability. This study determined the potential of some summer grasses to improve soil-aggregate stability and was a pilot experiment using six turfgrass species: *Paspalum vaginatum*; middle-leaf *Zoysia sp.*; *Cynodon dactylon*; coarse-leaf *Zoysia sp.; Axonopus compressus*; *Zoysia matrella*. Turfgrasses were planted using stolons in a 0.6 m^2 plot unit with 5 cm x 5 cm space. Lawn maintenance included irrigation, fertilizing, and weeding. Soil characteristics were observed six months after planting and showed that turfgrass increased the soil-aggregate index from 42.3% to 83.0% in control, and carbon particles measuring 6.4 µm from 28.3% to 63.0%.

1. Introduction

Coarse- and middle-leaf *Zoysia sp.* and *Axonopus compressus* have the potential to increase a soil aggregate's stability, stability index, 250 µm fractions of carbon (C), and quantity of organic matter (Idowu, 2003). Sustainable agriculture can be achieved by recovering natural vegetation (Li, Shao, Zheng, & Zhang, 2005) because revegetation can increase soil-aggregate stability and decrease soil erodibility (An, Darboux, & Cheng, 2013). Soil aggregation and soil structure are the basic properties of natural and managed ecosystems. Soil-aggregate stability impacts several of the characteristics of soil, including water infiltration and soil erosion (Amézketa, 1999), water movement and storage, soil aeration, soil erosion, biological activity, and crop growth (Zhang & Miller, 1996). Aggregate stability is also affected by organic fractions, including fungi microbial biomass, particulate organic matter, polysaccharides, humic substances, and lipids (Baldock, 2002; Abiven, Menasseri, & Chenu, 2009). Aggregate stability and organic matter content are significantly correlated (Loveland & Webb, 2003). Organic matter increases the soil-aggregate stability of silty soils (Albiach, Canet, Pomares, & Ingelmo, 2001; Tessier, Bruand, Le Bissonnais, & Dambrine, 1997), even though it depends on

the quality of the amendments (Ojeda, Alcañiz, & Le Bissonnais, 2008). Vegetation helps maintain soil-aggregate stability by protecting soil from direct rainfall, adding organic material from leaves, stems, and roots, and potentially improving soil structure. Turfgrass is an example of such vegetation. According to (Dougherty, Quinn, Endres, Voigt, & Barney, 2014), turfgrass features fast-growing roots, produces high levels of biomass, uses water efficiently, can grow on marginal land, and spreads easily to cover the soil surface. Soil coverage prevents damage to soil particles and aids soil-aggregate stability (Arifin, 2010). Planting vegetation over the land can improve soil-aggregate stability. Vegetation positively increases an aggregate by using organic matter to improve the soil's physical properties. According to Kadlec, Holubík, Procházková, Urbanová, & Tippl (2012), organic matter influences the size of soil C fractions.

Turfgrass is an important component of the landscape and has a unique social and aesthetic role, providing a surface for sports and recreation. That is, turfgrass is more ecologically beneficial than other types of vegetation because its services are functional, aesthetic, recreational, social, and economical; it also contributes to psychological or physical

health. Additionally, it has greater potential to reduce runoff, increase infiltration, purify water from sediment and pollutants, control erosion, improve soil quality, and reduce fire hazards (Monteiro, 2017). A well-managed turfgrass system accumulates large quantities of organic soil C, which supports a diverse and strong soil microbial community. Older turfgrass, meanwhile, increases polysaccharides and makes soil organic matter more resistant to decomposition (Shi, Dell, Bowman, & Iyyemperumal, 2006). Residential turfgrass soil can supply higher levels of organic soil C than agricultural soils by returning and recycling clippings, appropriate and efficient-fertilizer use, and irrigating based on the turfgrass' needs (Qian & Follett, 2012). A substantial correlation has been observed between soil aggregation, C sequestration, and the abundance of arbuscular mycorhizal fungi densities (Wilson, Rice, Rillig, Springer, & Hartnett, 2009). Common turfgrasses found in Indonesia are *Zoysia sp., Paspalum vaginatum, Miscanthus Sinensis, and Axonopus compressus*. *Zoysia sp.* grows naturally in Asia and has a high tolerance to heat, drought, and direct sunlight (Brosnan & Deputy, 2008). *Axonopus compressus* features leaves that spread to the side and tightly cover the soil, increasing the stability of the soil aggregate; Ibeh, Maxwell, & Bitrus (2013) define *Axonopus compressus* grasses, including carpet grass, as grasses that cover the soil. *Axonopus compressus* is a flat and thick grass with a shape like *Cynodon dactilon*, whose stem is small and flat and which features cavities in the thatch (Sirait, 2017).

Changes in land use from pasture to agriculture decrease both topsoil aggregation and the levels of aggregate-binding agents such as carbohydrates and glomalin (Spohn & Giani, 2010). Covering the soil with crops is a sustainable alternative for soil management because it increases OM and nutrients in the soil profile, improving porosity, soil structure, and the stability of aggregates (Sandoval, Celis, & Morales, 2011). However, glomalin can be used to indicate soil quality and, thus, monitor soil degradation (Fokom et al., 2012). Rillig, Wright, & Eviner (2002) reported that the stability of soil aggregates (1–2 mm size class) to water is determined by plant root length, soil glomalin, and ground-surface-coverage percentage. Glomalin and organic matter cooperate in the formation of stable water aggregates and the buildup of soil structure (Fokom et al., 2012). Glomalin has a direct effect on stabilizing soil aggregates, an effect more powerful than that of arbuscular hyphae mycorrhizal fungi themselves (Rillig et al., 2002).

Additionally, glomalin has adhesive properties and can, thus, help combine fine soil particles into soil aggregates (Purin, Filho, & Stürmer, 2006). The glomalin content in soil is generally associated with the proportion of insoluble humus or minerals (Wright, Franke-Snyder, Morton, & Upadhyaya, 1996). Lovelock, Wright, Clark, & Ruess (2004) reported that in tropical soils, the amounts of C and nitrogen (N) in glomalin are about 37% and 4%, representing 3% and 5% of soil C and N.

2. Materials and Method

This research was conducted on an experimental plot at the dry land experimental field of Sebelas Maret University – 7°37''46.3' South; 110°56''21' East; elevation 170 sea level–

between June 2017 and April 2018. The average temperature at the location is 27.8°C, the average humidity is 84%, and the average monthly rainfall during the experiment was 288 mm. The soil was Alfisols with the following characteristics: pH: 6.18; C-organic content: 0.83%; CEC: 26.1 me%; clay: 81.1%; silt: 3.7%; sand: 15.3%. This plot used a randomized-complete-block design with six types of turfgrass: *Paspalum vaginatum*, middle-leaf *Zoysia sp.* with 4 mm leaf texture, *Cynodon dactylon*, *Zoysia sp.* coarse leaf with 5 mm leaf texture, *Axonopus compressus*, and *Zoysia matrella* with 2.5 mm leaf texture. Each plot unit was repeated four times. The soil plot unit was 0.6 m x 0.6 m with cultivated stolons of turfgrass at a depth of 20 cm. The grass was cultivated by planting three-tiller stolons with a space of 5 cm between each. The plants were irrigated twice every day–once in the morning and once in the evening–for two months, then once a day. Before planting, 5 tons ha^{-1} of manure-based fertilizer was applied; 16 days after planting, 3 tons ha^{-1} of compost-based fertilizer was used. Leaf fertilizer was applied twice a week. The grass was harvested 8 months after planting using a green golf hole cutter with a depth of 10 cm.

The following variables were observed: root length, volume, and density (measured manually); thatch dry weight (weighed manually); soil density using the pycnometer method; volume weight using the gravimetric method; organic C using the Walkley and Black method; porosity using the calculation formula n = 1-(BV/BJ) (Partoyo, 2005); C-fraction using the particular organic matter method; soil aggregate using dry- and wet-sieve methods; easy-extracted glomalin bound to soil protein extracted using the Wright-and-Upadayana method (Musfal, 2010).

One gram of dry wind-dried soil sample was placed into a 50 ml centrifuge tube and mixed with 8 ml 50 mM sodium citrate (pH = 8). Then, the sample was autoclaved for 30 minutes. Supernatants were collected by centrifugation until a clear solution was obtained. Total glomalin was calculated using the Wright and Upadayana method: bound-to-soil protein was extracted with 8 ml of 50 mM sodium citrate (pH = 8), then the sample was autoclaved for 90 minutes. Using a Bradford assay with standard bovine serum albumin, the supernatant was determined to be protein-bound glomalin with soil. The stability of the soil aggregate was assessed by determining the mean weight diameter––the average diameter of the weighted soil aggregate––and the aggregate-stability index (Syamsiyah, Sunarminto, Hanudin, & Widada, 2014). Data were analyzed using one-way ANOVA (F) and 5% tests with a 5% DMR test level.

3. Results

Varying turfgrass cultivation for 10 months significantly affected root length and root volume (P≤0.01) but not root density. The turfgrass species with the longest root length was *Paspalum vagiatum* (30.6 cm), and species with the shortest was middle-leaf *Zoysia sp.* (18.2 cm). The turfgrass with the greatest root volume was *Axonopus compressus* (21 ml), and the species with the least were middle-leaf *Zoysia sp.* and *Cynodon dactylon* grass (6.3 ml). High root density indicated large volume and root quantity and vice versa.

Table 1. The roots of various turfgrasses at 10 months

Treatment	Root length (cm)	Root density (cm cm^{-3})	Root volume (ml)	Total Dry Weight of Thatch (g)
Paspalum vaginatum	30.6a	0.7a	11.5b	10.3ab
Middle-leaf Zoysia sp.	18.2d	0.8a	6.3c	7.3 ab
Cynodon dactilon	20.4cd	0.9a	6.3c	3.5 bc
Coarse-leaf Zoysia sp.	22.6bc	0.9a	7.3c	6.5 b
Axonopus compressus	24.7b	1.0a	21.3a	11.8a
Zoysia matrela	21.4c	0.6a	8.8bc	3.4 c

Remark: the average number followed by the same letter shows no significant difference at the 5% LSD level

Table 1 shows the various turfgrasses differed significantly in terms of thatch weight (P=0.02). The greatest root and thatch weights were for *Axonopus compressus* (11.8 g), and the lowest was for *Zoysia matrela* (3.4 g). Table 2 shows the results of various analyses indicating that 10 months of turfgrass cultivation did not significantly affect 150 μm or 50 μm C fractions, although there was a significant difference in 250 μm C fractions; for that size, the largest quantities were found in middle- and coarse-leaf *Zoysia sp.*, while the smallest was for *Zoysia matrela*. The large 250 μm soil organic C particles for middle-leaf *Zoysia sp.* could indicate soil-aggregate stability improvement. The results also showed that various turfgrass did not significantly affect soil bulk density, particle density, or porosity (Fig. 1 and 2).

Table 3 shows that the various turfgrasses significantly differed in particle size. The soil particles ranging from 2.4 μm to 6.4 μm weighed more than the control, resulting in an aggregation process of microparticles into macro soil particles. However, for particles ranging in size from 0.15 μm to 1.5 μm, the control treatment weighed more than the treated turfgrass. Table 4 shows that the turfgrass varieties were significantly affected by soil-aggregate stability and glomalin content. *Axonopus compressus* had the highest soil-aggregate stability value, while coarse-leaf *Zoysia sp.* and *Axonopus compressus* showed higher levels of glomalin.

Table 2. The analysis results of 250 μm, 150 μm, 50 μm carbon fractions from various turfgrasses

Treatment	C fraction size		
	250μm	150μm	50μm
Paspalum vaginatum	1.19b	1.36a	1.23a
Middle-leaf Zoysia sp.	1.60a	1.18a	2.04a
Cynodon dactilon	1.33a	1.32a	1.95a
Coarse-leaf Zoysia sp.	1.60a	1.50a	1.82a
Axonopus compressus	1.25a	1.29a	1.39a
Zoysia matrella	1.00b	1.12a	1.71a

Remark: The average number followed by the same letter shows no significant difference at the 5% LSD level
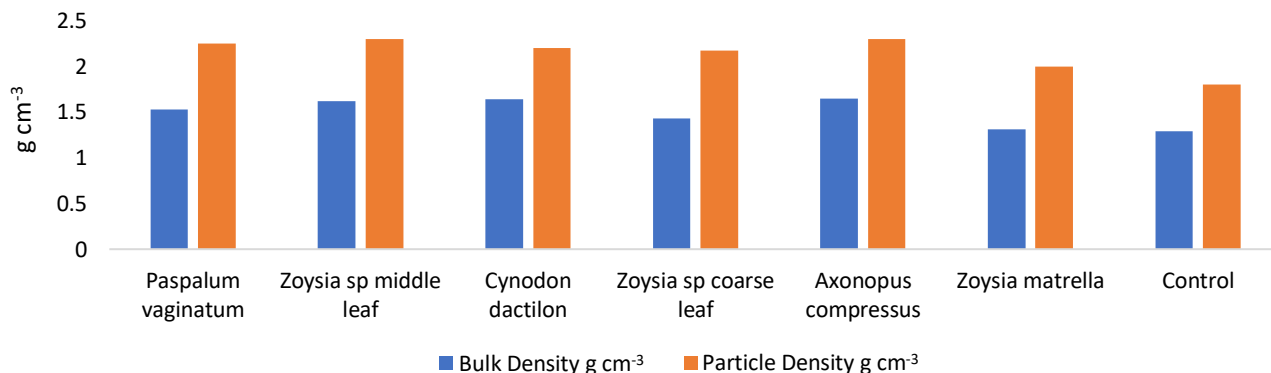

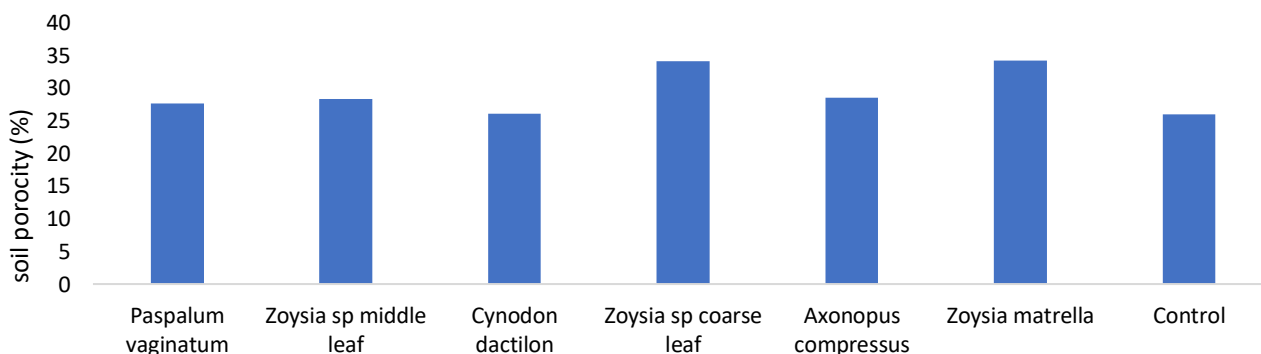**Figure 1.** Bulk density and particle density of the root area of various turfgrasses

Figure 2. Soil porosity for the root area of various turfgrasses

Table 3. Soil particle distribution under variation turfgrass.

Turfgrass	Soil particle size						
	6.4 µm	3.8 µm	2.4 µm	1.5 mm	0.75 µm	0.4 µm	0.15 µm
	(%)						
Paspalum vaginatum	61.1 a	13.0 a	7.1 a	7.5 ab	6.8 a	7.3 a	6.3 cd
Middle-leaf Zoysia sp.	54.3 b	7.7 a	5.2 a	8.8 a	6.9 a	5.6 a	4.6 d
Cynodon dactilon	60.1 ab	8.2 a	4.1 b	6.2 b	5.5 ab	5.4 a	7.0 bcd
Coarse-leaf Zoysia sp.	62.7 a	8.7 a	5.5 a	6.2 b	4.2 b	6.1 a	5.6 cd
Axonopus compressus	69.0 a	9.7 a	5.1 ab	7.7 a	8.9 a	5.6 a	8.9 b
Zoysia matrella	56.8 b	11.4 a	3.6 b	8.2 a	5.4 ab	6.2 a	8.1 bc
Control	42.3 c	8.4 a	5.1 ab	10.6 a	7.8 a	6.8 a	13.6 a

Remark: The average number followed by the same letter shows no significant difference at the 5% LSD level

Table 4. Soil-aggregate indexes and soil glomalin content

Treatment	Stability index	Level	Glomalin content (mg g⁻¹)
Paspalum vaginatum	56.75b	Rather steady	0.36ab
Middle-leaf Zoysia sp.	60.23b	Rather steady	0.35ab
Cynodon dactilon	66.16ab	Rather steady	0.31b
Coarse-leaf Zoysia sp.	72.97a	Steady	0.41a
Axonopus compressus	73.03a	Steady	0.40a
Zoysia matrella	60.91b	Rather steady	0.29b

Remark: The average number followed by the same letter shows no significant difference at the 5% LSD level

4. Discussion

Coarse-leaf *Zoysia sp.* and *Axonopus compressus* showed the most potential to improve soil-aggregate stability, as indicated by their stability indexes and levels of glomalin (Table 4) and organic soil C levels for the 250 µm fractions (Table 2). The 250µm C fraction indicated turfgrass species influenced the quantity of certain sizes of soil C. The 50µm and 150µm C fractions did not differ between turfgrasses. This supports the findings of (Trappe, 2015), who found that differently turfgrass species influence soil C differently, and small differences between species affect soil microbial activity and soil aggregation. Castro Filho, Lourenço, Guimarães, & Fonseca (2002) reported that in a no-tillage system, increasing organic C content is the key to producing the best aggregation for the 0–20 cm soil layer. Organic matter that is part of the soil's micro-aggregate is protected against overhaul to become more stable than the organic matter that is part of the macro-aggregate (Brodowski, John, Flessa, & Amelung, 2006). Kalhoro et al. (2017) reported that the type of land use affects soil aggregation and fraction-size distribution, that small fractions of aggregates form large fractions by cementing fresh organic matter, and that the increased organic soil C improves the formation of macro-aggregates.

Over time, turfgrass systems can build up organic soil C (Shi, Yao, & Bowman, 2006) by returning leaf clippings where turfgrass has been shown to increase soil C by 11 % over 10 years (Y. L. Qian et al., 2003). Organic matter is the key to improving aggregate stability (Albiach et al., 2001). Organic C

in the soil plays a role in binding soil particles to create more pore space (Refliaty & Marpaung, 2010), in binding soil particles to form soil structures (Six et al., 2002), and as an adhesive material within the soil (Isnawati & Listyarini, 2018). Increasingly, the subtle particle fraction determines the soil's aggregate stability, which is associated with the fraction's organic C content (Suwardji, Utomo, & Sukartono, 2012). Soil structure and soil aggregate are generally correlated to soil porosity; however, the turfgrasses were not significantly affected by soil porosity. (Mustoyo, Simanjuntak, & Suprihati, 2013) described compact soil as having a higher soil bulk density than loose soil. Too much bulk density can result in higher numbers of soil organisms, such as worms. According to Hartati (2008), soil organisms can reduce soil bulk density. The presence of organic matter influenced the degree of soil bulk density. Coarse-leaf *Zoysia sp.* and *Axonopus compressus* showed higher potential for soil aggregate formation because they demonstrated a higher proportion of 6.4 µm. Residues from different species of turfgrass have also been shown to affect soil aggregate mean weight diameter, soil microbial activity, and total soil C (Trappe, 2015).

Paspalum vaginatum and *Axonopus compressus* demonstrated high potential for soil aggregate stabilization by having long roots, large root volumes, and high thatch weight (Table 1). Water-stable aggregate was reduced when organic matter, root biomass, and limited microbial activity were low (Kalhoro et al., 2017). Root exudate is a ground source of C sources, supporting the contention of (Liu, Liu, Fu, & Zheng, 2008) that plants affect the soil organism community through the supply of C from root exudates. *Axonopus compressus* has the potential to improve soil aggregate because it has a compact and strong fiber root system, in contrast with *Cynodon dactylon* and *Paspalum vaginatum*, which have deep root systems and adventitious roots formed from the rhizome and stolon nodes (Lonard, Judd, & Stalter, 2015). Grassroots and thatch play a role in the formation of soil aggregates by uniting soil particles into primary aggregates. *Axonopus compressus* generated a higher total thatch dry weight (Table 1). Decay and thatch support the soil's organic matter, while root biomass and organic soil matter are supporting the formation of aggregates. Old roots effectively supply organic soil matter to stabilize soil aggregates (Supangat & Putra, 2010). Previous studies have suggested that macro-aggregates in the soil are mainly stabilized because of carbohydrate-rich roots (Y. Li et al., 2016).

Coarse-leaf *Zoysia sp.* and *Axonopus compressus* demonstrated the highest glomalin levels; *Zoysia matrella* showed the lowest levels (Table 4)*.* According to Musfal (2010), mycorrhizae, through their external roots, can produce glycoprotein glomalin compounds and organic acids that will bind soil grains into micro aggregates. The micro aggregates formed will form macro aggregates through the mechanism of external hyphae (Musfal, 2010). Mycorrhizal fungi also have a role in the process of soil aggregation: mycorrhizal hyphae can secrete substances that can help to bind the grains of primary soil into secondary soil particles and finally form soil aggregates (Syamsiyah et al., 2014). Long-term turfgrass management produces dramatic increases in soil C, N, and microbial biomass, ultimately improving microbial diversity and composition (Santoro, Boehm, & Francis, 2006).

5. Conclusion

Turfgrass maintenance over 30 weeks was shown to increase the soil-aggregate index from 42.3% to 83.0% and increase the number of 6.4 µm soil particles from 28.3% to 63.0%. Soil-aggregate stabilization can potentially be improved using *Axonopus compressus*, middle- or coarse-leaf *Zoysia sp.* because these varieties resulted in the highest soil-aggregate stability indexes. The results show that common turfgrasses have the potential to improve soil-aggregate stability. Middle-leaf *Zoysia sp.* produced more 250 µm and 50 µm C fractions, while *Axonopus compressus* increased levels of glomalin and organic matter, demonstrated long roots, large root volumes, and high thatch weights. Additionally, *Paspalum vaginatum* showed long roots, large root volume, and high thatch weight, and coarse-leaf *Zoysia sp.* featured high levels of 250 µm organic C fractions and high levels of glomalin.

Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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