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Recovering Soil Quality of Elephant Grass-Cultivated Suboptimal Land Through Mycorrhizae and Organic Fertilizer

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Abstract.
Bio and organic fertilizers have been used to improve soil quality for a long time in attempts to boost plant productivity. This field study used a randomized complete block design with three replications to investigate the effect of arbuscular mycorrhizal fungi with four doses (0, 15, 30, and 45 Mg Ha-1) of manure on the soil quality of elephant grass cultivated on suboptimal land. Mycorrhizae and manure improved the physical, chemical, and biological quality of the soil. Higher mycorrhizae-administered manure doses improved soil aggregate stability, pH, cation exchange capacity, organic carbon, total nitrogen, available phosphorous, exchangeable potassium, and the microbial population. Overall, the use of mycorrhizae and manure could aid in the recovery of suboptimal land quality.

Keywords: aggregate stability; arbuscular; biofertilizer; manure; nutrient; carbon

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1. Introduction

Soil is a general medium to support plant growth and development, and its quality influences plant productivity. Elephant grass (*Pennisetum purpureum* Schum), a perennial plant, has many outstanding potential purposes such as animal feed, improving soil fertility, erosion control, pest management, and bioenergy soils [1], also need fertile soil to grow well.

Nowadays, the availability of fertile soil is limited day by day because of land-use conversions. Thus, the suboptimal lands having many obstacles to cultivate plants will be inevitable to use. The land has poor aggregate stability and low pH, nutrient contents, organic matter, and microorganisms. Therefore, managing suboptimal land is an utmost prerequisite to be productive.

The application of chemical fertilizers is a widespread practice for improving soil fertility and crop yield but, their use is restricted by scarcity and cost. Other problems associated with the use of chemical fertilizers are acidity, nutrient imbalance [2,3]. Therefore, using beneficial microbes as biofertilizer agents is a friendly method suitable to conserve agricultural fields.

Arbuscular mycorrhizal fungi (AMF) forming a mutualistic relationship with 80-90% of terrestrial plants [4] able to alleviate the uncomfortable conditions for agricultural plants such as low nutrients [5,6], drought [7,8] calcareous [9], and saline [10]. Therefore, this biofertilizer was a satisfactory alternatve to improve plant production in suboptimal land.

This technology has yet to replace conventional chemical fertilizers in commercial agriculture [11], especially on suboptimal land. These fungi are not nutrient suppliers but make the nutrients available for plants [12] and enhance plant nutrient uptake [13]. Alternatively, application organic fertilizers involved in nutrient cycling [14] is an option.

In soils, the successful co-application of organic amendments and AMF on plant growth and productivity has been shown [15], but their effect is site-specific. Therefore, this study aimed to observe the effect of AMF and manure on the improvement of soil quality of elephant grass-cultivated sub-optimal land. The hypotheses are that both AMF and manure singly or in combination can improve the soil quality of elephant grass-cultivated sub-optimal land.

2. Methodology

This field study was in The Agricultural Extension Center, Pidie, Aceh. The soil was classified as Ultisol has very unstable aggregate (index 18), low in organic carbon (1.08%), total nitrogen (0.14%), and exchangeable K (0.28 $cmol_{(+)}$ kg^{-1}), medium in available phosphor (8.21 mg kg^{-1}) and cation exchange capacity (18 $cmol_{(+)}$ kg^{-1}), and has acid reaction (pH 5.42).

This study was arranged in a randomized complete block design with 2 X 3 treatments. The factors were mycorrhizae (0 and 10 g $hole^{-1}$) and cow manure (0, 15, 30, and 45 Mg Ha^{-1}).

The land was prepared in 24 plots with 2m x 2m each. The manure having 5.32% org. C, 0.69% tot. N, 0.32% tot. P, and 0.58% tot. K was mixed thoroughly in the plots as treatments on seven days before planting.

The mycorrhizal inoculum (a mix of *Glomus* sp., *Gigaspora decipien,* and *Acaulospora* sp.) inoculated in a hole just before planting the stem-cuttings of elephant grass. The cuttings used has 26 cm in length and 6 cm in diameter. Individual cutting included three nodes, two of that were buried in soil and planted in each planting hole.

The soil sample was collected after the 50 day-plants being harvested and analyzed for physical, chemical, and biological properties. The soil aggregate stability index was determined using a wet sieving device [16]. The soil was dilute with distilled water at a 1: 2.5 (w/v) ratio and the extract was measured for pH. Soil organic Ccarbon (org. C) was analyzed according to Walkley and Black method (Walkley and Black, 1934 [17]. The analysis methods for soil total nitrogen (tot. N) was Kjeldahl [18], available phosphor (av. P) was by Bray 1, while exchangeable potassium (exch. K) and cation exchangeable capacity (CEC) were extracted with ammonium acetate (1 *N*) buffer solution [19]. The number of soil microorganisms was determined by the diluted plate method [20] and cultured in a nutrient agar medium [21].

All the data were assayed for normality (Kolmogorov-Smirnov test) and homogeneity of variances (Levene's test) with the SPSS 25.0 software (IBM Inc., Armonk, NY, USA). The data were log-transformed before analysis where necessary to approximate normal distribution. A one-way analysis of variance (ANOVA) and Duncan significant difference test to determine significant differences in soil physical, chemical, and biological characteristics among mycorrhizal and organic fertilizer treatments.

3. Result and Discussion

Soil consisting of various physical, chemical, and biological aspects affects its quality. Soil quality cannot be measured directly, because it is multiple interactions among physical, chemical, and biological soil properties [22]. In addition, the soil quality was affected by land use and soil management [23,24]. Several studies in recent times have documented that the addition of organic amendments and biofertilizers are practices to improve soil quality [25,26].

This study (Table 1) showed that AMF and manure significantly improved the soil quality of elephant grass-cultivated suboptimal land. The AMF affected significantly soil aggregate stability, pH, CEC, org. C, av. P, and microbial population, while manure affected significantly all soil quality indicators evaluated. This study also revealed that the ability of AMF to increase the soil tot. N was affected by manure doses.

ns = not significant * = significant ** = very significant

3.1. Soil aggregate stability index

The stability of soil aggregate plays a role in crop production and soil quality. It is an urgent soil quality indicator which influences soil structure [27] and soil functioning such

Table 1: Significance of the effect AMF and manure on soil physical, chemical, and biological properties on elephant grass rhizosphere.

	Aggregate stability index	pH	CEC	Org. C	Tot. N	Av. P	Exch. K	Microbial population
AMF (A)	**	*	*	**	ns	**	ns	**
Manure (M)	**	**	**	**	**	**	**	**
A*M	ns	ns	ns	ns	*	ns	ns	ns

as carbon storage [28], organic matter stabilization [29], water holding capacity [30], and biota [31].

This study showed that either AMF or manure applications significantly increase soil aggregate stability. Table 2 indicated that soil aggregate stability was increased 10.37% with AMF and 11.30 to 23.54 with manure applications. This result is in agreement with some studies that showed the increased soil aggregation by AMF [32]. AMF is a producer of extracellular polymeric substances that bind soil particles together, creation a wide network of hypha, and production of glomalin [32,33].

The positive effects of manure application on soil aggregate stability were also reported by Zhang *et al.* [34]. The aggregate is formed by cohesion and clustering of mineral particles and organic matter [35].

3.2. Soil acidity

Soil pH is a measure of active acidity of the sample and is the most frequently used indicator for estimating soil quality [36]. These critical characteristics regulate soil nutrients and microbial growth [37]. This study (Table 2) indicated that AMF and manure significantly improved soil pH. Both treatments rendered the soil less acidic from pH 5.96 to 6.23 by AMF and varying pH as low as 5.56 to as high as 6.55 by manure applications.

The increased soil pH by AMF occured by HCO_3^- or OH^{--} excreted by mycorrhizal roots through the excess absorption of anions over cations [38]. Chen *et al.* [39] also reported that mycorrhizae affected the concentration of H^+ in soil.

The effect of manure application on improving the soil pH increased by increasing application doses, but only 45 Mg ha^{-1} of manure changed soil acidity status from slightly acid to neutral. In agreement with this result, Xiao *et al.* [40] also showed that the soil pH increased with increasing manure dose application, while Adams *et al.* [41] reported that pH buffering of manure was higher with the higher manure rate (40 Mg ha^{-1}).

3.3. Cation exchange capacity

Cation exchange capacity is a soil quality indicator that gives insight into the nutrient retention capacity of the soil. Higher soil CEC results in more nutrient storage and CEC, hence more fertile soil [42], otherwise with soils with low CEC.

The CEC values obtained in this study were increased either by AMF or manure applications (Table 2). Response of soil CEC was in a linear relationship with soil pH (Table 2). The CEC was higher as the soil pH increased. Shi *et al.* [43] also showed similar findings.

Application of AMF and manure contributed to soil organic matter, and thus increased soil CEC. The highest CEC value found at the highest dosage (45 Mg ha^{-1} of manure) could be reduced leaching, and there were more exchangeable cations such as Na^{+}, Ca^{2+}, Mg^{2+}, and K^{+} incorporated by soil organic matter and manure itself. Similar findings on changes in soil CEC with AMF and manure are also reported by Fang *et al.* [44] and Shi *et al.* [43], respectively.

Table 2: The effect of AMF and manure on soil physical, chemical, and biological characteristics.

Treatments	Aggregate stability	pH	CEC cmol$_{(+)}$ kg^{-1}	Org. C (%)	Tot. N (%)	Av. P (mg.kg^{-1})	Exch. K cmol$_{(+)}$ kg^{-1}	Microbial population (Log CFU g^{-1} dry soils)
AMF								
AMF	44.92 a	5.96 a	19.73 a	1.46 a	0.20 a	4.28 a	0.34 a	5.80 a
+ AMF	49.58 b	6.23 b	20.90 b	1.64 b	0.21 a	8.44 b	0.36 a	5.90 b
Organic manure								
0 Mg ha^{-1}	42.23 a	5.56 a	17.87 a	1.25 a	0.16 a	1.93 a	0.31 a	5.47 a
15 Mg ha^{-1}	47.50 b	6.25 bc	19.40 b	1.49 b	0.20 b	4.53 ab	0.35 b	5.58 b
30 Mg ha^{-1}	47,00 b	6.04 b	21.60 c	1.59 b	0.22 c	5.91 b	0.34 ab	5.73 c
45 Mg ha^{-1}	52.17 c	6.55 c	22.40 c	1.87 c	0.23 c	13.08 c	0.38 b	6.63 d

Different lower case letters indicate significant difference among different AMF treatment with the same manure levels at $p < 0.05$.

3.4. Soil Organic Carbon

Soil organic carbon content is a soil biological and chemical quality indicator and indirectly affects soil physical quality [45]. This result also indicated that both AMF and manure significantly increased SOC.

AM fungi contributed to SOC by exudating the labile carbon substrates to the surrounding soil [46] and secreting glomalin [47]. In consistence, another study [48] reported manure increased SOC content by 0.23–0.26 and 0.18–0.19 g $kg^{-1}yr^{-1}$ compared to no fertilizer and NPK, respectively.

3.5. Soil nutrients

Among macronutrients observed, AMF inoculation significantly increased soil available P but not significantly on total N and exch. K. Otherwise, the organic fertilizer significantly ($p \geq 0.05$) increased all soil nutrient parameters, including total N, available P, and exchangeable K.

The effect of AMF to improve soil tot. N depended on manure doses application (Figure ??), otherwise on soil av P and exch. K. This result also revealed that the AMF effect on increasing significantly soil tot. N was decreased by increasing the dose of manure application. The soil nutrient status was affected by AMF through increasing mineralization, reducing leaching, and producing organic acids [49-51]

There are also notable differences in the soil nutrient contents (tot. N, av. P., and exch K) between the control and the various manure doses-amended soils (Table 2). The higher doses of manure, the higher value of the soil nutrient observed. Manure is a valuable source of macro and micronutrients for plants, so the introduction of these organic materials into soil causes an increase in nutrient contents [52,53].

3.6. Microbial population

In the past, soil quality indicators consisted of only physical and chemical properties [45]. Soil microorganisms occupy only a minuscule portion (0.5%) of the total volume of soil [54] could be a predictor for evaluating soil quality [50,55]. They act in SOM decomposition, nutrient cycling, soil aggregation, and soil health [56-58].

This study (Table 2) indicated that AMF symbiosis was significantly modulated microbial population in the soil. These results were in line with Hao *et al.* [59] who reported that AMF promoted the enrichment of plant growth-promoting microbes in soils spiked with Lanthanum 500 mg kg^{-1}. Arbuscular mycorrhizal fungi mycelial exudates influence the microbial population. The exudate types that affect the microbial population include soluble sugar [60], strigolactanes [61], and carboxylate [62].

Likewise, manure application also improved soil microbial population. This effect was higher with higher application doses. Ding *et al.* [63] also showed that a higher rate of manure led to a larger microbial population. The microbial population was related to the nutrient content of organic fertilizer applied required to support their life.

Figure 1. The effect of manure doses on soil total N content at different AMF treatments.

Different lower case letters indicate significant differences among AMF treatment with the same manure levels at $p<0.05$.

4. Conclusion

Arbuscular mycorrhizal fungi and manure effectively improved soil physical, chemical, and biological quality of elephant grass-cultivated suboptimal land. Both soil amendments increased soil aggregate stability, pH, CEC, organic C, total N, av. P, exch. K and the microbial population. The soil tot. N status was affected by the combination of AMF and manure application, and the effectivity of AMF was lower with increasing manure doses. The highest effect of manure on improving soil quality indicator evaluated was at 45 Mg Ha^{-1}. It concluded that AMF and manure could be a sustainable manner to recover soil quality.

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