Early Growth Characteristics of Corn Under Different Arbuscular Mycorrhizal Fungi (AMF) Inoculant Sources in a Conventional Cultivation System

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Abstract: Arbuscular Mycorrhizal Fungi (AMF) are widely recognized as biological agents that improve nutrient uptake, particularly phosphorus, and enhance plant adaptation under suboptimal soil conditions. This study aimed to evaluate the effects of different inoculant sources on the early vegetative growth of corn under a conventional cultivation system. A randomized complete block design was used with five inoculant treatments: unsterilized soil, sterilized soil, tidal soil, local tidal AMF propagules, and commercial mycorrhizae, with four replications. The observed variables included plant height, leaf number, stem diameter, and leaf greenness at 2, 3, and 4 weeks after planting (WAP). The results showed that inoculant source significantly affected plant height, leaf number, and stem diameter at 4 WAP. Leaf greenness was not significantly affected by treatment at all observation periods. Tidal soil treatment resulted in the highest plant height (53.92 cm), leaf number (6.58 leaves), and stem diameter (43 mm) at 4 WAP. Growth in unsterilized and sterilized soil treatments was relatively similar. Lower performance of local AMF propagules and commercial mycorrhizae may be associated with differences in inoculum compatibility; however, root colonization was not quantitatively measured in this study. These findings indicate that tidal soil has potential as a biological inoculant source for early corn growth under conventional cultivation.

Keywords: Biological Inoculation, Root Symbiosis, Plant Physiology, Soil Fertility

INTRODUCTION

Food security represents a strategic concern in Indonesia, shaped by factors such as population growth, climate change, and reliance on food imports. In response, the government initiated the food estate program to enhance food security by developing large-scale agricultural areas using modern technology. The effectiveness of this program depends on systematic planning, active participation of local communities, and the implementation of environmentally sustainable agricultural practices. Effective implementation of the food estate program can improve food security and support sustainable development (Robifahmi *et al.*, 2024). The urgency to develop food estates arises from the decreasing availability of agricultural land in Indonesia. Consequently, expansion efforts have targeted suboptimal wetlands, particularly tidal flats. The use of tidal flats for agricultural development offers a potential solution to challenges in the agricultural sector, especially for increasing food crop production. These areas have significant potential to be converted into productive agricultural land. Indonesia possesses approximately 20.1 million hectares of tidal flats suitable for development (Ghulamahdi, 2017). Tidal lands are characterized by high acidity, toxic concentrations of Al and Fe, and limited availability of macronutrients such as phosphorus, nitrogen, and potassium (Sefrila *et al*., 2024). Saturated water cultivation systems provide an alternative approach to mitigating plant stress in these challenging environments. In addition, the application of soil microorganisms, particularly Arbuscular Mycorrhizal Fungi (AMF), represents a promising biological strategy. AMF establish mutualistic symbiosis with plant roots, facilitate nutrient uptake, especially phosphorus, and enhance plant tolerance to abiotic stress (Husna *et al*., 2017). Exploration and trapping of local AMF from corn plants in tidal land demonstrated that these propagules can promote corn growth, as evidenced by increased plant height, leaf greenness, and AMF root infection (Sefrila *et al*., 2024).

AMF inoculants derived from corn rhizospheres under water-saturated cultivation conditions can enhance phosphorus uptake, plant phosphorus content, relative inoculant efficiency, the number of filled pods, and seed weight in Tanggamus soybean varieties. Water-saturated cultivation improves root growth by maintaining adequate water availability, which enables plants to develop more roots and root nodules (Muis *et al*., 2016). Although previous studies reported the effectiveness of AMF under saturated soil cultivation systems, the application of local AMF inoculants under conventional cultivation systems remains limited. Conventional cultivation is still widely practiced by farmers; therefore, evaluating AMF performance under this system is important for broader agricultural application. AMF has been shown to be effective in improving marginal land conditions and increasing the productivity of various crops, such as nutmeg (Husna *et al*., 2021), orange (Sari *et al.*, 2024), soybean (Triarta NA, Proborini MW, 2019), and revegetation plants on mining land (Muis, 2021). Recent studies have shown that local AMF from host plants grown in target ecosystems (e.g., corn in tidal flats) have higher adaptability to extreme environments than commercial or non-local AMF (Sefrila *et al*., 2024). The use of AMF in water-saturated systems remains limited in research, offering an opportunity to develop site-specific technologies. This study aimed to evaluate the effect of different AMF inoculant sources on the early vegetative growth of corn under a conventional cultivation system.

RESEARCH METHODS

This research was conducted at the Research/Experimental Garden of the Faculty of Agriculture, Sriwijaya University. AMF isolation was conducted at the Plant Physiology Laboratory and the Ecology Laboratory of the Department of Agricultural Cultivation, FP Sriwijaya University. This study used a Randomized Complete Block Design (RCBD) consisting of five inoculant treatments (non-sterile soil, sterile soil, tidal soil, tidal local AMF propagules and commercial mycorrhizae) and four replications, resulting in 20 experimental units. Each experimental unit consisted of one polybag containing 10 kg of growing media and one corn plant. Two seeds were initially planted per polybag, and thinning was conducted at 7 days after planting to maintain one uniform plant per experimental unit; each treatment unit consisted of 3 plants. The materials used were Pioneer hybrid corn seeds 27, local tidal AMF propagules from corn hosts, commercial mycorrhizae, mineral soil, Nitrogen fertilizer, Phosphorus fertilizer, Potassium fertilizer, manure, tidal soil, and Dolomite. The tools used were 35 cm x 50 cm polybags, soil scoops, stationery, and analytical scales.

The research procedures include preparation of planting media (sterilization of soil as a planting medium is sterilized by oven at a temperature of 105 ^{0}C for 1 x 24 hours, planting and application of AMF, maintenance until harvest. The prepared soil medium is placed in 35 cm x 50 cm polybags, with 10 kg per polybag, and each is given fertilizer and dolomite at a dose of 2 tons/ha, then left for 2 weeks. Next, planting holes are made, and each hole is filled with two corn seeds per planting hole. The AMF inoculant source treatment was given when the corn seeds were planted, each amounting to 100 g/polybag. Maintenance includes watering, fertilizing, and weeding. Urea was applied twice at 300 kg/ha (1/3 at planting and 2/3 at 4 WAP). Phosphate and potassium fertilizers were applied at planting at 250 kg/ha SP-36 and 100 kg/ha KCl. The data obtained were analyzed using analysis of variance (ANOVA), and if there was a significant effect, further LSD testing was conducted at a significance level of 5%. The observation data were processed using the STAR (*Statistical Tool for Agricultural Research*) application software and Microsoft Excel version 2021.

RESULTS AND DISCUSSION

Early Growth Characteristics of Corn Plants

The application of AMF inoculant sources had a significant effect on advanced vegetative growth (4 weeks after planting), particularly on plant height, leaf number, and stem diameter (Table 1).

Table 1. Analysis of Variance (ANOVA) of Early Growth Variables of Corn Under Different AMF Inoculant Sources

Variable	F-Value	CV (%)
Plant Height (cm) 2 WAP	3.02	8.61
Plant Height (cm) 3 WAP	3.46*	9.85
Plant Height (cm) 4 WAP	4.76*	14.04
Number of Leaves (leaflets) 2 WAP	1.67	8.19
Number of Leaves (leaflets) 3 WAP	2.37	11.17
Number of Leaves (leaflets) 4 WAP	5.36*	9.86
Stem Diameter (mm) 2 WAP	0.87	14.70
Stem Diameter (mm) 3 WAP	2.66	10.29
Stem Diameter (mm) 4 WAP	5.60*	10.90
Leaf Greenness Level 2 WAP	0.50	6.96
Leaf Greenness Level 3 WAP	1.49	16.86
Leaf Greenness Level 4 WAP	1.77	5.17
F-table 5% = 3.25	F-table 1% = 5.41	

Description: Numbers followed by the same letter in the same column are not significantly different at the LSD test 5%.

However, in the early phase, the treatment had no significant effect because the plants were still in the adaptation phase and experienced relatively slow initial growth. Leaf greenness did not differ significantly at any observation age. Observations of plant height at 2, 3, and 4 WAP (Table 2) indicate that the mycorrhizal inoculant source treatments provided different responses to the vegetative growth of corn plants. Plant height at 2 WAP ranged from 25.33 cm to 30.15 cm. Based on the 5% LSD test, all mycorrhizal inoculant source treatments did not differ significantly and had no significant effect on plant height at 2 WAP. AMF colonization of the roots required 2–3 weeks before nutrient transfer function increased consistently (Begum *et al*., 2019). In this phase, plants still rely on food reserves in the seeds, and root morphology is still adapting, so that differences in AMF inoculant sources have not significantly affected growth.

The tidal soil AMF inoculant at 3 weeks post-sowing showed an increase in plant height (38.42 cm) and was significantly higher than other treatments. This was due to the more stable activity of tidal soil AMF compared to other inoculant sources that had not yet fully colonized. Tidal soil supports plant growth due to its redox dynamics, which increase nitrogen mineralization and phosphorus availability (Setiawan *et al*., 2021). At 4 weeks after planting (WAP), the tidal soil inoculant showed the highest plant height (53.92 cm), providing optimal support for vegetative growth. At this phase, plants begin to increase photosynthetic activity, leading to higher nutrient requirements and more visible differences between treatments. The inoculant sources of unsterilized soil (control) and sterilized soil showed the same plant height (47.67 cm). This similarity indicates that soil sterilization did not significantly affect plant height growth.

Table 2. Height of Corn Plants with The Provision of Various Inoculant Sources in Conventional Cultivation Systems

AMF Inoculant Source	Plant Height (cm)		
	2 WAP	3 WAP	4 WAP
Unsterilized soil	28.49±0.90	35.50±2.91ab	47.67±6.59ab
Sterile soil	27.82±2.07	35.17±2.90ab	47.67±5.44ab
Tidal soil	30.15±1.21	38.42±2.63a	53.92±4.85a
Local tidal AMF propagules from corn	25.48±2.41	31.63±2.30b	41.00±4.23bc
Commercial mycorrhizae	25.33±3.62	30.67±5.54b	35.92±8.00c
LSD test 5% :	-	5.21	9.79

Description: Numbers followed by the same letter in the same column are not significantly different at the LSD test 5%.

The inoculant sources of unsterilized soil (control) and sterilized soil showed the same plant height (47.67 cm). This similarity indicates that soil sterilization did not significantly affect plant height growth. This could be due to the role of microorganisms in the soil, which may not have a significant influence at this phase, or the soil conditions still providing sufficient macronutrients for growth. In contrast, treatments with local AMF inoculant (41.00 cm) and commercial mycorrhizae (35.92 cm) resulted in comparatively lower plant growth. The effectiveness of mycorrhizae can be influenced by the compatibility of mycorrhizal species with the host plant, environmental conditions, and the level of colonization that occurs (Yadav *et al*., 2020). Natural local AMF are more effective because they have evolved and adapted to local conditions, thereby exhibiting greater compatibility than commercial mycorrhizal inoculants (Rosmana *et al*., 2023).

Leaf number data at 2, 3, and 4 weeks after planting (WAP) showed variations in corn plant responses to mycorrhizal inoculant source treatments (Table 3). At 2 WAP, tidal soil treatment produced the highest number of leaves (5.08 leaves), followed by sterile soil (4.83 leaves), unsterilized soil (5.00 leaves), local AMF propagules (4.58 leaves), and commercial mycorrhizae (4.50 leaves). However, these differences were not statistically significant.

Table 3. The Number of Corn Leaves in Conventional Cultivation Systems when Given Various Inoculant Sources

AMF Inoculant Source	Number of Leaves (Blades)		
	2 WAP	3 WAP	4 WAP
Unsterilized soil	5.00±0.27	4.33±0.54	5.67±0.61b
Sterile soil	4.83±0.33	4.75±0.69	5.83±0.43a
Tidal soil	5.08±0.32	5.08±0.42	6.58±0.42a
Local tidal AMF propagules from corn	4.58±0.50	4.25±0.17	5.75±0.57ab
Commercial mycorrhizae	4.50±0.43	4.17±0.43	4.75±0.69c
LSD test 5%	-	-	0.86

Description: Numbers followed by the same letter in the same column are not significantly different at the LSD test 5%.

At 3 weeks after planting (WAP), the number of leaves remained consistent, with tidal soil remained numerically higher (5.08 leaves), although treatment effects were still not significant, indicating that this inoculant source supported continued leaf development. Unsterilized and sterilized soils showed relatively close values (5.50 and 5.33, respectively). Local AMF propagules increased to 4.83, but remained lower than those from the unsterilized soil inoculant source. This indicates that the sterilized soil microbes are beginning to adapt but have not yet contributed significantly to increased leaf number. Commercial mycorrhizae consistently exhibited the lowest value (4.50), suggesting that this type is less suited to the prevailing environmental conditions or host plant. In contrast, local arbuscular mycorrhizal fungi (AMF) are typically better adapted to local soil conditions, resulting in greater compatibility with host plants compared to general commercial inoculants (Zhang *et al*., 2023). At 4 WAP, tidal soil treatment produced the highest leaf number (6.58 leaves), significantly higher than commercial mycorrhizae treatment, demonstrating that this inoculant source was optimal for promoting canopy growth. These findings suggest that while mycorrhizae generally enhance nutrient uptake, particularly phosphorus, their effectiveness depends heavily on interactions among spore type, environmental conditions, and plant compatibility. Stem diameter showed growth variation influenced by various treatments (Table 4). Stem diameter is an important indicator for assessing plant vigor and vegetative biomass accumulation. Stem diameter increased in all treatments as the plants aged from 2 to 4 weeks after planting.

Table 4. Diameter of Corn Stalks in Conventional Cultivation Systems when Given Various Inoculant Sources

AMF Inoculant Source	Stem Diameter (cm)		
	2 WAP	3 WAP	4 WAP
Unsterilized soil	0.16±0.03	0.23±0.02	0.40±0.05a
Sterile soil	0.17±0.03	0.24±0.03	0.40±0.06a
Tidal soil	0.18±0.02	0.25±0.01	0.43±0.03a
Local tidal AMF propagules from corn	0.16±0.01	0.21±0.02	0.38±0.04a
Commercial mycorrhizae	0.15±0.02	0.20±0.02	0.30±0.02b
LSD test 5%	-	-	0.06

Description: Numbers followed by the same letter in the same column are not significantly different at the LSD test 5%.

At 2 WAP, stem diameters were still relatively small, ranging from 0.15 mm to 0.18 mm. The tidal soil inoculant treatment had the highest value (0.18 cm), while the commercial mycorrhizal treatment had the lowest (0.15 cm). At 3 WAP, all treatments showed a significant increase. The tidal soil inoculant treatment had a diameter of 0.25 cm. At 4 WAP, stem diameters reached their optimal values during this observation period, ranging from 0.30 cm to 0.43 cm. The stem diameters in the tidal soil inoculant treatment were higher; this can be attributed to the characteristics of the soil, which generally has a higher organic matter content. In addition, this inoculant source was obtained from the rhizosphere of corn plants aged 60 HST, where AMF are usually more active and abundant. These conditions support the activity of soil microorganisms and accelerate the mineralization of nutrients, especially nitrogen and phosphorus. Nitrogen plays a role in the formation of vegetative tissue, while phosphorus supports cell division and the differentiation of vascular tissue, thereby contributing to increased stem diameter (Begum *et al*., 2020). Leaf greenness is an important indicator of photosynthetic efficiency and plant nitrogen (N) status. The data in Table 5 show that various mycorrhizal inoculant source treatments affected plant physiological status in the early growth phase (2 and 3 WAP).

Table 5. The greenness level of corn leaves in conventional cultivation systems when various inoculant sources are provided

AMF Inoculant Source	Leaf Greenness Level		
	2 WAP	3 WAP	4 WAP
Unsterilized soil	31.92±2.55a	32.65±5.04a	49.87±2.59a
Sterile soil	33.07±3.29a	35.05±7.44a	47.79±3.84a
Tidal soil	33.52±1.40a	39.04±5.30a	50.60±1.63a
Local tidal AMF propagules from corn	31.73±0.41a	32.32±5.59a	49.65±0.69a
Commercial mycorrhizae	31.97±1.49a	29.84±2.47a	47.54±2.01a

Description: Numbers followed by the same letter in the same column are not significantly different at the LSD test 5%.

Leaf greenness values tended to be numerically higher in tidal soil treatment at 4 WAP (50.60); however, ANOVA results showed that these differences were not statistically significant. Therefore, leaf greenness responses should be interpreted cautiously. This confirms that the chemical-physical conditions of tidal soil can support chlorophyll formation better than other treatments. The local AMF treatment also performed well (49.65), approaching the value of unsterilized soil (49.87), indicating that the local inoculant can make a positive contribution to supporting leaf nutritional status.

Corn plants inoculated with AMF can be easily identified by the presence of internal hyphae (Fig. 1). Internal AMF hyphae in corn roots help corn plants absorb water and nutrients (especially P). The use of mycorrhizae can increase corn plant growth by up to 20% by helping to increase the number of root branches and elongate secondary roots, which contributes to plant resistance to drought (Marya & Ilmiasari, 2025). Furthermore, the presence of internal hyphae in corn roots can also increase corn plant growth. AMF plays a role in increasing the efficiency of plant nutrient absorption, which expands the root absorption area (Waruwu *et al*., 2024).

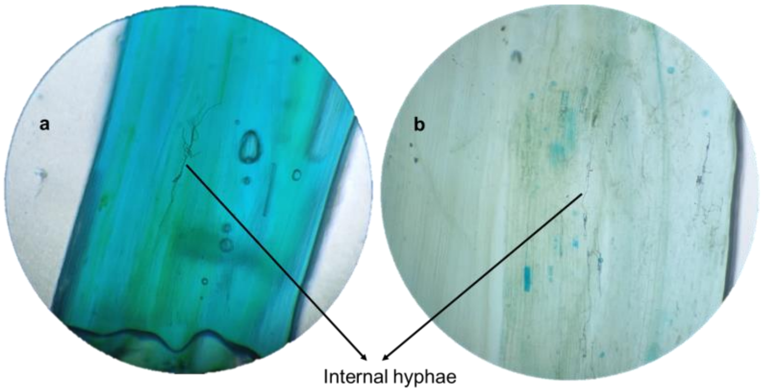

Figure 1. Corn roots infected with mycorrhizal fungi. magnification 10x (a); 40x (b)

CONCLUSION

1. Different inoculant sources influenced early vegetative growth of corn, particularly plant height, leaf number, and stem diameter at 4 WAP.
2. Tidal soil treatment produced the best growth performance during early vegetative stages. Leaf greenness was not significantly affected by inoculant treatments.
3. Growth responses under local AMF propagules and commercial mycorrhizae were relatively lower; however, further studies measuring root colonization quantitatively are needed to explain these responses.

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