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Research Article
Effectiveness of Arbuscular Mycorrhizal Fungi and NPK Fertilizer in Increasing the Production of Sweet Corn Plant

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Abstract

Background and Objective: Sweet corn is a very popular agricultural commodity because of its delicious and sweet taste, so demand is increasing. However, the average sweet corn production obtained by farmers is still low. This study aims to analyze the effectiveness of the application of arbuscular mycorrhizal fungi and NPK fertilization to increase the production of sweet corn. **Materials and Methods:** The experiment was arranged based on the split plot design which consisted of a main plot and subplots and was repeated three times. Application treatment of arbuscular mycorrhizal fungi as the main plot consisting of three doses, namely: Without mycorrhizae, 350 and 700 kg mycorrhizae per ha. The NPK fertilization as child plots consists of three doses: 100, 200 and 300 kg ha^{-1}. This experiment consisted of nine treatment combinations. The plant growth, production components and crop production per hectare was analyzed. **Results:** The experimental results showed that the application of mycorrhiza and NPK fertilization and the interaction between the two significantly affected the growth and increase in the yield of sweet corn. The application of 700 kg mycorrhizal ha^{-1} resulted in 19% greater sweet corn production (19.19 t ha^{-1}) than without mycorrhizal application. The application of 700 kg mycorrhizal+300 kg NPK ha^{-1} increased the available P nutrient availability by up to 51% and total soil P increased by 23% than to without AMF. The application of 350 kg mycorrhizal ha+200 kg NPK ha^{-1} increased the total N nutrient by 19% than to no mycorrhizal application with the same dose of NPK. **Conclusion:** The application of mycorrhizal fungi accompanied by NPK fertilizer increases the availability of nutrients (especially N and P) and ultimately increases the production of sweet corn plants.

Key words: Arbuscular mycorrhizal fungi, fertilization, growth, NPK, production, sweet corn

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sweet corn (*Zea mays saccharata* Sturt.) is one type of corn plant that has a characteristic that is high sugar content, especially sucrose so this corn has a sweet taste[1]. The high sugar content in sweet corn causes this corn to be favored by consumers, so the demand for sweet corn has increased, in Asia, Europe and America. This can be seen from the increasing volume of sweet corn exports from year to year.

Currently, the average production of sweet corn in Indonesia is only 6-8 tons ha^{-1} [2]. While the potential for sweet corn production can reach 18-20 tons ha^{-1}. Therefore, efforts are needed to increase sweet corn production by improving cultivation techniques[3], such as fertilization which aims to provide nutrients for plant growth. Among the nutrients needed by plants, there are three nutrients, namely nitrogen, phosphorus and potassium which are needed by plants in large quantities[4,5] and to meet the availability of these nutrients, it is necessary to add compound fertilizers such as NPK.

The availability of nutrients through the application of inorganic fertilizers such as NPK fertilizer is often problematic because the N element is easily leached, while the element is easily bound by other elements, as well as the limited mobility of the K element. Therefore, to increase the efficiency of the given NPK fertilizer, it needs to be combined with biological fertilizers. Biofertilizers play a role in providing nutrients through the action of nitrogen fixation, dissolving phosphorus and triggering plant growth through the synthesis of plant growth promoters[6]. Furthermore, it was stated by Bhardwaj *et al.*[7] and Kawalekar[8] that the application of beneficial microbes as biofertilizers has become very important in the agricultural sector, because of the ability of biofertilizers to increase sustainable crop production. One type of biological fertilizer that can be used is arbuscular mycorrhizal fungi (AMF).

The AMF is a form of symbiosis between fungi and plants[9]. The presence of mycorrhiza in the root area will help plants increase nutrient uptake, due to the hyphae formed from the association of plants and mycorrhiza[10]. Hyphae threads from mycorrhizae have a wider range because mycorrhizal plant roots can increase the area of the nutrient exploitation zone by up to 20 times[11,12]. Research results Cruz *et al.*[13] and Subaedah *et al.*[14] showed that mycorrhizal applications increased the availability of N and P nutrients and ultimately increased crop yields. The present study aims to analyze the effectiveness of the application of AMF and NPK fertilization to increase the production of sweet corn.

MATERIALS AND METHODS

The research was conducted in Campagaya Village, Galesong District, South Sulawesi, Indonesia, from April to September, 2022. Annual rainfall in the study area ranges from 2300-3100 mm per year with the number of rainy days ranging from 100-180 rainy days per year. The air temperature in the Takalar area is between 21-33°C with a relative humidity level of ±81%. The soil type is alluvial with soil pH 5.1-6.0, soil N-total content of 0.11% and P_2O_5 9.41 ppm.

The materials used in the experiment included: Sweet corn seeds of the Paragon variety, NPK fertilizer, arbuscular mycorrhizal fungi (AMF) and insecticides. The tools used include tractors, hoes, shovels, meters, sliding rulers, scales, ropes, hammers, measuring cups and stationery.

Experimental implementation: This study was structured using a split plot design consisting of a main plot and subplots and was repeated three times. This study was structured using a split plot design consisting of a main plot and subplots. The main plot is the AMF application which consists of three levels, namely:

- M0: Without AMF
- M1: 350 kg AMF ha^{-1}
- M2: 700 kg AMF ha^{-1}

As a subplot is NPK fertilization which consists of three dose levels, namely:

- J1: 100 kg NPK ha^{-1}
- J2: 200 kg NPK ha^{-1}
- J3: 300 kg NPK ha^{-1}

The combination of treatment of the two factors is as follows:

M0J1	M1J1	M2J1
M0J2	M1J2	M2J2
M0J3	M1J3	M2J3

Implementation procedure: The land to be planted is processed first. After that, the land was divided into three groups. Each group was divided into three main plots with a size of 9×4 m each. Each main plot is into 3 sub plots, each measuring 30×4 m. Sweet corn seeds are planted 2 seeds per hole with a spacing of 75×25 cm. Plant maintenance includes watering every three days. The NPK fertilization and application of mycorrhizal biofertilizers were carried out when the plants were 1 week old with the dosage according to the treatment requirements.

Parameters observed: Plant growth (height and the number of leaves), production components and crop production per ha. Analysis of the chemical properties of the soil included the total N content of the soil analysed by the Kjeldahl method, the P total soil was analyzed by the Olsen method and the P available soil was analyzed by the Bray method.

Statistical analysis: Observation data were analyzed using variance analysis based on split plot design with a significance level of 0.05. The results of data analysis that had a real effect were continued with the least significant difference (LSD) test at 0.05.

RESULTS

Height of plant: The results of the analysis of the height of the sweet corn plants showed that the application of mycorrhiza and NPK fertilizer had a significant effect. The plant heights presented in Table 1 show that the application of 350-700 kg AMF ha^{-1} produced significantly taller plants, namely 222.22 cm, compared to the plant heights obtained without mycorrhizal applications with a resulting plant height of 197.22 cm. In the NPK fertilization treatment, it was shown that the application of NPK as much as 300 kg NPK per ha obtained the highest plant, namely 225.56 cm and was significantly different from fertilization with doses of 100 and 200 kg NPK ha^{-1}. The results of this analysis also indicate that the application of mycorrhizae can increase plant height growth by 12.7% compared to that without mycorrhizal application. Likewise, the NPK fertilization treatment showed that an increase in the dose of 300 kg NPK ha^{-1} increased the height growth of sweet corn plants by 9%.

Number of leaves: The results of the observation on the number of leaves presented in Table 2 show that: Application of 700 kg AMF ha^{-1} obtained significantly more sweet corn leaves, namely 12.44 strands compared to the application of 350 kg FMA ha^{-1} and without mycorrhiza with the leaves produced respectively 11.83 and 11.11 strands. While NPK fertilization showed that the application of 300 kg NPK ha^{-1} produced significantly more leaves, namely 12.61 leaves compared to doses of 100 and 200 kg NPK ha^{-1}.

Cob length: The average cob length of sweet corn with the application of arbuscular mycorrhizae presented in Table 3

Table 1: Sweet corn plant height (cm) at the age of 7 WAP with the application of AMF and NPK fertilizer

	NPK (kg ha^{-1})				
AMF	100	200	300	Average	LSD (0.05)
Without AMF	193.33	195.00	203.33	197.22^{b}	16.97
350 kg ha^{-1}	213.33	216.67	236.67	222.22^{a}	
700 kg ha^{-1}	213.33	214.67	236.67	221.56^{a}	
Average	206.67^{b}	208.78^{b}	225.56^{a}		
LSD (0.05)	14.76				

Numbers followed by the same letters in the same row and columns are not significantly different based on the LSD test α = 0.05

Table 2: Number of leaves (sheet) of sweet corn plants at the age of 7 WAP with AMF application and NPK fertilization

	NPK (kg ha^{-1})				
AMF	100	200	300	Average	LSD (0.05)
Without AMF	10.33	11.00	12.00	11.11^{c}	0.59
350 kg ha^{-1}	11.00	11.67	12.83	11.83^{b}	
700 kg ha^{-1}	11.67	12.67	11.78	12.44^{a}	
Average	11.00^{c}	11.78^{b}	12.61^{a}		
LSD (0.05)	0.58				

Numbers followed by the same letters in the same row and columns are not significantly different based on the LSD test α = 0.05

Table 3: Cob length (cm) of sweet corn with AMF application and NPK fertilizer

	NPK (kg ha^{-1})				
AMF	100	200	300	Average	LSD (0.05)
Without AMF	24.80	24.80	24.53	24.71^{b}	1.50
350 kg ha^{-1}	26.67	26.47	25.93	26.36^{a}	
700 kg ha^{-1}	26.60	27.17	26.67	26.81^{a}	
Average	26.02	26.14	25.71		

Numbers followed by the same letters are not significantly different based on the LSD test α = 0.05

Table 4: Cob diameter (mm) sweet corn with AMF application and NPK fertilizer

	NPK (kg ha^{-1})			
AMF	100	200	300	LSD (0.05)
Without AMF	55.67^{bc}	54.73^{c}	61.63^{ab}	6.74
350 kg ha^{-1}	59.68^{bc}	67.27^{a}	60.43^{bc}	
700 kg ha^{-1}	62.27^{ab}	60.40^{bc}	59.47^{bc}	

Numbers followed by the same letters are not significantly different based on the LSD test α = 0.05

Table 5: Cob weight of sweet corn per plant (g) with the application of mycorrhizae and NPK fertilizer

	NPK (kg ha^{-1})				
AMF	100	200	300	Average	LSD (0.05)
Without AMF	351.13	345.67	368.73	355.18^{b}	26.50
350 kg ha^{-1}	361.87	385.40	409.87	385.71^{a}	
700 kg ha^{-1}	377.53	410.00	409.27	398.93^{a}	
Average	363.51^{b}	380.36^{ab}	395.96^{a}		
LSD (0.05)	24.36				

Numbers followed by the same letters in the same row and columns are not significantly different based on the LSD test α = 0.05

Table 6: Sweet corn production (tons ha^{-1}) with the application of mycorrhiza and NPK fertilizer

	NPK (kg ha^{-1})				
AMF	100	200	300	Average	LSD (0.05)
Without AMF	15.34	15.70	15.91	16.02^{b}	1.22
350 kg ha^{-1}	18.11	19.23	19.15	18.83^{a}	
700 kg ha^{-1}	18.66	19.95	18.96	19.19^{a}	
Average	17.37	18.30	18.01		

Numbers followed by the same letters are not significantly different based on the LSD test α = 0.05

shows that the application of 700 kg AMF ha^{-1} resulted in significantly longer cobs, namely 26.811 cm compared to the cob length obtained by treatment without mycorrhizal applications with long cobs resulting 24.71 cm. The NPK fertilization treatment did not significant difference in the cob length of the sweet corn plant.

Cob of diameter: Table 4 shows that the interaction between 350 kg ha^{-1} mycorrhizal application and 200 kg NPK ha^{-1} fertilization resulted in a cob diameter of 67.27 mm, but not significantly different from cob weight resulting from 700 kg ha^{-1} mycorrhizal application and fertilization 100 kg NPK ha^{-1}. While the interaction between without mycorrhiza and 200 kg NPK ha^{-1} fertilization obtained the smallest cob diameter of 54.73 mm. These results also show that the application of 350 kg ha^{-1} mycorrhiza and 200 kg NPK ha^{-1} increased cob diameter by 23% compared to no mycorrhizal application with the same dose of NPK fertilizer.

Cob weight: The weight of sweet corn cobs presented in Table 5 showed that the application of 700 kg AMF ha^{-1} resulted in significantly heavier sweet corn cobs, namely 398.93 g compared to that without AMF application which only produced cobs weighing 355.18 g. In the NPK fertilization treatment, cobs were significantly heavier, namely 395.96 g with an application of 300 kg NPK ha^{-1} compared to 100 kg NPK ha^{-1} fertilization. From this data, it can also be seen that the application of 700 kg AMF ha^{-1} resulted in cobs that were 12% heavier than without mycorrhiza, while 300 kg NPK ha^{-1} increased cob weight by 9%. The results of data analysis also show that the application of 700 kg AMF+200 kg NPK ha^{-1} obtained the highest cob weight, namely 410 g/plant.

Sweet corn production: Sweet corn cob production per ha with AMF application and NPK fertilization presented in Table 6 showed that the AMF application 700 kg ha^{-1} resulted in heavier sweet corn cob production, namely 19.19 tons ha^{-1} compared to the product resulting from treatment without mycorrhizal application, namely 16.02 tons ha^{-1}. This shows that the application of mycorrhizae increased the production of sweet corn by 20% compared to that without mycorrhizae. Table 6 also shows that the application of 700 kg AMF+200 kg NPK ha^{-1} obtained the highest sweet corn production, namely 19.95 tons ha^{-1}.

Soil chemical properties analysis results

Soil P total content: The P total soil content in Fig. 1 illustrated that the application of mycorrhizae (M1 and M2) increased the total P content of the soil compared to that

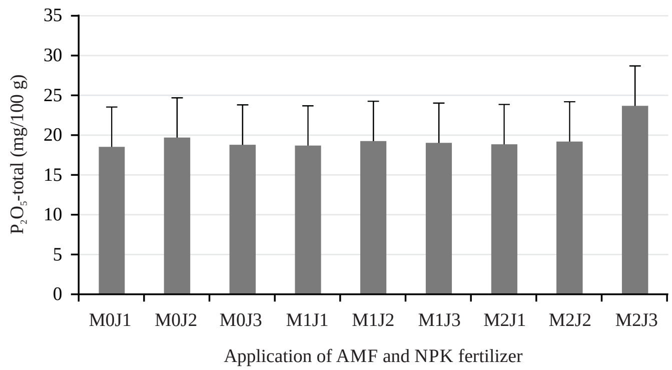

Fig. 1: Soil P total content (mg/100 g) with application of AMF and NPK fertilizer

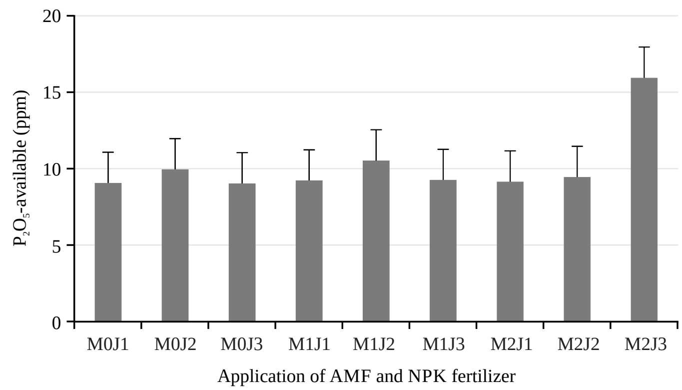

Fig. 2: Soil P available content (ppm) with AMF and NPK fertilizer applications

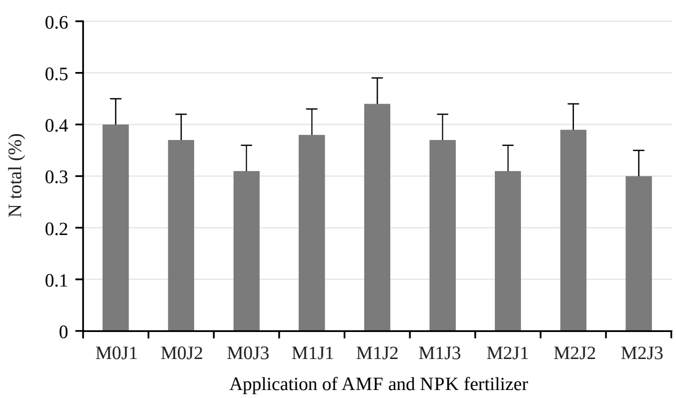

Fig. 3: Soil N total content (%) with the application of AMF and NPK fertilizer

without mycorrhizae (M0). The highest total P content was in the application of 700 kg AMF+300 kg NPK ha^{-1} (M2J3).

Soil P available content: Figure 2 showed that the application of 700 kg ha^{-1} mycorrhiza and 300 kg NPK ha^{-1} fertilization (M2J3) resulted in the highest available P content of 15.92 ppm. These results indicated that the use of 700 kg ha^{-1} AMF increased available P levels up to 51% higher than without mycorrhizal administration accompanied by NPK fertilization at the same dose.

Soil N-total content: The total N-content of the soil in Fig. 3 illustrated that the highest total soil N content was in the application treatment of 350 kg AMF/ha+ 200 kg NPK/ha fertilizer with a total soil N content of 0.44%.

DISCUSSION

The increase in the growth activity of sweet corn plants with the application of mycorrhiza and NPK fertilization is related to the ability of AMF associated with plant roots to form hyphae which will expand the surface of the roots, resulting in increased absorption of nutrients and water by plants. This was stated by Mosse[15] that the association of roots and mycorrhizal fungi will cause an expansion of the root surface due to the hyphae that are formed. Sneha *et al.*[6] suggested that fungal hyphae can increase root length by up to 100 times. This condition allows plant roots to reach deeper areas of the soil, thereby allowing maximum absorption of nutrients and water.

The existence of a wider network of hyphae, causes an increase in the effectiveness of the NPK fertilization given because the absorption of nutrients from the given fertilizer runs optimally. Naher *et al.*[16] suggested that soil penetration by mycorrhizal hyphae can increase the ability of host plant roots to absorb more nutrients and water. The results of this study were in line with the results of research conducted by Pérez and Urcelay[17] which stated that AMF can increase the growth of certain host plants that are compatible with AMF.

The increase in sweet corn production with the application of AMF and NPK fertilization is associated with an increase in the availability of N and P nutrients (Fig. 1-3). This shows that the application of AMF can increase the availability of nutrients from the NPK fertilizer given, resulting in higher plant growth and production. The results of the research by Subaedah *et al.*[18] showed that increased soybean production was associated with increased availability of nutrient P. The study of Rini *et al.*[19] shows that the best dose of NPK fertilizer for oil palm seedlings inoculated with AMF is 500 mg/plant, while without AMF inoculation it is 1000 mg/plant. In other words, the application of AMF reduces the need for compound fertilizer for oil palm seedlings by 50%. While, Cui *et al.*[20] reported that the application of mycorrhiza to wheat increased production by up to 40%. Likewise, the results of Saleh *et al.*[21] and Laila *et al.*[22] reported that the application of mycorrhizae increased shallot production higher than without mycorrhizae. Plants associated with mycorrhizae will have a positive influence on the growth and production of host plants[23,24]. Branching hyphae are formed in the cells of the root cortex and play a role in exchanging nutrients with the host plant, as well as spores which are formed from external hyphae[25].

The results of the analysis of soil total P content and available P presented in Fig. 1 and 2 show that the application of 700 kg ha^{-1} AMF+300 kg NPK ha^{-1} resulted in a 23% higher total soil P-content, available P increased to 51% compared with no FMA application with the same NPK dose. The N total soil parameter (Fig. 3) shows that the application of 350 kg ha^{-1} AMF and 200 kg NPK ha^{-1} resulted in a 19% increase in N total soil compared to no AMF application with the same dose of NPK. This was in line with the findings of Astiko *et al.*[26], who argued that the application of mycorrhizae increased the levels of N, P and K, soil organic matter compared to those without mycorrhizal application. Likewise, the results of a study by Subaedah *et al.*[27] reported that the application of AMF increased available P levels by 30% higher than without mycorrhiza. A study conducted by Barchia *et al.*[28] also found that an increase in the availability of N and P nutrients correlated with an increase in the dose of NPK given and also correlated with plant growth. The increase in the availability of P nutrients with the application of AMF and NPK fertilization is due to the ability of AMF to increase the activity of acid phosphatase in the soil so that P-organic compounds in the soil can become available to plants after being hydrolyzed by phosphatase enzymes[29]. Increasing the availability of nutrients (especially N and P) with the application of mycorrhizae is very meaningful for plant growth because nutrients N and P are macronutrients that are needed by plants in large quantities while their availability is often problematic.

CONCLUSION

The AMF application resulted in better sweet corn plant growth and increased production up to 19% (19.19 tons ha^{-1}) compared to without AMF application. The fertilization of 300 kg NPK ha^{-1} resulted in better growth and production of sweet corn as shown by taller plants, more leaves and heavier cob weight. The application of 350 kg AMF per ha with fertilization of 200 kg NPK per ha increased the availability of N total nutrients by 19% compared to no application of AMF with the same dose of NPK and obtained a larger corn cob diameter. Meanwhile, the application of 700 kg AMF per ha accompanied by fertilization with 300 kg NPK per ha increased the availability of P available nutrients by 51% higher than without AMF with the same dose of NPK fertilizer.

SIGNIFICANCE STATEMENT

This research aims to analyze the effectiveness of AMF applied with NPK fertilizer in increasing sweet corn production. Application of AMF accompanied by NPK fertilizer. Increased nutrient availability, especially N and P, so that it effectively increased sweet corn production. Therefore, using AMF plays an important role in environmentally friendly nutrient management and can potentially complement chemical fertilizers in ensuring agriculture sustainability.

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