Ilmu Pertanian (Agricultural Science)

http://journal.ugm.ac.id/jip

Vol. 5 No. 2 August, 2020: 76–85| DOI: doi.org/10.22146/ipas.47535

NPK uptake and growth of maize on ombrogenous peat as affected by the application of mycorrhizal fungal multi-spores and compound fertilizers

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Received: 11th July 2019; **Revised**: 10th March 2020; **Accepted**: 17th March 2020

Keywords:
Dolomite fertilizer, hemic, inorganic fertilizer, mychorrizal population, root infection

ABSTRACT

This study investigated the effectiveness of mycorrhizal fungal multi-spores and inorganic fertilizers in increasing NPK uptake and growth of maize on ombrogenous peat soils in Riau. The experiment, which was carried out in a plastic house, was arranged in a completely randomized design (CRD) with two factors, consisting of five replications. The first factor was the application of mycorrhizal fungal multi-spores, consisting of two levels (with and without application). The second factor was the application of inorganic fertilizer, consisting of three levels (P0: without fertilizer, PM-1: mixture of 225 kg Urea + 100 kg SP-36 + 75 kg KCl + 1000 kg Dolomite, and PM-2: Mixture of 450 kg Urea + 200 kg SP-36 + 150 kg KCl + 2000 kg Dolomite). Observed data consisted of agronomic observations, soil observations, and mycorrhiza observations. Agronomic observations consisted of plant height, root dry weight, shoot dry weight, and N, P, K nutrient uptake, and soil observations consisted of total and available N, P, K nutrients in the soil. Meanwhile, mycorrhiza observations consisted of infected roots and spore populations. The data obtained were then analyzed using DMRT α=5% to see the significant effect of the treatments. There was no interaction effect of mycorrhiza and compound fertilizer on the variables of shoot and root dry weight, but the interaction effect was observed on the variables of of shoot N, P, K uptake and root P and K uptake.

INTRODUCTION

Agriculture on peatlands is always carried out by providing very high inputs although there is no guarantee for the effectiveness of fertilization on peatlands. High input from inorganic fertilization will cause peat to degrade rapidly. Crop cultivation on degraded peatlands may have high productivity potential. One type of food crops that can be developed on ombrogenic peatlands is maize.

Conventional maize cultivation on peatlands is usually carried out with high input that is impossible to maintain. Besides, drying is also needed so that the peat supports the growth of the maize plant because maize cannot grow optimally in high humidity conditions. Such cultivation activities accelerate the rate of degradation of peatlands. To overcome this problem and to improve maize productivity and peatland sustainability, the existing conventional planting methods need to be changed.

Peatland cultivation must maintain the original state of peatlands by maintaining peatland moisture to remain hydrophilic. In principle, it is not that maize is unable to live in high humid conditions, but its roots cannot modify their morphology during anaerobic conditions like rice plants do. Mycorrhizal application can be an alternative because mycorrhizal hyphae can modify maize roots to be able to grow in a water saturated state. Research studies that have been carried out show the ability of indigenous mycorrhizae to increase nutrient uptake and plant growth on peatlands.

According to Sasli and Ruliansyah (2012), the use of native mycorrhizal fungi originating from specific location from different inoculum host plants can increase the growth of maize on peatlands, Kinany et al. (2019) also prove that the use of commercial non-indigenous mycorrhiza also indicates that mycorrhizal inoculation combined with compost amendment clearly reinforces growth performance of date palm, including dry and fresh biomass, the number of roots and leaves, and total mineral content. Therefore, this study attempted to use commercial mycorrhiza not from peat soil inoculums, but from acid mineral soils.

The selection and propagation of native mycorrhizae is impossible for farmers, considering the time, cost, and knowledge. Mycorrhizae in the form of commercial fertilizer packages are widely available in the market and are easier to obtain by farmers. This study aimed to determine the effects of the application of mycorrhizal fungal multi-spores from acid mineral soil inoculums and compound fertilizers (a mixture of NPK and dolomite) on the nutrient uptake and growth of maize on ombrogenic peat and to find out the effectiveness of non-indegeneous mycorrhiza in increasing the growth of maize plants.

MATERIALS AND METHODS

This research was conducted from September to December 2017. The origin of mycorrhizal multi-spores inoculants used was from acid mineral soil (not peat). Spore identification, infectivity test, and spore population were carried out at the Soil Microbiology Laboratory of the Faculty of Agriculture, Universitas Gadjah Mada. Mycorrhizal biofertilizer application test was carried out in the ombrogenic peatlands of Pelalawan District, Riau. The study consisted of four stages, namely (1) identification of spores (arbuscular mycorrhiza), consisting of (a) arbuscular mycorrhizal spore population; (b) identification of mycorrhizal types; and (c) infective propagule test, (2) the test of arbuscular mycorrhizal application test on maize plants in peatland, (3) arbuscular mycorrhizal application carried out to test the effectiveness of arbuscular mycorrhizae as biofertilizer. The experiment was arranged in a completely random design with two factors. The first factor, mycorrhizae, consisted of two levels, namely M0 (without mycorrhizae) and M1 (mycorrhizae as biological fertilizer). The second factor, dose of basic fertilizer, consisted of three levels, namely P0 (without fertilizer), PM-1 (mixture of 225 kg Urea + 100 kg SP-36 + 75 kg KCl + 1000 kg Dolomite), and PM-2 (mixture of 450 kg Urea + 200 kg SP-36 + 150 kg KCl + 2000 kg Dolomite). There were five replications within each treatment, thereby resulting in six treatment combinations and 30 experimental units. Observations were made on the characteristic variables of soil, agronomy, and mycorrhizae.

The seeds of maize cultivar Bonanza F1 were coated with mycorrhizae: biological fertilizer with a ratio of 20 kg:100 g. The maize seeds were coated by moistening them with water first, and then the seeds were drained briefly and mixed evenly. The seeds were planted no later than six hours after the mixing process. The seeds were planted in a planting hole as deep as 5 cm with two seeds per planting hole and one week after planting only one plant was left in each planting hole.

The observations of the plant growth were made on variables of plant height (three times: 15, 30, and 45 days after planting). Meanwhile, the observations of maximum vegetative growth (post-harvest) were made on variables of shoot dry weight, root dry weight, percentage of roots infected by mycorrhizal fungi, and NPK uptake by shoot and root. Tissue analysis was performed on total N, available N and N in tissue (Kjeldahl), total P in tissue (spectrophotometer), total K (wet destruction), base saturation, and Cation Exchange Capacity (CEC) (NH_4Oac pH7). Tissue analysis was carried out with a wet decomposition of concentrated $HClO_4$ + HNO_3 mixture.

Soil observations were carried out three times, namely preliminary soil observations to determine the nature of soil before being treated, post-incubation soil observations at 30 days after dolomite application to determine soil response to dolomite administration, and post-harvest observations to determine total nutrient content and available after cultivation. Before and after treatment, the observations were performed on pH-H_2O (1: 2.5), organic C (Combustion), total N, available N and N in soil (Kjeldahl), total P in the soil (spectrophotometer), available P (Bray I), total K (wet destruction), base saturation and cation exchange capacity (CEC) (NH_4Oac pH7). Peat soil analysis has the same method as the tissue analysis method because peat soil is originated from plant tissue.

The amount of nutrient uptake of N, P, and K was obtained by multiplying the nutrient levels in the organ of the plant by the biomass weight. Meanwhile, the values of agronomic effectiveness (EA) and nutrient uptake (ES) were calculated by the following equation:

EA= (Gf–Gu)/Na..................(Fageria et al., 2005).

Remarks: Gf: Yield with treatment per plot (Kg); Gu: Yield without treatment per plot (Kg); Na: Amount of nutrients applied (Kg).

ES= (SN–SK/HN) x 100%......(Fageria et al., 2005).

SN: Nutrient uptake with fertilizer treatment; SK: Nutrient uptake without fertilizer treatment; HN: Total fertilizer applied. Analysis of variance (ANOVA) at α=5% was performed to determine the effect of treatments on the soil and plant. DMRT analysis at α=5% was done to define the differences between the treatments.

RESULTS AND DISCUSSIONS

Chemical properties of ombrogenous peat soil

Ombrogenous peat with humic maturity level, which is not thick and influenced by river mud, generally has moderate (mesotrophic) fertility. The properties of ombrogenic peat used before treatment were presented in Table 1. Table 1 showed that the pH of the peat soil used was included in the very acidic criteria. Peat soil consists of reactive groups, such as carboxylic (-COOH) and phenolics (C_6H_4OH), that dominate the exchange complex and are weak acids so that they can dissociate and become sources of H^+ ions and continue to produce large quantities of H^+ ions (Tan, 1988).

The high H-ion produced will also affect the CEC of peat soils because the negative charge (which determines the CEC) on the entire peat soil is a pH dependent charge, in which the CEC will increase if the peat pH is increased. The negative charge formed is the result of hydroxyl dissociation in carboxylic or phenol groups. Therefore, CEC determination using acetate ammonium extract (at pH 7) will produce a high CEC value. Meanwhile, CEC determination using ammonium chloride extractor (at actual pH) will result in a lower value. High CEC shows high sorption capacity yet weak sorption power so that K, Ca, Mg, and Na cations that do not form coordination bonds will be easily washed out (Agus and Subiksa, 2008).

Organic C content in peatlands is always high. It is because the composition of the parent material of peat soil is organic matter, thus the organic C content is high, resulting in a high total N and C/N ratio. If the C/N ratio is high, N is not available to plants because N is present in peat soils as complex organic matter, meaning that N is a component of peat organic matter, therefore, not available to plants.

The total P and available P were classified as medium and high. It is because total P is in the form

Table 1. Chemical properties of the soil

Chemical properties	Value	Characteristics
pH H_2O	4.58	Very acidic
pH KCl	3.92	Very acidic
Organic C (%)	31.20	Very high
Total N (%)	0.94	Very high
C/N	33.19	Very high
Total P (%)	8.30	Medium
Total K (%)	34.80	Medium
P-Bray I (ppm)	24.30	Medium
Ca-exc (Cmol. kg^{-1})	1.80	Very low
Mg-exc (Cmol. kg^{-1})	0.54	Low
K-exc (Cmol. kg^{-1})	0.32	Medium
CEC	102.80	Very high

Remarks: Values were based on the properties of peat soil (Subagyo, 2006).

of organic P and as a component material of peat. The available P is high due to the high content of organic matter, which is the peat itself and organic matter from previous cultivation. Tidal influences can also increase the availability of P in inorganic form through several reactions resulting in a high value of available P. Besides, the peat soil used is humic, meaning that some of the organic matters have been decomposed and mineralized so that the P element is released. The value of available P was classified as moderate because there was fertilizer input given by the farmer at the research location.

Effects of incubation

pH is a basic chemical property that is important to know because it can affect other soil chemical properties. The results of the analysis showed that the administration of mycorrhizal fungi and inorganic fertilizers gave a significant interaction effect on soil pH after incubation. The combination of M1 and PM2 treatments was the best treatment, with a soil pH of 5.7 (Table 2). The highest increase in soil pH was only 1. PM2 treatment with dolomite fertilizer application at a dose of 2 ton.ha^{-1} will provide alkaline cations of CaO and MgO into the soil with a high amount so that the soil pH increases because the acid cation (H^+) will be replaced by Ca cations and Mg in the sorption complex.

The presence of mycorrhizal fungi can increase soil pH and improve soil fertility. It is because mycorrhizal metabolic activities that produce and release organic compounds playing a role in binding the cations cause acidity of the soil. In accordance with the opinion of Tan (1998), organic compounds are able to bind cations in the soil sorption complex, leading to a high concentration of base saturation.

Infectivity of mycorrhizae

Maize plants are natural host plants of mycorrhizae because maize plants have characteristics that are suitable for the development of mycorrhizal spores to reach the optimum point of spore development and spread. Mycorrhiza requires host plants that can grow well and are in accordance with mycorrhizal spores, including mycotrophic properties, can adapt to climatic conditions and growing media, and are resistant to drought. Host plants must also have a spread of roots and lots (Talanca, 2010).

Table 3 showed that there was no interaction effect of mycorrhizae and fertilizer doses on the percentage

Table 2. Analysis of pH (H_2O) of peat soils in each treatment after incubation

Mycorrhizae	Fertilizer			Average
	P0	PM1	PM2	
M0	4.56 c	4.93 b	5.37 ab	4.95
M1	4.73 bc	5.37 ab	5.7 a	5.268
Average	4.64	5.15	5.54	(+)

Remarks: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 kg.ha^{-1} + SP36 200 kg.ha^{-1} + KCl 150 kg.ha^{-1} + dolomite 2000 kg.ha^{-1} and PM2: Urea 225 kg.ha^{-1} + SP36 100 kg.ha^{-1} + KCl 75 kg.ha^{-1} + dolomite 1000 kg.ha^{-1}; Means followed by the same letters in the same row and column were not significantly different according to DMRT at α=5%. (+): significant interaction effect.

Table 3. Effects of mycorrhizae and inorganic fertilizer doses on the infected root (%)

Mycorrhizae	Fertilizer			Average
	P0	PM1	PM2	
M0	1.33	5.33	6.67	4.44 b
M1	33.33	46.67	62.67	47.56 a
Average	17.33 ns	26.00 ns	34.67 ns	(-)

Remarks: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 kg.ha^{-1} + SP36 200 kg.ha^{-1} + KCl 150 kg.ha^{-1} + dolomite 2000 kg.ha^{-1} and PM2: Urea 225 kg.ha^{-1} + SP36 100 kg.ha^{-1} + KCl 75 kg.ha^{-1} + dolomite 1000 kg.ha^{-1}; Means followed by the same letters in the same row and column are not significantly different according to DMRT at α=5%. (-): no significant interaction effect; (ns): no significant effect.

of infected roots. The percentage of infected roots was significantly affected by mycorrhizae treatment alone. The results of further tests showed that M1 treatment gave a significantly higher percentage of infected roots compared to M0.

The fertilizer doses did not have a significant effect on the percentage of infected roots. However, infection also occurred in M0 treatment. Infection occurring in M0 treatment wass presumably caused by mycorrhizal fungi originating from local soil (indigenous). This is in accordance with the results of the study of Sasli and Ruliansyah (2012), who concluded that mycorrhizal originating from plant rhizosphere or cultivated plants in the field can directly infect plant roots that are being cultivated as host plants so that the mycorrhizae can be propagated naturally in maize plants without trapping or propagation.

Shoot and root dry weight

Plants, during their lifetime, produce biomass that is used to form organs occurring along with the age of the plant. Biomass produced by plants is strongly influenced by vegetative growth. The better the vegetative growth, the greater the biomass produced.

Table 4 showed that there was no interaction effect of mycorrhizae and fertilizer on the shoot and root dry weight. However, the shoot and root dry weight were significantly affected by mycorrhizae treatment and fertilizer doses, separately.

The significant effect of mycorrhizae and fertilizer doses was due to the absorption of water and nutrients by mycorrhizae and nutrient supply from given fertilizer. Water plays an important role in the photosynthesis process so that the ability of plants to store water will affect the dry weight of plants. Plants with good vegetative growth will have a high fresh weight followed by a low water content resulting in high dry weight.

NPK nutrient uptake by shoot and root

N uptake by mycorrhizae is associated with extraradical mycorrhizal hyphae activity that absorbs NH4+, NO3-, and amino acids through the transport and proton ATPase pump possessed by hyphae. N in peat soil is generally in the form of organic N, which is dominated by amino acids or proteins. The presence of mycorrhizae will be able to provide and absorb N for plants cultivated on peat material. Application of N fertilization will increase the percentage of N dissolved in the soil, thereby making it available to plants in the form of NH^{4+} and NO^{3-}. In plants with mycorrhizae, NH^{4+} and NO^{3-} are assimilated into arginine at the ends of hyphae and transferred to plants and possibly transferred as NH3 at the plant-mycorrhizae interface, and then NH_3 can be absorbed directly by the roosts (Smith and Smith, 2011).

There was no interaction effect of mycorrhizae and fertilizer doses on the nitrogen uptake in shoot. However, the treatment of mycorrhizae alone had a very significant effect on the N uptake in the shoot as seen in Table 5, which showed that the combination treatment of M1P0 has the same average value as M0PM2. Table 5 showed that there was no interaction effect of mycorrhizae and fertilizer doses on the

Table 4. Effects of mycorrhizal fungal multi-spores and inorganic fertilizer doses on the shoot and root dry weight (g)

Parameter	Mycorrhizae	Fertilizer			Average
		P0	PM1	PM2	
Shoot dry weight	M0	1.57	3.00	4.06	2.88 b
	M1	5.75	7.14	8.24	7.04 a
	Average	3.66 c	5.07 b	6.15 a	(-)
Root dry weight	M0	0.58	1.44	1.66	1.23 b
	M1	1.47	2.25	2.58	2.10 a
	Average	1.02 c	1.85 b	2.12 a	(-)

Remarks: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 $kg.ha^{-1}$ + SP36 200 $kg.ha^{-1}$ + KCl 150 $kg.ha^{-1}$ + dolomite 2000 $kg.ha^{-1}$ and PM2: Urea 225 $kg.ha^{-1}$ + SP36 100 $kg.ha^{-1}$ + KCl 75 $kg.ha^{-1}$ + dolomite 1000 $kg.ha^{-1}$; Means followed by the same letters in the same row and column were not significantly different according to DMRT at α=5%. (-): no significant interaction effect.

Table 5. Effects of mycorrhizal fungal multi-spores and inorganic fertilizer doses on the shoot and root dry weight (g)

Parameter	Mycorrhizae	Fertilizer			Average
		P0	PM1	PM2	
Shoot N uptake	M0	0.74 f	4.36 e	7.14 cd	4.08
	M1	6.93 d	9.92 b	15.98 a	10.94
	Average	3.84	7.14	11.56	(+)
Root N uptake	M0	0.12	0.57	0.92	0.54 b
	M1	1.12	1.73	2.50	1.78 a
	Average	0.62 c	1.15 b	1.71 a	(-)
Shoot P uptake	M0	0.15 f	0.36 de	0.59 d	0.37
	M1	1.36 bc	1.77 b	4.46 a	2.53
	Average	0.75	1.06	2.53	(+)
Root P uptake	M0	0.09 f	0.21 e	0.30 d	0.20
	M1	0.63 c	0.88 b	1.88 a	1.13
	Average	0.36	0.55	1.09	(+)
Shoot K uptake	M0	0.14 f	0.37 e	0.61 d	0.37
	M1	1.99 c	3.01 b	5.88 a	3.63
	Average	1.07	1.69	3.24	(+)
Root K uptake	M0	0.05 f	0.15 e	0.29 cd	0.16
	M1	0.30 cd	0.61 b	0.90 a	0.60
	Average	0.18	0.38	0.60	(+)

Remarks: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 $kg.ha^{-1}$ + SP36 200 $kg.ha^{-1}$ + KCl 150 $kg.ha^{-1}$ + dolomite 2000 $kg.ha^{-1}$ and PM2: Urea 225 $kg.ha^{-1}$ + SP36 100 $kg.ha^{-1}$ + KCl 75 $kg.ha^{-1}$ + dolomite 1000 $kg.ha^{-1}$; Means followed by the same letters in the same row and column were not significantly different according to DMRT at α=5%. (-): no significant interaction effect; (ns): no significant effect.

root N uptake. However, each treatment showed a significant effect independently. Mycorrhizae treatment showed a greater effect on root N uptake compared to fertilizer doses treatment.

Maize plants, in their vegetative phase, need more nitrogen (N) for the formation of vegetative parts. The highest N ratio in the plant tissues is in the leaves and stems forming carbohydrates, while the roots function to absorb nutrients and water for carbohydrate-forming ingredients. This is in accordance with by Wen et al. (2018) that N was accumulated in the leaves of maize plants in the vegetative period. The P element given is only able to be absorbed by 20% (Hagin and Tucker, 1982). There was a significant interaction effect of mycorrhizae and fertilizer doses on the P uptake in the root. The highest value of 0.55 was observed in plants treated with mycorrhizae and PM2 fertilizer dose, while the other treatments showed low P levels below critical nutrient sufficiency P (0.30–0.60).

The uptake of the P element is based on the movement of three types of ion movements, namely interception, mass flow, and diffusion. The presence of mycorrhizae is capable of supporting the movement of P ions in these three ways. An interception occurs with the distribution of hyphae, which extends root absorption. The wider the absorption of roots, the greater the potential to absorb water so that water-soluble P ions will be absorbed (mass flow). Besides, the presence of mycorrhizae will also stimulate host plants to produce exudates that invite other microorganisms in the roots area resulting in many enzymatic reactions that cause the concentration of the solution in the root area to be higher. Consequently, the surrounding soil solution flows to higher concentrations, which is in the area of the mycorrhizal root (diffusion).

The treatment of fertilizer alone without the administration of mycorrhizae still increased P uptake, along with the increasing of the doses. The highest P uptake was observed in plants with PM2 fertilizer at a dose of 0.59 mg per plant and increased to 4.46 mg per plant when followed by mycorrhizae administration.

According to Table 5, there was interaction effect on the K uptake in the shoot and root. Mycorrhizae treatment alone showed significantly different values between K uptake in the shoot and in the root. Meanwhile, the treatment of fertilizer doses had a significant effect on the K uptake in the shoot and root showing values, which were increasing with the increasing dose. The highest K uptake in the shoot and root was observed in the combination treatment of M1PM2. In the K nutrient uptake, hyphae from mycorrhizae act as a bio processor or a living pipe that can absorb water, while 90% of K ions are absorbed by plants by mass flow. K ions dissolved in water are absorbed by mycorrhizal hyphae.

Effectiveness of mycorrhizae and compound fertilizer in increasing dry weight and nutrient uptake of maize plants (%)

The productivity of maize on peat land, which is not optimal was caused by low fertilization efficiency (Table 6). Agronomic efficiency is one of five ways to determine the efficiency of fertilizer applied.

The application of balanced fertilizer is one way to improve fertilizer efficiency. This is because, in balanced fertilization, biological fertilizers are also given in addition to N, P, and K fertilizers. It can increase the availability of N, P, K, and soil fertility so that the fertilization given will be more efficient. The effectiveness of nutrient uptake is the ratio between nutrients that can be absorbed by plants and the nutrients given. The more nutrients that can be absorbed from the given fertilizer, the greater the efficiency of the nutrient uptake (Peñuelas et al., 2013).

The purpose of calculating the efficiency of nutrient uptake is to determine the percentage of fertilizer absorbed by plants from the amount of fertilizer given. Table 7 showed that a higher percentage of the effectiveness of N, P, and K was observed in the treatment combination of M1 and PM1. This is in accordance with Willmann et al. (2013), stating that maize plants with mycorrhizae will be more effective in absorbing P elements with low availability.

Nutrient availability after harvest (maximum vegetative growth)

N availability in peat soils for plants is relatively low because N in peat soil is available in the form of organic N (Hartatik et al., 2011). Nitrogen in peat soil is difficult to be absorbed by plants because N is used by microorganisms in the decomposition of organic matter contained in the peat soil. Radjagukguk (2001) states that total nitrogen content in peat soils is generally high, but N will only be available after drainage and mineralization. Meanwhile, in peat soils that are inundated, existing nitrogen will be used to decompose the peat material by microorganisms so that it is not available.

Available N levels in the soil can be decreased because nitrogen in the soil is bound by clay minerals in the form of NH^{4+}. N loss in the soil is caused by N being converted to NH^{4+} absorbed by adsorbing NH^{4+}so that NH^{4+} (ammonium) is difficult to change into NO^{3-} (nitrate). The adsorbed ammonium will be released slowly through cation exchange.

Table 6. Effects of mycorrhizal fungal multi-spores and inorganic fertilizer doses on the agronomic effectiveness of plants dry weight (g.g^{-1} per plant)

Treatments		AE N		AE P		AE K	
Mycorrhizae	Fertilizer	Shoot	Root	Shoot	Root	Shoot	Root
M0	P0	0	0	0	0	0	0
	PM1	0.45	0.28	1.02	0.62	1.36	0.83
	PM2	0.39	0.17	0.89	0.39	1.18	0.52
M1	P0	0.66	0.89	1.49	0.32	1.99	0.42
	PM1	1.77	0.53	3.98	1.19	5.30	1.59
	PM2	1.06	0.32	2.38	0.72	3.17	0.95

Remark: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 kg.ha^{-1} + SP36 200 kg.ha^{-1} + KCl 150 kg.ha^{-1} + dolomite 2000 kg.ha^{-1} and PM2: Urea 225 kg.ha^{-1} + SP36 100 kg.ha^{-1} + KCl 75 kg.ha^{-1} + dolomite 1000 kg.ha^{-1}; AE: Agronomic efficeiency

Table 7. Effects of mycorrhizal fungal multi-spores and inorganic fertilizer doses on the effectiveness of NPK uptake (%).

Treatments		N uptake efficiency		P uptake efficiency		K uptake efficiency	
Mycorrhizae	Fertilizer	Shoot	Root	Shoot	Root	Shoot	Root
M0	P0	0	0	0	0	0	0
	PM1	13.85	1.81	2.56	1.48	3.57	1.46
	PM2	11.33	1.46	2.12	1.06	2.89	1.38
M1	P0	9.82	1.58	4.30	1.92	8.81	1.21
	PM1	31.49	5.49	12.63	6.31	28.67	5.79
	PM2	25.37	3.97	15.92	6.71	28.00	4.28

Remark: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 kg.ha^{-1} + SP36 200 kg.ha^{-1} + KCl 150 kg.ha^{-1} + dolomite 2000 kg.ha^{-1} and PM2: Urea 225 kg.ha^{-1} + SP36 100 kg.ha^{-1} + KCl 75 kg.ha^{-1} + dolomite 1000 kg.ha^{-1}

Table 8. Effects of mycorrhizal fungal multi-spores and inorganic fertilizer doses on the N, P, and K available in the soil (mg per plant)

Parameter	Mycorrhizae	Fertilizer			Average
		P0	PM1	PM2	
NH^{4+}	M0	12.95 e	36.86d	50.19 c	33.33
	M1	35.40 d	67.57b	78.27 a	60.41
	Average	24.17	52.21	64.23	(+)
NO^{3-}	M0	64.98 cd	69.70 bc	65.84 cd	66.84
	M1	43.54 e	72.10 a	70.14 ab	61.93
	Average	54.26	70.9	67.99	(+)
P_2O_5	M0	5.89	7.79	10.07	7.92 b
	M1	7.66	10.12	10.51	9.43 a
	Average	6.78^{ns}	8.95^{ns}	10.29^{ns}	(-)
K_2O	M0	0.07	0.10	0.14	0.10^{ns}
	M1	0.08	0.09	0.12	0.10^{ns}
	Average	0.08^{ns}	0.10^{ns}	0.13^{ns}	(-)

Remark: M0: without mycorrhizae, M1: with mycorrhizae, P0: without fertilizer, PM1: Urea 450 kg.ha^{-1} + SP36 200 kg.ha^{-1} + KCl 150 kg.ha^{-1} + dolomite 2000 kg.ha^{-1} and PM2: Urea 225 kg.ha^{-1} + SP36 100 kg.ha^{-1} + KCl 75 kg.ha^{-1} + dolomite 1000 kg.ha^{-1}; Means followed by the same letters in the same row and column were not significantly different according to DMRT at α=5%. (+): significant interaction effect; (–): no significant interaction effect

Based on Table 8, there was an interaction effect of mycorrhizae and fertilizer doses on available N levels in peat soil. The addition of N through fertilization will increase the availability of N and the presence of mycorrhizae will attract other microorganisms that may utilize available N. N loss from the soil can be caused by some things, such as the N use by plants or microorganisms (Jacoby et al., 2017), leaching, binding with clay minerals, and denitrification processes. The organic N added to peat soil causes a decrease in inorganic N when compared to soil without the addition of organic matter. There are three main forms of N in the soil, namely organic N, NH^{4+}, and NO^{3-}. NH^{4+} ions are more stable in the soil when compared with NO^{3-} because they can be bonded in the adsorption site both in organic and inorganic clay, thus NH^{4+} is maintained in the soil.

When P is not available, mycorrhizae will process the mineralization of organic matter. Organic P compounds are broken down into inorganic forms available to plants with the help of phosphatase enzymes produced by mycorrhizae. This is accordance with Willmann et al. (2013), mentioning that maize with mycorrhizae will be more effective in absorbing P elements with low availability. Biological phosphate dissolution occurs because these microorganisms produce enzymes, including phosphatase enzymes and phytase enzymes. Phosphatase is an enzyme that will be produced if phosphate availability is low. Phosphatase is excreted by plant roots and micro-organisms, both of which microorganisms are more dominant in producing phosphate (Smith et al., 2011).

K is very easily lost from the soil due to leaching and the influence of temperature, which causes K to be absorbed. Desorption of K occurs when the soil temperature is high. High soil temperatures will also cause evapotranspiration, causing water-soluble K to evaporate with water in the process of evapo-transpiration, resulting in K lost (Hundal and Pasricha, 1998). The presence of mycorrhizae that can absorb water plays a role in maintaining plant temperature. In addition, the presence of mycorrhizae in root areas will maintain soil moisture, controlling soil temperature. Therefore, K elements are not desorbed and available to plants.

CONCLUSIONS

The application of non-indigenous commercial mycorrhizal multi-spores strengthened the growth of maize plants, including dry and fresh biomass, macronutrients content and uptake, and absorption effectiveness. Nutrient uptake increased to 31.49% for N, 12.63% for P, and 28.67% for K. N was available in the best NO^{3-} form at treatment of 225 kg Urea + 100 kg SP-36 + 75 kg KCl + 1000 kg Dolomite, while N was available in the best NH^{4+} form at treatment of 450 kg Urea + 200 kg SP-36 + 150 kg KCl + 2000 kg Dolomite.

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