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Enhancement of Eggplant Production in Intercropping Systems through Integrated Nutrient Management

Moch. Dawam Maghfoer[1,*], Mahayu Woro Lestari[2]

[1] Faculty of Agriculture, Universitas Brawijaya Malang, East Java, Indonesia

[2] Faculty of Agriculture, Universitas Islam Malang, East Java, Indonesia

Abstract: This research aimed to increase eggplant production in intercropping systems. Therefore, integrated nutrient management was carried out in Poncokusumo, Malang, from April to October 2018. It was conducted using a factorial randomized block design with two factors and three replications. The first factor was various doses of goat manure, which consisted of 3 levels, namely, 10, 20, and 30 tons ha^{-1}. Meanwhile, the second was microbial concentration and consisted of 7 levels, namely, without microbes as control, and 10, 20, 30 ml L^{-1} EM4, and ml l^{-1} PGPR (Plant Growth Promoting Rhizobacteria), respectively. The results showed no significant interaction between the doses of goat manure and microbial concentration on the growth and yield of the eggplants. Furthermore, the manure application at doses of 20 and 30 t ha^{-1} increased the production of the plant's fruits to 60.33 and 64.83 t ha^{-1}, respectively. While the use of EM4 and PGPR at concentrations of 20 and 30 ml L^{-1} led to the production at 63.16, 68.39, 61.57, and 64.61 t ha^{-1}. The results also showed that goat manure and microbes in the intercropping system of eggplant, curly lettuce, and chickpeas increased land productivity. Furthermore, treatment with the manure at doses of 20 and 30 tons ha^{-1} had the same land equivalent ratio (LER) of 2.20. Finally, applications of 10, 20, and 30 ml of L^{-1} EM4 let to LER values of 2.14, 2.20, and 2.29, respectively, while PGPR at concentrations of 20 and 30 ml L^{-1} let to the values of 2,16 and 2.20.

Keywords: eggplant, nutrient management, goat manure, microbes.

通过综合营养管理提高间作系统中茄子的产量

摘要：该研究旨在提高间作系统中茄子的产量。因此，综合养分管理于 2018 年 4 月至10月在玛琅柚木进行。采用因子随机区组设计，具有两个因素和三个重复。第一个因素是不同剂量的山羊粪，包括3个水平，即10、20和30吨公顷$^{-1}$。同时，第二个是微生物浓度，由7个级别组成，即没有微生物作为对照，分别为10、20、30毫升升$^{-1}$有效微生物4和毫升升$^{-1}$植物生长促进根际细菌。结果表明，山羊粪的剂量和微生物浓度之间对茄子的生长和产量没有显着的相互作用。此外，以 20 和 30 t公顷$^{-1}$ 的剂量施肥使植物的果实产量分别增加到 60.33 和 64.83吨公顷$^{-1}$。虽然使用浓度为 20 和 30毫升升$^{-1}$ 的有效微生物 4 和促进植物生长的根际细菌导致产量为63.16、68.39、61.57和64.61t公顷$^{-1}$。结果还表明，茄子、卷心莴苣和鹰嘴豆间作系统中的山羊粪便和微生物提高了土地生产力。此外，用 20 吨和 30 吨公顷-1 的粪便处理具有相同的土地当量比 2.20。最后，应用 10、20 和 30毫升升$^{-1}$ 有效微生物 4 分别使土地当量比值达到 2.14、2.20 和 2.29，而促进植物生长的根际细菌在浓度为 20 和 30 毫升升$^{-1}$ 时达到 2,16和 2.20。

关键词：茄子，养分管理，山羊粪，微生物。

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About the authors: Moch. Dawam Maghfoer, Faculty of Agriculture, Universitas Brawijaya Malang, East Java, Indonesia; Mahayu Woro Lestari, Faculty of Agriculture, Universitas Islam Malang, East Java, Indonesia

Corresponding author Moch. Dawam Maghfoer, mdm-fp@ub.ac.id

1. Introduction

Eggplant is a vegetable with good prospects to be developed and can improve nutrition, food security, promote rural development, and support sustainable land management [1]. Furthermore, this vegetable has a nutritional value comparable with other vegetable crops. Therefore, it is necessary to improve its production [2].

Enhancement of eggplant production faces many challenges. They include depreciation of agricultural land, global environmental change, a decline in soil fertility, climate change leading to drought, and environmental pollution [3]. Meanwhile, the increased use of inorganic fertilizers, including herbicides and pesticides, monoculture or crop rotation practices, and the utilization of available resources in intensive farming systems is a threat to ecosystem sustainability [4]. Therefore a system is needed to integrate various practices of soil fertility maintenance. This system is the integrated nutrient management and intercropping system, and it aims to increase vegetable production sustainably [5].

Increased eggplant production is mainly influenced by the availability of nutrients in sufficient quantities. This plant is a long-lived plant with high yields, thus requiring nutrients in large quantities [6]. In many cases, its growth and yield are often hampered by an inadequate supply of nutrients. Thus, additional sources of nutrients are needed to support continuous fruit harvesting [7]. In soils with low fertility rates, eggplant requires 150-200 kg N ha^{-1}, 100-150 kg P_2O_5 ha_{-1}, and 60-100 kg K_2O ha^{-1}. Furthermore, their productivity could be improved using the integrated nutrient management techniques and eggplant varieties with good production and quality [8]. The application of organic and chemical fertilizer had a significant effect on the vegetative growth and yield of eggplant [9].

Intercropping systems and integrated nutrient management could sustainably increase eggplant production. Moreover, sustainable development in agriculture and improvement of crop yields could be achieved through restoration and management of land productivity [10]. The basic concept underlying the integrated nutrient management system is the suitability of soil fertility and plant nutrient supply to the optimum level to maintain the desired plant productivity by optimizing the utilization of all resources in an integrated nutrient [7]. Many studies show that the balance of inorganic and organic fertilizers could increase soil organic carbon and maintain soil productivity [11]. Additionally, the use of microbes and nutrient management technologies could provide nutrients, protect plants from pathogens, and obtain optimum eggplant yield environmentally [12]. The combination of inorganic, organic, and biological fertilizers increases the growth and yield of eggplant [13].

Meanwhile, the intercropping system could improve soil fertility and nutrient balance and reduce weeds, pests, and diseases, thereby reducing the risk of crop failure and maximizing farmers' benefit [14]. This system also helps improve soil fertility and supports its physical structure. Finally, intercropping systems positively affect soil conservation, increase soil fertility, support more stable yields, and reduce pests and diseases [9].

Based on the above description, and due to the lack of research information on the combination of integrated nutrient management and intercropping systems in vegetable crops, this study was conducted to determine the effect of intercropping systems and integrated nutrient management on increasing eggplant production and land productivity.

2. Materials and Methods

The research was conducted in Poncokusumo, Malang Regency – East Java, from April to October 2018. It used a factorial randomized block design with two factors and three replications. The first factor was various doses of goat manure consisting of three levels, namely 10, 20, and 30 $t.ha^{-1}$. Meanwhile, the second was the type and concentration of microbes consisting of seven levels, namely 0, 10, 20, 30 ml L^{-1} EM4, and 10, 20, and 30 ml L^{-1} PGPR. To calculate the land equivalent ratio (LER) of the planted eggplant, curly lettuce, and monoculture bean, each was treated the same, as in the intercropping system.

In the intercropped plant, curly lettuce was planted simultaneously with the eggplant, and after 35 days, beans were planted, post-harvesting of the lettuce or eggplant. Furthermore, the curly lettuce and bean were planted at a 15 cm distance between rows of the eggplants and were in 50 cm distance in the rows.

The application of goat manure was carried out together with soil tillage. Furthermore, the dosage of the manure was based on the treatment and was carried out by spreading on the soil surface. The dose of EM and PGPR in each application was 50 ml per plant, with concentration according to treatment. Additionally, the application was carried out by splashing around the plants.

Growth observations were carried out four times within two weeks intervals, starting from 14 to 56 days after planting (dap). Furthermore, the non-destructive variables observed were plant height, number of leaves, and stem diameter. At the same time, the destructive variables observed twice at 56, and 105 daps were dry weight and leaf area per plant. The results were obtained by observing the fruit weight, number per plant, and weight of fruits per hectare. Furthermore, the land productivity was calculated based on yield per unit area of each plant, both on the intercropping and monoculture systems. Analysis of variance was adopted to analyze data. Finally, 5% LSD was conducted when there were significant differences between treatments based on ANOVA.

3. Results and Discussion

3.1. Growth

The results of the analysis of variance showed that there was no interaction between manure dosage and microbial concentration on height, number of leaves, stem diameter, leaf area, and dry weight of the eggplants intercropped with curly lettuce and beans at various ages of observation. Meanwhile, the various doses of the manure significantly affected plant height, number of leaves, and plant stem diameter at 21 to 56 dap. The manure also significantly affected leaf area and plant dry weight at 56 and 105 dap.

The provision of beneficial microbes significantly affected plant height, leaf number, and stem diameter in all observation ages and leaf area and plant dry weight at 56 and 105 days after planting. These results are similar to those of the research, which showed that the application of organic fertilizers and microbes caused better plant growth than inorganic fertilizers alone [12].

The application of goat manure significantly affected the growth of the eggplants that were intercropped with curly lettuce and chickpeas. That was evidenced in Fig. 1, 2, and 3, which showed that the application of manure significantly affected the height of the eggplant, the number of its leaves, and stem diameter at 28 to 56 dap. That is because depositing the manure nutrients was carried out slowly, and its influence on the soil properties also occurred slowly. It is suspected that at 28 daps, nutrients were available in sufficient quantities, and there were changes in soil properties. Additionally, in such a condition, nutrient uptake and the plant's metabolism would run more effectively to increase plant growth. Based on the results of soil analysis after the research, it was discovered that there was a change in the value of CEC. Before the research was conducted, this value was moderate, and it increased to a high level after the study was completed. The increase in soil CEC had a great effect on the availability of nutrients for the plants. CEC is one of the factors related to soil fertility and is a good indicator of soil quality and productivity [15]. Higher soil CECs cause an increase in alkalinity, which leads to higher fertility. Conversely, when CEC is low, the soil would not hold nutrients properly. Thus, they are easily washed away by water.

Application of goat manure at a dose of 30 t ha^{-1} produced better eggplant growth. That was because the availability of nutrients for the plants increased at this dose, and soil properties improved. Organic fertilizers help increase plant growth by providing macro and micronutrients through the mineralization process and improving the soil's physical and chemical properties [16]. Moreover, increased availability of nutrients and improved soil properties improve nutrients and metabolic processes. In Fig. 1, it could be seen that the application of goat manure at a dose of 30 t ha^{-1} produced taller plants compared to the other doses, although the difference wasn't significantly different from the dose of 20 t ha^{-1}.

Moreover, the increase in plant height was followed by an increase in the number of eggplant leaves. That could be seen in Fig. 2, where the leaf number in the plant fertilized with goat manure at a dose of 30 t ha^{-1} was higher than the dose with the application of the doses at 10 t ha^{-1} and 20 t ha^{-1}. Also, the higher number of leaves would increase the total surface area of the leaves of the eggplant, and consequently, allow in more sunlight and improve photosynthesis. Fig. 4 showed that the leaf area at 56 dap and 105 dap in the plants fertilized with the goat manure at doses of 20 and 30 t ha^{-1} were higher than those fertilized with a dose of 10 t ha^{-1}. The increased availability of nutrients and improvement of soil properties, accompanied by the increase in the area of the leaves, improved photosynthesis, thus allowing for better plant development. The formation of plant biomass depends on the amount of light interception through the leaves and its effectiveness [17]. Moreover, the wider the surface area of the leaves, the more sunlight could be trapped, therefore, allowing for abundant plant biomass.

The use of microbes in the intercropping system had a significant effect on eggplant growth. That is because microbial inoculation into the soil significantly affected the height of the plants, the number of leaves, and stem diameter from 14 to 56 dap. Furthermore, it affected the plants' leaf area and dry weight at 56 and 105 dap (Fig. 1, 2, 3, and 4). The activity of soil organisms is very important to maintain the availability of nutrients to satisfy the needs of plants [18]. That is because beneficial microorganisms are very efficient in dissolving and providing nutrients for plants.

The concentration of various beneficial microbes had a significant effect on the growth of the eggplants. Microbial applications at lower concentrations, both from EM or PGPR, resulted in reduced growth, while at higher concentrations, up to 30 ml L^{-1}, the growth was increased. Fig. 1, 2, and 3 show that at age 14 and 28 dap, the application of EM and PGPR at concentrations of 10 and 20 ml L^{-1} resulted in the eggplant height, the number of leaves, and stem diameter being lower compared to other concentrations. Meanwhile, at the age of 42 and 56 dap, the PGPR application at a concentration of 10 ml L^{-1} resulted in lower plant growth which was not significantly different from plants that were not given EM or PGPR. The application of beneficial microbes at low concentrations result in fewer bacteria being in the soil, and thus, insufficient amounts of nutrient being added to the soil. That causes the effects of the microbes to be less optimal [19].

Application of PGPR at concentrations of 20, 30, and 30 ml L^{-1} led to the production of a higher number of leaves (Fig. 2). Moreover, the more the leaves, the more the total surface area available to trap sunlight. Therefore, this could increase photosynthetic activities.

The application of EM and PGPR at 30 ml L^{-1} could lead to higher plant height, the number of leaves, and stem diameter (Fig. 1, 2, and 3). Furthermore, the formation of plant organs could increase the dry matter (Fig. 4). During the growth period, the formation of plant biomass is strongly influenced by the amount of received solar radiation [20]. Therefore, the greater the leaf area, the higher biomass, which could contribute to plant organs' formation.

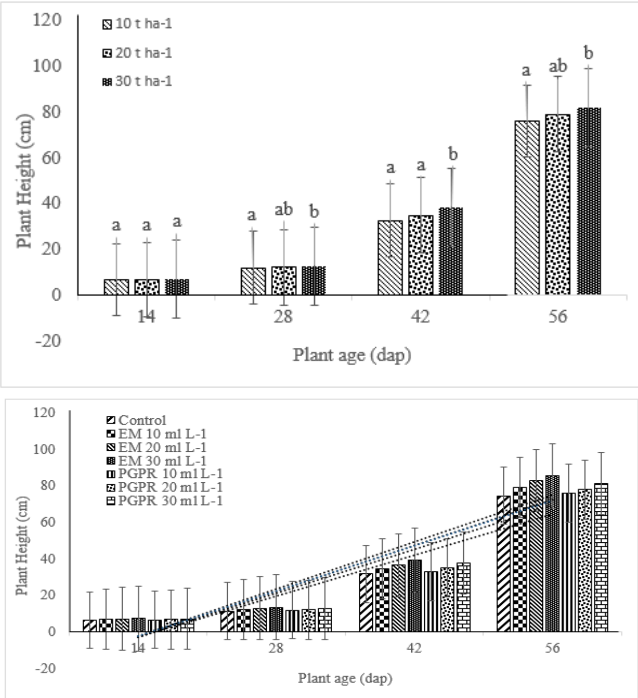
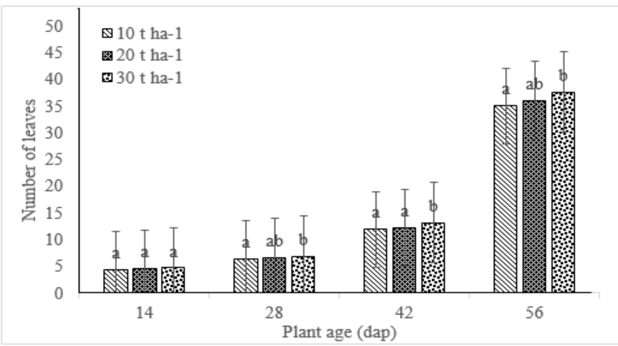


Fig. 1 The height of eggplant in the intercropping system of eggplant, curly lettuce, and bean caused by the use of goat manure and microbes



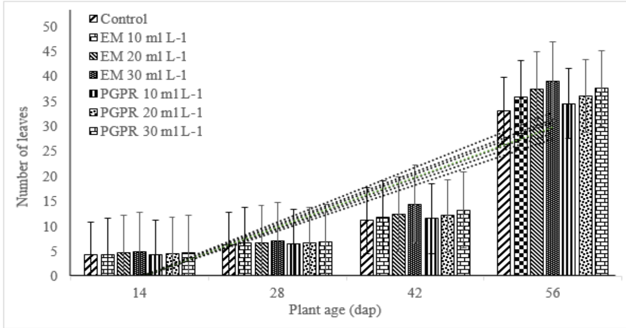


Fig. 2 The number of leaves on the eggplants in the intercropping system due to the use of goat manure and microbes

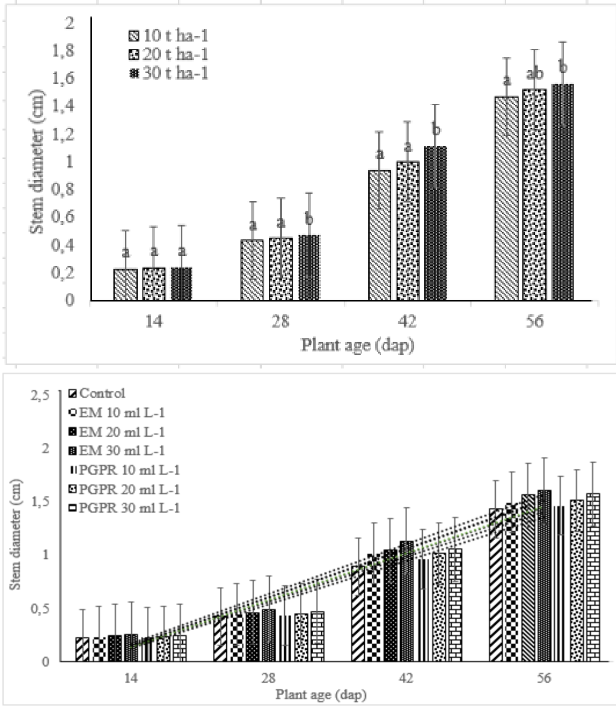


Fig. 3 The stem diameter of the eggplant in the intercropping system is due to goat manure and microbes

3.2. Yield

The application of goat manure significantly affected the weight of the eggplant fruits (Table 1). Furthermore, at a 10 t ha^{-1}, the manure led to the production of the lowest fruit weight, while at 20 and 30 t ha^{-1}, it resulted in higher weights. This manure directly improves crop yields by increasing the availability of nutrients and indirectly by improving soil properties. Its application at doses of 20 and 30 t ha^{-1} could provide more nutrients and improved soil properties than at 10 t ha^{-1}. Thus, the higher the dose, the more available phosphorus (P) is in the soil, which is needed for fruit formation and an increase in weight. The increase in the availability of P within soil affects its release and adsorption complex [21]. Meanwhile, the use of organic matter in the soil could reduce the adsorption of P, which Fe and Al oxide carry out.

Based on Table 1, it could be seen that the provision of microbes had a significant effect on the weight of eggplant fruits. That is because the eggplants which were not given microbes had the lowest fruit weight compared to those given the microbes. Moreover, microbial applications from either EM or PGPR at a concentration of 10 ml L^{-1} produced eggplant fruit with a lower weight than those of the other concentrations. Thus, the increase in weight was due to an increase in beneficial microbes. That is because EM and PGPR contain bacteria that could fix nitrogen and phosphate solvents. Furthermore, they also synthesize the plant growth regulator. The utilization of beneficial microbes is an attempt to manage environmentally friendly nutrients [22].

Table 1 showed that the eggplants treated with 20 and 30 ml L^{-1} of EM or PGPR resulted in more fruit per plant. Furthermore, the higher concentration of microbes given, the more that would be available in the soil. Finally, the use of microbes with phosphate solvent bacteria can increase plant growth, yield, and nitrogen fixation ability [23].

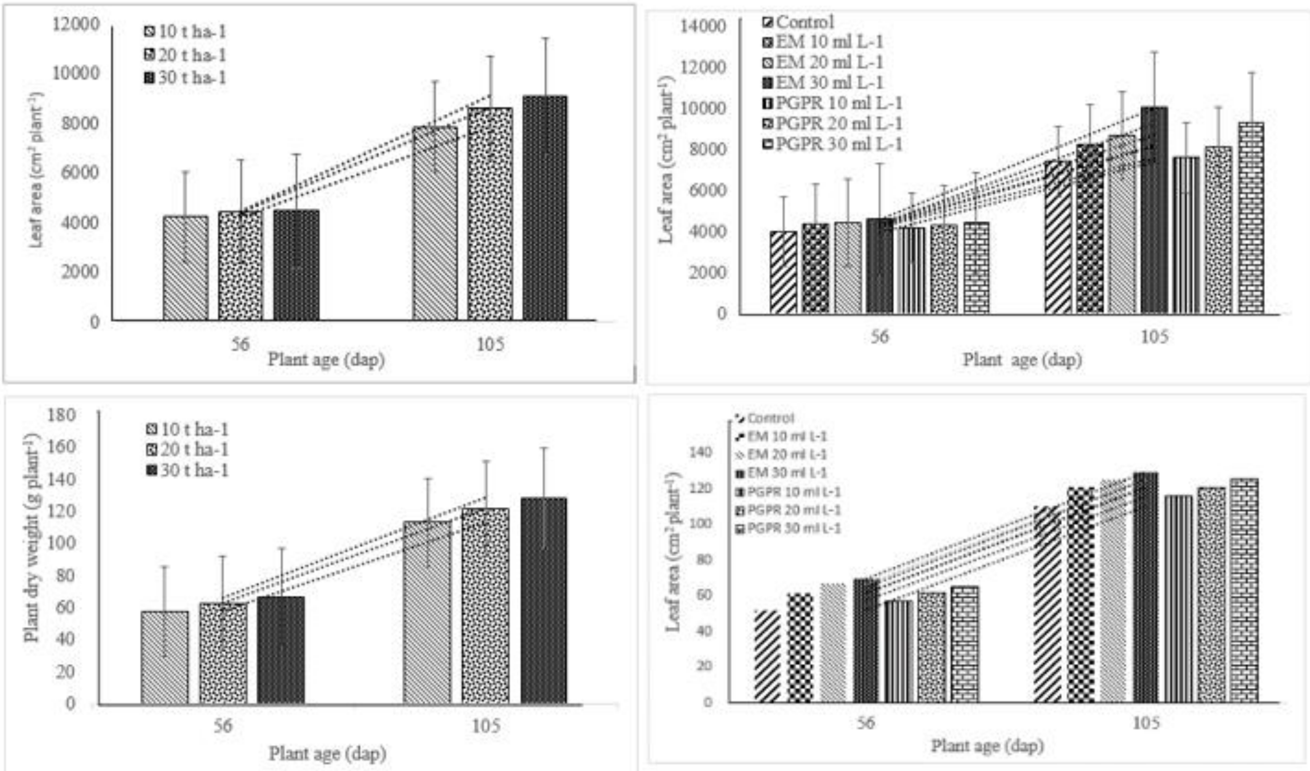


Fig. 4 The leaf area and dry weight of eggplant in the intercropping system of eggplant, curly lettuce, and bean were caused by the use of goat manure and microbes at 56 and 105 dap

Table 1 The weight and number of harvested eggplant fruit in the intercropping system due to the use of goat manure and microbes (Numbers in the same column followed by the same letter were not significantly different on LSD 5%)

Treatment	Fruit weight			Fruit number plant^{-1}
	kg plant^{-1}	ton ha^{-1}	g fruit^{-1}	
Doses of goat manure:				
10 t ha^{-1}	2.39 a	55.67 a	299.75	7.95 a
20 t ha^{-1}	2.59 b	60.33 b	303.36	8.56 b
30 t ha^{-1}	2.78 b	64.83 b	311.53	8.92 b
LSD 5%	0.20	4.62	ns	0.39
Microbial concentration:				
Control	2.02 a	47.19 a	292.27	6.94 a
EM 10 ml L^{-1}	2.58 bc	60.11 bc	301.78	8.57 bc
EM 20 ml L^{-1}	2.71 bcd	63.16 bcd	307.66	8.79 bcd
EM 30 ml L^{-1}	2.93 d	68.39 d	320.44	9.19 d
PGPR 10 ml L^{-1}	2.44 b	56.90 b	294.30	8.26 b
PGPR 20 ml L^{-1}	2.64 bcd	61.57 bcd	311.62	8.54 bc
PGPR 30 ml L^{-1}	2.77 cd	64.61 cd	306.09	9.04 cd
LSD 5%	0.30	7.05	ns	0.60

Table 2 The land equivalent ratio (LER) in the intercropping system due to the use of goat manure and microbes (Numbers in the same column followed by the same letter were not significantly different on LSD 5%)

Treatment	Yield of intercropping (t ha^{-1})			Yield of monoculture (t. ha^{-1})			LER
	Eggplant	Curly lettuce	Beans	Eggplant	Curly lettuce	Beans	
Doses of goat manure:							
10 t ha^{-1}	55.67	5.45	7.61	46.49	13.10	15.08	2.07a
20 t ha^{-1}	60.33	6.39	8.92	49.68	14.10	15.43	2.20 b
30 t ha^{-1}	64.83	7.11	8.09	51.77	15.16	15.66	2.20 b

LSD 5%	-	-	-	-	-	-	0.10
Microbial concentration:							
Control	47.19	3.88	6.75	39.81	10.04	13.97	2.02 a
EM 10 ml L^{-1}	60.11	5.35	8.03	49.57	12.06	15.31	2.14 ab
EM 20 ml L^{-1}	63.16	7.46	8.64	51.56	16.08	15.71	2.20 bc
EM 30 ml L^{-1}	68.39	8.56	9.26	53.71	17.78	16.19	2.29 c
PGPR 10 ml L^{-1}	56.90	4.51	7.64	47.59	10.85	15.00	2.08 ab
PGPR 20 ml L^{-1}	61.57	6.67	8.34	50.63	15.04	15.47	2.16 ab
PGPR 30 ml L^{-1}	64.61	7.80	8.79	52.33	16.98	16.02	2.20 bc
LSD 5%	-	-	-	-	-	-	0.15

3.3. Land Equivalent Ratio (LER)

Land productivity could be increased through an intercropping system. The width of the eggplant spacing and the length of its harvest time could be utilized for planting short-lived vegetables such as curly lettuce followed by beans. Moreover, increased land productivity would reduce farm costs and increase farmer's income. Intercropping is more advantageous in terms of economy, space, efficient use of nutrients, and moisture in unused space [24]. In addition to increased land productivity, this cropping system is also important for integrated nutrient management.

The use of goat manure in various doses resulted in different land equivalent ratios (LER). The increase in the dose from 20 to 30 t ha^{-1} increased the LER value to 2.20. Moreover, the higher doses increased the availability of nutrients and improved soil properties, thereby increasing nutrient uptake efficiency, which resulted in increased crop yields. The application of organic fertilizer in high doses could increase the availability and efficiency of nitrogen use by plants to increase crop yields [25].

The utilization of microbes had a significant effect on increasing LER value in the intercropping system. Thus, the cropping system that did not use beneficial microbes resulted in a lower LER value of 2.02. The higher LER values obtained through EM and PGPR at concentrations of 20 and 30 ml L^{-1} were 2.20, 2.29, 2.16, and 2.20, respectively. Moreover, the increase in LER could increase the number of beneficial microbes in the soil. Meanwhile, this increase in bacteria number could allow for more nitrogen fixation and increased phosphate solvent, thus, more available nutrients for the plants. This condition could then increase the yield of the plants. The application of microbes at sufficient concentrations would increase the number of beneficial microbes in the soil. These microbes can convert nutrients from inaccessible to accessible forms for plants by altering organic matter, N fixation, or dissolving P into the available form [23]. The beneficial microbes also produce growth regulators that could increase plant growth and crop yields.

Intercropping system increased crop yields and LER. Moreover, the system also increased eggplant yield per hectare. Table 2 showed that the yield of eggplant per hectare due to the treatment with goat manure or microbial utilization in the intercropping system was higher than in the monoculture system. Moreover, this increased yield could modify microclimate and improve nutrient efficiency for a better result.

The intercropping system increases the availability of nutrients and water, reduces pest attacks, suppresses weed growth, and maintains and improves soil fertility (especially the intercropping with beans). Moreover, the system decreased the total yield of curly lettuce and bean. These plants were planted at a population of 50% less than in a monoculture system. Thus, the yield per unit of the land area was lower than the monoculture.

4. Conclusion

There was no interaction between the dose of goat manure and microbial concentration on the growth and yield of eggplant. The application of 20 and 30 t ha^{-1} of the manure increased the growth and yield of eggplant, with fruit yields of 60.33 and 8.92 t ha^{-1}. Furthermore, the application of 20 and 30 ml L^{-1} EM or PGPR induced the highest growth and yield of this plant, with fruit yields of 63.16, 68.39, 61.57, and 64.61 t ha^{-1}, respectively. Intercropping systems could increase land productivity. The application of goat manure significantly affected the LER value, where at doses of 20 and 30 tons ha^{-1}, the value was higher at 2.20. The use of microbes significantly increased land productivity. Moreover, higher LER values of 2.14, 2.20, and 2.29 were obtained due to treatment using 10 to 30 ml L^{-1} EM. While the treatment with 20 and 30 ml L^{-1} PGPR led to LER values of 2.16 and 2.20.

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