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Effect of Growth Space on The Productivity of Maize Using Three Sisters Cultivation with Bee Pollination

Nadia Damika Putri[1], Acep Purqon[2], Ramadhani Eka Putra[3]*

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[1,3]Agricultural Engineering, School of Life Sciences and Technology, Jl. Let. Jend. Purn. Dr. (HC) Mashudi No.1, Jatinangor, Sumedang, West Java- Indonesia, 45363, [2]Department of Physic, Faculty of Mathematics and Natural Sciences, Jl. Ganesha No. 10 Bandung, West Java, Indonesia, 45363

e-mail:
[1]*elnadiadamikaputri@gmail.com*
[2]*acep.purqon@gmail.com*
[3*]*ramadhaniputra@gmail.com*

**Corresponding author*

Abstract. *The increasing number of food needs is one of the driving factors for increasing agricultural production, but there are constraints on the availability of land. A polyculture system with corn, beans, and pumpkins, commonly known as the three sisters, can create positive interactions that can enhance the growth and development of each plant. This system has a vast potency to be applied to urban farming inside a grow bag because it does not require ample space, the placement of plants is flexible, and it produces a variety of yields. However, it is necessary to assess the effect of growing space on the growth of maize (Zea mays) cultivated by the three-sister system. This study used a completely randomized design with three treatments and six replications. The treatment consists of three planting spaces with various growing bags (treatment A:75 L, B:100 L, and C:200 L). The results of this study showed that the highest corn productivity was in the largest growing space (treatment C), which weighed 318.40 g/cob, and without husks 246.42 g/cob, but not significantly different from treatment B (grow bag 100 L), which weights 316.20 g/cob and without pods of 240.63 g/cob. This study found that the 100 L grow bag was the optimal growing space for planting corn in containers using the three sisters technique.*

Keywords: *corn, grow bag, growth space, three sister*

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INTRODUCTION

The increasing number of food needs due to the population growth every year is one factor that encourages agricultural production. Food security is an essential factor because it is estimated that the population in Indonesia will continue to increase, with an estimated 319 million people in 2045 (Statistics Indonesia (BPS), 2020). Thus, the future challenge in agriculture is to provide enough nutrition for the growing human population in the urban area. Urban agriculture may provide a foundation for asustainable food production system and other benefits related to a sustainable city (Nogeire-McRae et al., 2018). This system can be a solution for cutting the food supply chain and supporting micro-household food independence, which produces food for local needs (Ghosh, 2008; Eigenbrod & Gruda, 2015). This independent food production can reduce the costs of food purchases, adjust production results to the dietary preferences of each individual, and consume fresher and more affordable food (Andini et al., 2021).

However, urban agriculture's common challenges are low land availability and de-

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clining soil fertility due to improper land management, as the lands were not intended to be used as farmland. Crop productivity on limited land can be increased through a polyculture cropping system and improved land cover with vegetative mulching. The critical components to ensure the success of polyculture are a correct combination of polyculture pattern, population size or spacing, and planting method (Ceunfin, 2018).

A traditional polyculture system with maize, beans, and pumpkin, commonly referred to as "three sisters", is one system that can be used to increase relative yields in low-fertility soil, which is common in urban areas. Polyculture systems can reduce the abundance of plant pathogens (pests, diseases, and weeds) and increase nutrient acquisition efficiency. This is a specific example of the general theory that biodiversity can improve productivity and resource utilization (Zhang et al., 2014). According to Pleasant (2016), combining corn, beans, and pumpkin is a sustainable cropping system that can provide soil fertility and high production yields.

Another overlooked component that may improve agriculture productivity is biodiversity. Local biodiversity provides significant ecosystem services related to agriculture, e.g., nutrient cycling, pest control, and pollination. Pollination is considered the most direct and straightforward to observe among those services. All of the "three sisters" crops, which are maize, bean, and pumpkin, are cross-pollinated crops that require pollinating agents, such as insects or wind. Compared to wind pollination, insect pollination has tremendous pollination success due to their higher and more precise activities in flowers related to reward collection (Normasari, 2014). Even though maize predominantly uses wind as a major pollination agent, maize flowers are frequently visited by several bee species (Painkra et al., 2021) and improved productivity (Putra and Murnita, 2020). Since most urban areas are not ideal habitats for wild insect pollinators, the pollination service should be provided by domesticated bees. Among domesticated bees, stingless bees are considered the perfect candidate due to their small size, no sting, high adaptability to the environment, easy handling, ease of domestication, and production of various products such as honey and propolis (Kek et al., 2014; Jalil, 2014; Ya'akob et al., 2019). Studies also showed the incredible potency of stingless bees as pollinator agents for various crops (Putra et al., 2014; Das et al., 2015; Agussalim et al., 2017; Atmowidi et al., 2018; Efin et al., 2019; Sayusti et al., 2021).

This study focused on three-sisters system. Unlike the traditional three-sister system, all crops were cultivated inside the grow bag, which simulated the land restriction of urban agriculture. Stingless bee colonies were also integrated into this system to provide pollination service. However, their impact on productivity was not the objective of this study. The result was then analyzed as the base for the urban agriculture polyculture model, which is limited by land availability.

MATERIALS AND METHODS

Study Period and Location

The study was conducted for four months, from October 2021 to February 2022. The field study was conducted in Tani Kota farming area, Bandung. The average temperature was 24.78°C, and the average humidity was 55.98%.

Study Design

Three sisters system is a plantation system in which maize is planted together with legumes (beans) and pumpkins. The basic

principle of this system is that corn will act as a staple fruit, which provides the foundation for climbing beans. The beans will provide additional nitrogen to the soil while acting as a source of protein for farmers. On the other hand, pumpkin is a cash crop that provides soil coverage as protection against sunlight while preventing weed growth.

The study was conducted in a completely randomized design consisting of 3 groups based on the size of the grow bag where the cultivation was conducted. The study groups consisted of:

(1). Treatment A on 75 L grow bags (46 cm diameter, 46 cm height), (2). Treatment B on 100 L grow (51 cm diameter, 50 cm height), (3). Treatment C on 200 L grow bag (65 cm diameter, 60 cm height).

Each study group was replicated six times. The organic cultivation procedure consisted of watering, weeding, hoarding, and planting. The growth media used in this study was the combination of soil and compost in 2:1 ratio.

Data Collection

Data collected in this study were:
(1). Soil edaphic (soil pH, N, P, K levels) was tested at the Laboratory of Soil Fertility and Plant Nutrition, Padjadjaran University, (2). Harvest data consisted of corn cob length (cm), diameter (cm), and fruit weight (grams). The corn cob's length, diameter, and weight were measured by digital balance, ruler, and tape measurements, (3). Nutrition quality, which consisted of proximate test levels, was measured. The test was conducted on the corn cob, which was harvested 86 days after planting. The data collected were the ash content, energy from fat, total fat content, water content, total energy, carbohydrates, and protein content in corn fruit samples. The laboratory of PT Saraswati Indo Genetech, Bogor conducted all proximate tests.

Statistical Analysis

One-way ANOVA was applied to determine the significant impact of the growing space on the productivity and nutrition quality of the harvested product. The one-way ANOVA statistical testing results, which showed a $P < 0.05$ (significant), were subjected to post-hoc testing using the Duncan test. All data analysis was conducted by SPSS 22.0.0.

RESULTS AND DISCUSSION

The soil edaphic test showed some notable changes in all tested variables. There were increasing nitrogen, phosphorus, and potassium levels in the soil after the experiment while the soil pH was decreasing. The N-total level increased to 54.5%, phosphorus increased up to 1996.25%, and potassium level increased to 23.48% when compared between the highest value of the final test and initial soil test (Table 1).

The increase in nitrogen, phosphorus, and potassium nutrient levels was caused by compost used as a mixture of planting media. Compost functions are improving soil structure, increasing soil aeration, and providing energy sources for soil microbes. These functions would improve soil stability to prevent nutrient leaching and improve the activity of soil organisms to carry out the biomineralization process. Both processes accumulate nutrients in the soil, which may stimulate plant growth and development, accelerate harvest time, and increase productivity (Hayati et al., 2012).

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Table 1. Soil test results before planting with three sisters system

Parameter	Unit	Before	Criteria	After	Criteria
pH : H_2O	-	7.45	Neutral	7.00 – 7.24	Neutral
N-total	%	0.25	Moderate	0.21 – 0.55	Low to high
P_2O_5 (Olsen)	ppm P	5.87	High	93.91 – 123.05	Very high
K-dd	cmol/kg	3.96	Very high	2.94 – 4.89	Very high

Compost as a mixture of planting media also encouraged the growth of earthworms, as indicated by the number of worm droppings around the planting media and adult earthworms in planting media by the end of the study. These earthworms could have originated from eggs inside the soil as part of planting media or migrated from the surrounding area as the grow bags were kept directly above the bare soil. Earthworms can be used as indicators of soil fertility that play an essential role in improving soil productivity. They convert organic matter in the soil into worm droppings and urine rich in nitrogen, phosphorus, potassium, magnesium, and calcium which are essential for plant growth (Purniasari et al., 2019).

Based on the final test results, the best soil test results were found in treatment B (grow bag 100 L) because it could maintain and increase nitrogen, phosphorus, and potassium nutrients. This result could be explained by the speed of the decomposition process. The decomposition process depends on several factors, like the amount of compost, aeration, moisture, numbers, and diversity of soil organisms. In this study, a grow bag 100 L probably provides better aeration and better moisture for compost material. The distance between open air and compost inside the grow bag allowed air to be supplied while deep enough to prevent moisture loss. This condition allowed the mineralization process of compost to be carried out by soil microorganisms. Smaller grow bags probably had faster mineralization, while bigger ones had a slower process.

Another possible factor that affected the result was the size of the container which may affect the size of the root area. The 100 L grow bag may provide the perfect size for optimal root growth of corn, leading to optimal nutrition intake. The size also provides enough space for aeration and moisture. Smaller grow bags could be packed with overgrown roots as the room was limited, while bigger ones had more space. The size of the root area and their distance to the nutrient source affect the rate of nutrient loss from planting media.

The Effect of Growing Space on Corn Cob Weight (*Zea mays*)

The observations showed that the average weight of the cobs (with and without husk) was directly proportional to the size of the grow bag used. Among the three treatment groups, the weight of corn cobs of maize planted in 75 L grow bags was significantly lower than in the other treatment groups (Duncan, $P<0.05$). On the other hand, although maize planted in 200 L grow bag produced heavier corn cobs, statistically, it was not different from the result of maize planted in 100 L grow (Duncan, $P> 0.05$) (Figure 1).

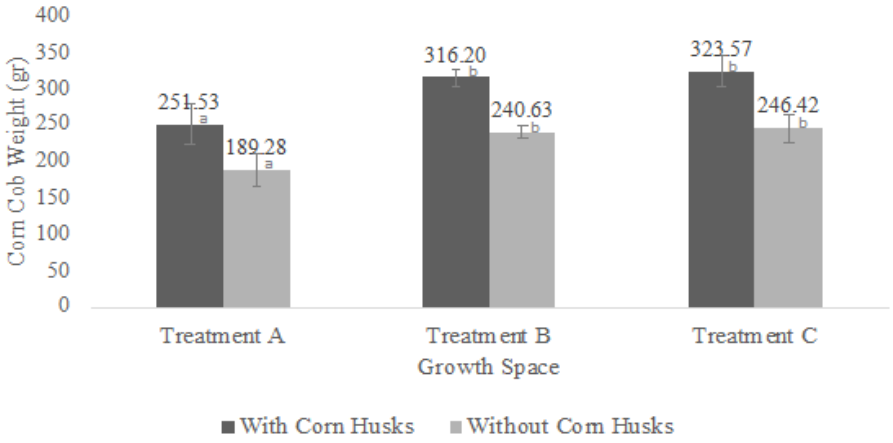

Figure 1. Corn cobs weight graph in each treatment

This study showed the positive effect of increasing grow bag size on productivity. Bigger bags store more nutrients and provide better space for roots (Kartika, 2018). However, it seems there is a limit of optimal space for root as maize root growth tends to be concentrated near the soil surface, which may explain the similarity between groups B and C. However, a bigger 200 L grow bag was not fully utilized, which could be caused by a lack of water penetration as water was provided only from the soil surface.

Compared to the conventional planting method in the field, the weight of the corn cob without husk was better than that of maize planted within a short distance (Maulanazri et al., 2020) and slightly smaller compared to maize planted within a larger distance (Silaban et al., 2013) (Table 2). The result showed the three sisters' suitability to apply as a planting system for limited space. This model provided additional nutrients from the rhizospore of the legume. Installed stingless bee colonies provided supplemental pollination, which may compensate for the lack of nutrients compared to open fields. Stingless bees collected pollen and involuntarily transferred pollen among maize's flowers. Combining this process with the availability of nutrients in the growing medium could improve the productivity of maize (Putra et al., 2020).

Table 2. Comparison of the weight of corn cobs in this study with other studies

Planting Method	Weight of Cobs with Corn Husks (grams)	Weight of Cobs without Corn Husks (grams)	Sources
Organic three sister in grow bag	251.53 – 318.4	189.275-246.417	This study
Conventional in field with planting distance 60-80 x 30 cm	272.46-310.22	181.15-218.18	Maulanazri et al.,2020
Conventional in field with planting distance 70 x 40 cm	-	192.67	Silaban et al., 2013

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The Effect of Growing Space on Corn Cob Diameter (*Zea mays*)

The diameter of corn cobs, with and without husks, of group A (grow bag 75 L) was significantly smaller than in the other treatments (Duncan, P<0.05) (Figure 2). The highest diameter recorded in group B (grow bag 100 L) was not statistically different compared to group C (grow bag 200 L). Compared to other studies using local cultivars, the corn cob diameter found in this study was bigger (Table 3).

Corn cob diameter is affected by several factors, such as genetic and non-genetic. Important non-genetic factors are nitrogen level and moisture (Desyanto & Susetyo, 2014; Ashraf et al., 2016; Adhikari et al., 2021). It seems that the bigger grow bag and soil coverage by both pumpkins can maintain the soil moisture necessary for increasing the size of the corn cob diameter. Furtherly, higher nutrient content and continuous nutrient supply through decomposition and mineralization process by soil organisms are most likely to occur in bigger grow bags where the material and energy source were higher than in smaller grow bags.

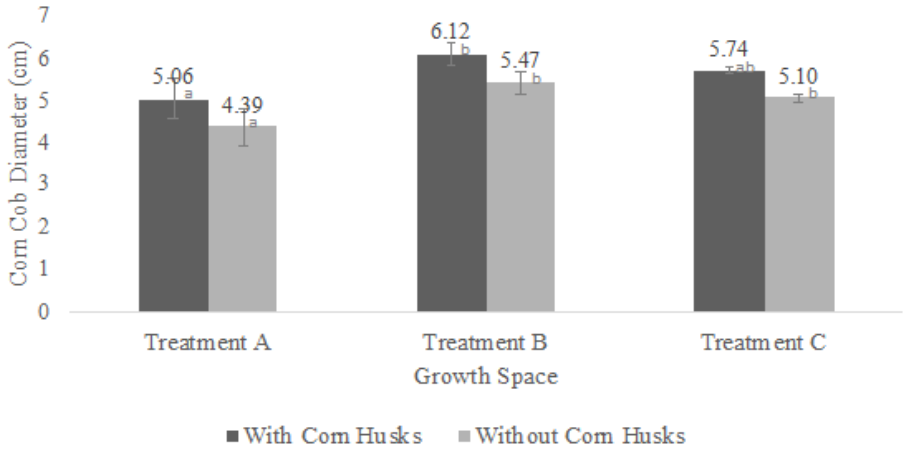

Figure 2. Corn cobs diameter graph in each treatment

Table 3. Comparison of corncob diameter in this study with other studies

Treatment	Diameter of Cobs with Corn Husks (grams)	Diameter of Cobs without Corn Husks (grams)	Sources
Organic three sister in grow bag	5.06 – 6.13	4.39 – 5.09	This study
Conventional in field with planting distance 25 x 40-80 cm	-	3.96 – 4.30	Desyanto & Susetyo, 2014
Planting Distance 70 x 40 cm Var Bonanza	-	4.01	Silaban et al., 2013

The Effect of Growing Space on Corn Cob Length (*Zea mays*)

The length of the corn cob of group A was significantly lower than other treatments (Duncan, P<0.05) (Figure 3). There was no significant difference in the corn cob length between groups B and C, although group C had longer corn cobs (Figure 3). Compared to the result of other studies, the corn cob length produced in this study was longer (Table 4).

Similar to diameter, the length of the corn cob is also affected by available nitrogen in the grow bag and the moisture of grow media. Further application of three sister planting techniques provides soil with additional nitrogen from legumes and moisture protection from the shade of pumpkin leaves. However, this is related to the size of the grow bag as small and narrow growing spaces can reduce production yields due to competition for nutrients and water and leaves that shade each other so that only the upper leaves get sunlight while the lower leaves are closed. As a result, photosynthesis in each plant is less than optimum and affects the plant's metabolic processes. On the other hand, when the growing space becomes more tenuous or larger, the soil surface area cannot be shaded, so the process of soil evaporation and weed growth will also be higher (Kartika, 2018).

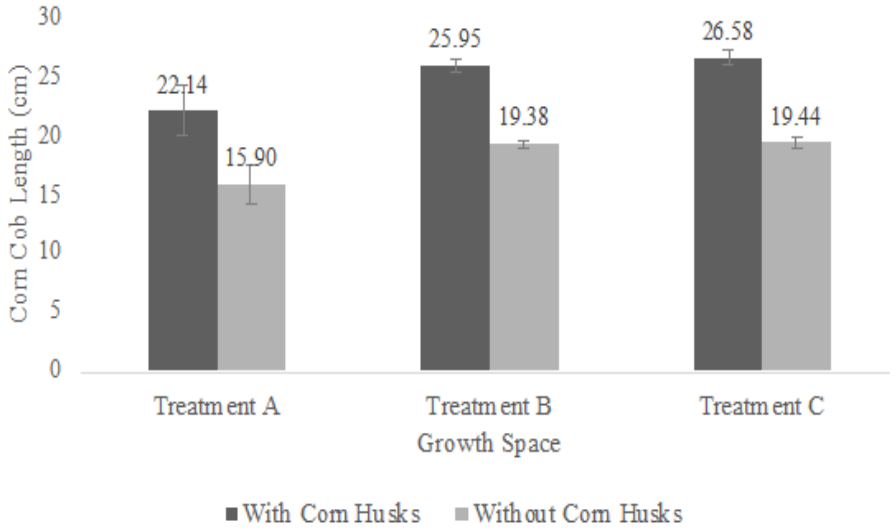

Figure 3. The antibacterial activity of CFS, precipitated bacteriocins, dialysis, *Lactobacillus plantarum* BP102

Table 4. Comparison of corn cob length in this study with other studies

Treatment	Length of Cobs with Corn Husks (grams)	Length of Cobs without Corn Husks (grams)	Sources
Grow bag 75 L, 100 L, 200 L Var Paragon	22.14-26.58	15.90-19.44	This study
Planting Distance 25 x 40-80 cm Var Bisi		14.57-16.50	Desyanto & Susetyo, 2014
Planting Distance 70 x 40 cm Var Pioneer		11.9	Bhato, 2016

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Analysis of Corncob Proximate Test Results for Each Treatment

The highest ash content value was found in group C (grow bag 200 L) at 0.70%, but not much different from other treatments. The energy of fat, total energy, and the highest total fat content were found in group B (grow bag 100 L). Furthermore, the highest water content parameter was found in group A (grow bag 75 L) at 83.76% (Table 5).

Table 5. Comparison of corn cob length in this study with other studies

Parameter	Results				
	Group A	Group B	Group C	Other Study	Reference
Ash Content (%)	0.69	0.60	0.70	0.7-1.3	Evangelista & Felix, 2020
Energy from Fat (Kcal/100 g)	3.69	8.19	7.11	-	
Total energy (Kcal/100 g	64.25	75.39	74.15	-	
Total Fat Content (%)	0.41	0.91	0.79	3.20-5.13	Evangelista & Felix, 2020
Water Content (%	83.76	81.69	81.75	73.88-78.90 %	Evangelista & Felix, 2020
Carbohydrate (%)	12.29	14.02	14.18	51.42	
Protein	2.85	2.78	2.58	2.55-2.95 %	Soetrisno, 1995

The ash content parameter shows no big difference between the treatments. The Ash content of corn cob could related strongly and less to fruit maturity (Evangelista & Felix, 2020; Wojcieszak et al., 2020). Fruit maturity itself is affected by growing conditions (Erwin et al., 2015). In this study, the growing condition was limited by the root growing space. As the level of ash content is relatively near 0.7 – 1.3%, it could be concluded that applying the three sisters technique in the grow bag had no negative effect on maize.

According to Evangelista and Felix (2020), water content decreases along with fruit ripening. This study showed the possibility that the level of fruit maturity in group A was lower than in other groups, further supported by additional information such as water and protein content in which group A had the highest.

On the other hand, maize grown in the bigger grow bag had higher carbohydrate and fat content, which was higher than the value reported by Nweke (2010) (fat content of 0.91 and 0.79% compared to 0.5%). The differences in carbohydrate levels might be caused by differences in the varieties of corn used and nutrients received by maize.

This study discovered the potency of applying the three sisters plantation technique, an old technique developed by Native Americans, in a grow bag or container with limited root growing space. The result could be beneficial for urban farming setup or plantation of maize with limited root grow space (such as above bedrock). This study could provide baseline information to uncover more information on the interactions of companion plants in limited space and isolated systems that many researchers were skeptical about.

CONCLUSION

Three sisters system could be implemented in grow bags in urban agriculture with grow space as the major limiting factor. The application of stingless bees as pollinators could improve productivity and help overcome the lack of root growth space. This study showed the potency of the application of the polyculture technique for limited space and soil.

AUTHOR CONTRIBUTION

N.D.P., R.E.P., and A.P. conceived and designed the study., N.D.P conducted the experiment and collected data under supervision by R.E.P and A.P., N.D.P., R.E.P., and A.P. performed data analysis, interpretation, and wrote the manuscript. All the authors have read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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