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(RESEARCH ARTICLE)

The potential of N-fixing bacteria consortium inoculation and NPK application in increasing soil N-total, plant N uptake and tomato (*Lycopersicum esculentum* Mill.) yields in Andisol

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Abstract

Nitrogen is an essential nutrient for growing tomato plants (*Lycopersicum esculentum* Mill.) on Andisol soil order. However, many farmers tend to use an excessive amount of inorganic fertilizers, which can have adverse effects on both the environment and tomato yield. To combat this problem, an alternative solution is to replace the inorganic fertilizer through inoculation of *Azotobacter* as an N-fixing bacteria. An experiment was conducted to examine the combined effects of the N-fixing consortium with NPK on total soil N, N uptake, Azotobacter spp. population, growth and the tomato plants yield. The experiment was performed on Andisols, located roughly 1250 m above sea level in West Java Province. The experimental design used was a Randomized Block Design, in three replications, consisting of A (Control), B (N-fixing inoculation), C (N-fixing + ¼ NPK), D (N-fixing + ½ NPK), E (N-fixing + ¾ NPK), F (N-fixing + 1 NPK), and G (1 NPK). The experiment revealed that the Lembang Andisol had an acidic pH, moderate available N, and high P retention. Applying *Azotobacter* sp. and *Azotobacter vinelandii* (N-fixing consortium) combined with one dose of NPK increased plant height and the total soil N content. N-fixing inoculation combined with 1/4 NPK, ½ NP, and ¾ NPK increased plant N uptake. The inoculation of N-fixing + ¼ NPK increased fruit weight, the number of fruits, and the yield per hectare of tomatoes. Inoculating *Azotobacter* sp. and *Azotobacter vinelandii* in mixed culture can reduce NPK usage by 75%, resulting in higher tomato yield.

Keywords: Andisol; *Azotobacter* spp.; *Lycopersicum esculentum*; N-fixing bacteria

1. Introduction

Nitrogen deficiency is a common problem that limits crop production. Nitrogen is an essential nutrient for plants and is often added as a fertilizer to increase the yield of important crops [4, 7].

Andisols are soils formed from volcanic eruptions (such as volcanic ash, pumice, ash, and lava) whose colloid fraction is dominated by short-range-order minerals (allophane, imogillite, ferrihydrite) or Al-humic [6, 23]. The distribution pattern of Andisols worldwide is mainly in areas included in the Pacific Ring of Fire, including Indonesia [23]. In Indonesia, the area of Andisols is around 5.4 million hectares or 3.4% of the total land area, most of which is in the highlands [29].

Tomatoes (*Lycopersicum esculentum* Mill.) are a popular horticultural commodity grown in Indonesia. Tomato cultivation in Indonesia is mainly carried out in the highlands, which generally have soil in the Andisols order. Andisols are young, developing soils that originate from volcanic material, mainly volcanic ash, which contains a lot of volcanic

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glass [29]. Andisols have good soil fertility for physical, chemical, and biological properties that are required by plants. However, Andisols soil, which is made from volcanic ash, contains minimal amounts of nitrogen. Plants' ability to absorb nitrogen originating from urea or ammonium sulfate could be more efficient, or the absorption rate could be higher [25]. Tomato productivity tends to vary from year to year. Low productivity of tomato yield may be attributed to poor crop management, particularly in terms of the fertilization strategies adopted by farmers. The use of fertilizer in tomato cultivation can significantly impact the production outcomes and the income of farmers, as highlighted by Budi and Karmini [3]. Tomato plants require high amounts of nutrients such as nitrogen, phosphorus, and potassium. However, the continuous use of inorganic fertilizers can harm the soil and the environment. Sustainable agriculture can be achieved by using alternatives such as applying N-fixing bacteria as biofertilizers and PGPR to reduce the need for nitrogen in Andosol and to increase plant yield. The one of potential N_2-fixing bacteria is *Azotobacter* spp.

Azotobacter is a genus of bacteria found in soil, water, and sediments that plays an important role in regulating the nitrogen cycle. It binds atmospheric nitrogen that is inaccessible to plants and releases it into the soil in the form of ammonium ions. This process is known as nitrogen fixation. Azotobacter is a Gram-negative, motile, pleomorphic aerobic bacterium that forms thick-walled cysts and may produce large quantities of capsular slime, and also may produces catalase [26]. In addition to nitrogen fixation, Azotobacter has been found to synthesize growth-promoting substances and antibiotics [27]. It is known to have one of the most highly active cytochrome oxidases and notably active superoxide dismutase and catalase systems [8]. Azotobacter can benefit plants in many ways, including playing nutritional and stimulatory roles that increase growth and yield in various crops such as cereals, pulses, vegetables, fruits, and cash crops [2]. Azotobacter is a widely dispersed genus that can establish symbiotic relationships with different parts of plants and may develop unique structures as the site of nitrogen fixation [5, 28]. Field trials have demonstrated that inoculation of Azotobacter under certain environmental conditions sustained fixing nitrogen in soil and also stimulate plant growth through the secretion of stimulating hormones like gibberellins, auxins, and cytokinins [7, 19, 28]. Some species Azotobacter have found produce exopolysaccharides with high potential value related to their wide range of commercial applications and for Mercury bioremediation [28]. This justifies the interest in these microorganisms for their ability to fix nitrogen and solubilize phosphates [1]. It is important to note that each Azotobacter species has varying effectiveness and unique characteristics when applied to different soils and conditions. Kizilkaya [11] reported that the presence of *Azotobacter* sp. in soils has beneficial effects on plants, but the abundance and effectivity of these bacteria is related to many factors such as organic matter conten, pH, temperature, and microorganisms properties. Therefore, it is crucial to assess the effectiveness of *Azotobacter* sp. and *Azotobacter vinelandii* on Andisol soils to enhance tomato production and soil health.

The objective of this study is to examine the effect of the inoculation of *Azotobacter* sp. and *Azotobacter vinelandii* in consortium culture as N-fixing bacteria combined with N, P, K on the soil total-N, N uptake, *Azotobacter* spp. population, growth and yield of tomato plants (*Lycopersicum esculentum* Mill.).

2. Material and methods

The experiment was conducted on land in Manoko Village, Cikahuripan Village, Lembang District, West Bandung Regency, West Java Province. The land was Andisols, located at an altitude of approximately 1250 meters above sea level, with type C rainfall based on Schmidt-Fergusson. The average temperature was between 20-25°C, and the relative humidity was 88%. The Soil Chemistry and Soil Microbiology Laboratory, Faculty of Agriculture, Padjadjaran University, Jatinangor was used for experimental analysis. The soil in the experimental field belonged to the Andisols order. N-fixing bacteria isolate used in this experiment was consisting of two spesies: *Azotobacter* sp. and *Azotobacter vinelandii*, and chicken manure as essential organic fertilizer. Urea, SP36, and KCl fertilizer were also used as the treatment in various doses.

2.1. Experimental design

The Randomized Block Design (RBD) method was used. The method involved seven treatment combinations, including the control treatment, N-fixing culture consortium inoculation, and various recommended doses of inorganic fertilizer application. Each treatment was repeated three times, and each experimental unit was composed of four plants, dislay in Table 1.

Table 1 The treatment of Combination of N-fixing Inoculation and NPK Application on Tomato Plants (*Lycopersicum esculentum* Mill.) Amala variety

Code	Treatment	N-fixing consortium culture (l/ha)	NPK Fertilizer standard Dosage per ha (kg)		
			Urea	SP-36	KCl
A	Control	0	0	0	0
B	N-fixing culture	3	0	0	0
C	N-fixing + ¼ NPK	3	37.5	25	125
D	N-fixing + ½ NPK	3	75	50	25
E	N-fixing + ¾ NPK	3	112.5	75	37.5
F	N-fixing + 1 NPK	3	150	100	50
G	1 NPK	0	150	100	50

Noted:

- The control treatment was treated without Azotobacter culture and without the addition of N, P, and K nutrients.
- The standard NPK fertilizer is the locally recommended dose of inorganic fertilizer for tomato plants, consisting of 150 kg of Urea, 100 kg of SP-36, and 50 kg of KCl per hectare.
- The treatment dose for N-fixing liquid culture is 3 liters per hectare, achieved by suspending 1 liter of N-fixing liquid culture in 500 liters of water.
- The lay out of the experiment, and the tomato plant growth performance at vegetative phase (Figure 1. dan 2.)

Figure 1 Lay out of the experiment

Figure 2 The Tomato plant in the vegetative phase condition

Observations made in this research include: a). N-total analysis using the Kjeldahl method. b). Analysis of N uptake using the Kjeldahl method. c). Population analysis of *Azotobacter* spp. with the serial dilution Total Plate Count (TPC) method. d). Yield of tomato plants in each treatment (weight per fruit, weight per plant and number of fruits per plant). e). Initial soil analysis. f). Rainfall data. g). Growth components which include plant height.

2.2. Experiment land preparation and tomato plant seeds

The experiment started with land preparation for planting tomato seeds. The soil used was Andisols from Lembang. The land was cleared of weeds and other plant debris, and 20 tons/ha of essential fertilizer in animal manure were added. Bunds were then made, 30 cm-40 cm high, with a bed length of 18 m and a width of 1 m in 3 beds with a distance of 1 m between beds. Black and silver plastic mulch was installed on the bunds. Planting holes were then made at 40 cm x 60 cm. Next, the tomato seeds were soaked in warm water (50^{o}C) for one hour before being sown. The seeds were spread evenly on the nursery bed with media in husks covered with banana leaves for 2-3 days. The nursery bed was roofed with a transparent screen to avoid pathogen attacks. After 7 days, the seedlings were moved into the shade. Seedlings were planted after they had four leaves. One tomato plant seed was planted in each planting hole.

2.3. Application of inorganic fertilizer and Azotobacter culture inoculation

Animal manure fertilizer is applied two weeks before planting at 20 tons/ha. Inorganic fertilizer treatment (N, P, and K) was applied 15 days after planting (DAT) and 45 DAT, mixed evenly and given to the side of the plant hole (5 cm distance). Meanwhile, N-fixing consortium culture inoculation was applicated three times at 21 DAT, 35 DAT, and 49 DAT. The way to apply N-fixing culture is by spraying biological fertilizer dissolved in the appropriate dosage on the soil. Watering is done every day if there is no rain, namely in the morning, to maintain soil moisture.

2.4. Observation and Harvest time

Observations of plant growth parameters, including plant height (cm), were observed starting from plant age 2 WAP to 8 WAP. Observation of plant height is carried out by measuring the height of the plant starting from the base of the stem on the surface of the planting medium to the tip of the highest stem before the top branch. Population analysis of *Azotobacter* spp. was carried out using the total plate count serial dilution method. The soil samples taken are soil in the rhizosphere and analyzed in the laboratory according to the parameters to be tested. Harvesting is done when the plants are 72-85 HST, with the characteristics being that the fruit's skin is reddish, the edges of the old leaves are dry, and the stems are yellow. Harvesting is done in the morning when the weather is sunny. Harvesting is done five times and done once a week.

2.5. Statistical analysis

Experimental datas were analyzed using Statistical Product and Service Solutions (SPSS) version 15.0. Analysis of variance (ANOVA) was performed, and significant differences were assessed at a significance level of 5% ($p < 0.05$).

3. Results and Discussion

3.1. Characteristics of Andisol soil order from Lembang

The characteristics of initial Soil based on the results of the soil analysis, they are presented in Table 1.

Table 1 The Characteristics of Andisos soil order from Lembang

Type of Analysis	**Unit**	**Result**	**Criteria***
pH H_2O		5.45	Acid
pH KCl		4.90	Acid
Organic-C	(%)	2.88	Moderate
N-Total	(%)	0.30	Moderate
Available P_2O_5	(ppm)	11.55	Moderate
Potential P_2O_5	(mg 100 g^{-1})	10.13	Very low
Potential K_2O	(mg 100 g^{-1})	103.59	Very high
P retention	(%)	87.42	High
CEC	(cmol.kg-1)	21.53	Moderate
Cation arrangement			
K – dd (cmol/kg)	(cmol.kg-1)	2.28	Very high
Na – dd (cmol/kg)	(cmol.kg-1)	0,34	Low
Ca – dd (cmol/kg)	(cmol.kg-1)	2.47	Low
Mg – dd (cmol/kg)	(cmol.kg-1)	0.25	Very low
Texture:			
Sand	(%)	9.75	Dusty Clay
Dust	(%)	41.24	
clay	(%)	49.01	
Azotobacter spp. population	CFU/g	$0.5x10^3$	Low

Description: Results of soil chemical analysis at the Soil Chemistry Laboratory, Department of Soil Science and Land Resources, Faculty of Agriculture, Padjadjaran University

Based on the analysis results, the Andisols at the experimental location possess the following chemical and physical properties: The pH value of H2O is 5.45, which is acidic. This soil pH is suitable for tomato plants, whose pH requirements range from 5.00 to 7.00. The pH value affects the absorption of macro and micronutrients. The N-total value is 0.30%, considered moderate. The available P content in the experimental field is 11.55 ppm, which is also moderate. However, the potential P value of 10.13 mg.100 g^{-1} is very low. The potential K value of 103.59 mg.100 g^{-1} is very high. The organic C value is 2.88%, which is moderate. - CEC 21.53 cmol.kg^{-1} is moderate as well. The P retention value is high, at 87.42%. This is typical of Andisols, which have high P retention. However, it also inhibits the availability of P for plants, so fertilizer application is necessary. The cation composition varies: K-dd (2.28 cmol.kg^{-1}) is very high, Na-dd (0.34 cmol.kg^{-1}), and Ca-dd (2.47 cmol.kg^{-1}) is low, while Mg-dd (0.25 cmol.kg^{-1}) is very low. The soil texture on the experimental land is dusty clay. The population of *Azotobacter* sp. is 0.5 x 10^3 CFU/g in low categories population density.

The Lembang region experiences type C rainfall, which is slightly wet according to the classification of Schmidt and Fergusson [22]. The highest rainfall occurred in December during the experiment, with a monthly total of 376.5 mm and 19 rainy days. The average annual rainfall in Lembang is 1288.28 mm/year, which is slightly higher than the ideal conditions for tomato plant growth (750 mm-1250 mm/year). High rainfall can hinder plant development and nutrient absorption due to excessive leaching caused by rainwater. The average temperature during the experiment ranged between 20-25^{o}C, which is optimal for growing tomato plants. Meanwhile, the relative humidity during the experiment was 88%.

3.2. Plant height of Tomato plant

The growth components of tomato plants observed included the height of plants aged 2 WAP to 8 WAP shown in Figure 3. Plant height growth appeared to be relatively insignificantly different at 2 WAP between treatments.

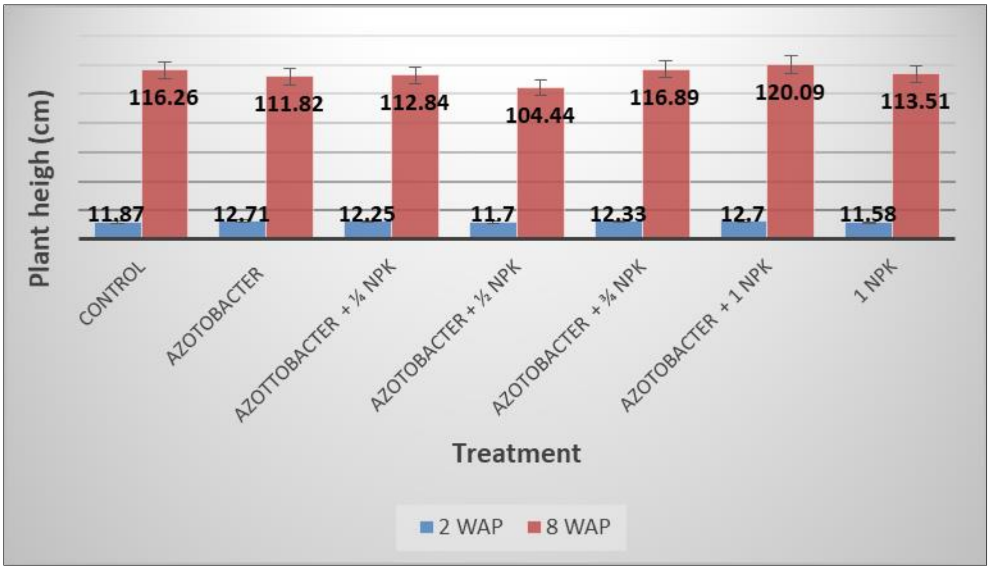

Figure 3 Graph of Average Height of Tomato Plants in Various Treatments at Age 2 WAP- 8 WAP

The following text discusses the growth of tomato plants and the effects of Azotobacter and NPK on their height. At the age of 2 WAP, the height of the plants remains uniform, ranging from 11-13 cm. However, during the final vegetative phase, known as 8 WAP, the growth of the tomato plants was observed to increase more rapidly. This is due to the inoculation of N-fixing consortium and NPK, which significantly affect plant growth. A combination of one recommended dose of NPK and N-fixing consortium culture inoculation produced the highest plant height of 120.09 cm, which is higher than the NPK application treatment alone. The study found that the N-fixing culture inoculation combined with ½ dose of NPK resulted in the lowest growth in plant height. This indicates that high nitrogen is required in Andisol soil order, but due to the Azotobacter inoculation was resulting an increase in plant height. The result proves that the role of N-fixing consortium supplied nitrogen and phytormones to plants. Azotobacter is known as an N-fixing bacteria that can provide the necessary soil requirements for plants and can synthesize growth-promoting substances such as IAA, cytokinin, and auxin, which are essential for plant growth [19, 28]. Azotobacter inoculation has been proven to increase the growth of vegetables, fruit, and cash crops. The inoculation with Azotobacter has beneficial effects on plant yields [2, 5] due to the increase of fixed nitrogen content in the soil and the microbial secretion of stimulating hormones, such as gibberellins, auxins, and cytokinins [19]. In this research that *Azotobacter* sp. and *Azotobacter vinelandii* in mixed culture showed have potent to increase height of tomato plant.

3.3. Soil total-Nitrogen

Based on the results of statistical analysis, it shows that the application of Azotobacter culture inoculation combined with NPK has a real effect on soil total-N, shown in Table 3.

Table 3 Effect of Combination of N-fixing Culture combined by NPK on Soil total-N in Lembang Andisol

Code	Treatment	Soil total-N (%)
A	Control	0.37a
B	N-fixing culture	0.39abc
C	N-fixing + ¼ NPK	0.40bcd
D	N-fixing + ½ NPK	0.38ab
E	N-fixing + ¾ NPK	0.39abc
F	N-fixing + 1 NPK	0.42d
G	1 NPK	0.39abc

Note: The numbers followed by the same letter are not significantly different based on Duncan's Multiple Range Test at the 5% level.

The study found that the treatment F, which involved N-fixing inoculation combined with one NPK dose resulted in the highest N-total value of 0.42%. This value was significantly different ($p<0.05$) from the control treatment, which yielded the lowest total N result of 0.37%. On the other hand, treatment A (Control treatment) resulted in the lowest total N value. The research showed that inoculating with Azotobacter can substitute for N availability and reduce the need for inorganic N fertilizer by 25% - 75%. The treatment with one dose of NPK was not significantly different from the treatments with doses of 1/4 N, 1/2 N, and 3/4 NPK (C, D, and E) added by N-fixing inoculation. The study also revealed that treatment C is the most efficient in fertilizing because it produces results that are not significantly different from the treatment with a higher dose of 1 NPK, despite using a lower dose of NPK.

This study has revealed that *Azotobacter* sp. and *Azotobacter vinelandii* (N-fixing bacteria consortium) can fix nitrogen from the atmosphere and convert it into a form that is available to plants, thereby increasing the total nitrogen content of the soil. The application nitrogen-fixing bacteria, as demonstrated by Mahendran and Kumar [15], can enhance soil nutrients more effectively than inorganic nitrogen fertilizers. Azotobacter speeds up the mineralization of organic residues in the soil, making certain nutrients such as carbon, nitrogen, phosphorus, and Sulphur available, while preventing the uptake of heavy metals [12]. Azotobacter is a favorable alternative to chemical fertilizers since it supplies nitrogen in the form of ammonia, nitrate, and amino acids without the risk of over-fertilization. It is one of the potential substitutes for inorganic nitrogen sources such as Urea.

3.4. N-uptake of Tomato Plant

The statistical analyses results show that the inoculation of *Azotobacter* sp. and *Azotobacter vinelandii* isolate cultures combined with NPK has a natural effect on the N uptake of tomato plants. The results are displayed in Table 4.

Table 4 Effect of the combination of N-fixing consortium culture with NPK on N-uptake of Amala variety tomato plants

Code	Treatment	N-level (%)	N-up take (mg/plant)
A	Control	15.83	4.69ab
B	N-fixing culture	15.94	5.38bc
C	N-fixing + ¼ NPK	20.71	6.60d
D	N-fixing + ½ NPK	19.80	6.33cd
E	N-fixing + ¾ NPK	16.92	4.90ab
F	N-fixing + 1 NPK	12.95	3.91a
G	1 NPK	13.16	4.03a

Note: The numbers followed by the same letter are not significantly different based on Duncan's Multiple Range Test at the 5% level

As an investigation result revealed that treatment C (N-fixing + ¼ NPK) showed the highest N absorption results compared to other treatments with a 6.60 mg/plant yield. In comparison, treatment F (N-fixing + 1 NPK) showed the lowest yield, 3.91 mg/plant. When the dose of NPK fertilizer given is higher than treatment C (N-fixing + ¼ NPK), such as in treatment D (N-fixing + ½ NPK), treatment E (N-fixing + ¾ NPK) or with the total dose of NPK in treatment F (N-fixing + 1 NPK) tend to decrease N uptake. It is suspected that N-fixing functional microbes can only provide N that plants with low doses of NPK can effectively absorb. In contrast, high doses of NPK will result in suppressed Azotobacter activity so that they cannot grow and fix N effectively. Maximum to provide soil N. This is because, due to high doses of NPK, the population of N-fixing microbes (*Azotobacter* spp.) tends to be suppressed and does not develop optimally, so it is ineffective in fixing N. According to Saraswati *et al*. [21], the fixation of N_2 by microbes can be hampered if excess mineral N is given. According to Katupitiya and Vlassak [10], existing high doses of N fertilizer inhibits the activity of the nitrogenase enzyme in N-fixing bacteria, thereby inhibiting N fixation.

The presence of N-fixing functional microbes like *Azotobacter* sp. and *Azotobacter vinelandii* in the soil can increase the overall nitrogen content, which tomato plants can absorb. Therefore, the uptake of nitrogen by tomato plants is higher as compared to the application of NPK fertilizer alone. This is supported by the research conducted by Mahendran and Chandramani [14], Mahendran and Kumar [15], Medhat *et al*. [16], Kader *et al*. [9], which indicates that bioinoculants containing Azotobacter sp. can enhance the nutrient uptake of plants by binding nitrogen. *Azotobacter* sp. also helps sustain plant growth and yield, even in soils with low phosphate content, while aiding the uptake of macro and certain micronutrients [8].

3.5. The population of Azotobacter spp.

The results of statistical analyses show that the application of liquid compound-biological fertilizer combined with NPK did not significantly affect the population of *Azotobacter* spp. They are shown in Table 5.

Table 5 Effect of Combination of N-fixing consortium inoculation with NPK on the Population of *Azotobacter* spp. on Andisols Lembang

Code	Treatment	*Azotobacter* spp. population (CFU/g)
A	Control	1.28×10^4a
B	N-fixing culture	1.45×10^4a
C	N-fixing + ¼ NPK	1.98×10^4a
D	N-fixing + ½ NPK	2.05×10^4a
E	N-fixing + ¾ NPK	2.33×10^4a
F	N-fixing + 1 NPK	1.80×10^4a
G	1 NPK	2.20×10^4a

Noted: numbers followed by the same letter are not significantly different based on Duncan's Multiple Range Test at the 5% level.

The initial population of Azotobacter spp. prior to the experiment was 0.5×10^3 CFU/g. As a result of the application of *Azotobacte*r sp. and *Azotobacter* sp., there was a significant increase in the population of *Azotobacter* spp. Treatment E (N-fixing + 3/4 NPK) produced the highest population of *Azotobacter* spp. at 2.33×10^4 CFU/g, while the lowest population was seen in treatment A (Control) at 1.28×10^4CFU/g. Even treatments without N-fixing inoculation, namely treatment A (Control) and treatment G (1 NPK), experienced an increase in the population of *Azotobacter* spp. compared to before treatment. This was due to the presence of *Azotobacter* spp—indigenous, which has good adaptability to the experimental field. The population of *Azotobacter* spp. increased with increasing Azotobacter application and NPK dose, as seen in treatments B (N-fixing) to E (N-fixing + ¾ NPK). The population of *Azotobacter* sp. tends to increase through inoculation of *Azotobacter* spp. isolates combined with the application of low NPK doses (¼, ½, and ¾), indicating the ability of *Azotobacter* sp. to grow well. However, in treatment F (N-fixing + 1 NPK), the population of *Azotobacter* spp. tends to be lower because the high dose of NPK results in the growth of *Azotobacter* spp. being depressed, so the population tends to be lower.

These results indicate that the *Azotobacter* spp. population can grow optimally under low NPK doses. The inoculation of *Azotobacter* sp. and *Azotobacter vinelandii* tend to increase the population of Azotobacter spp. in soil, although there is no significant difference between treatments. The presence of root exudates in the environment around the rhizosphere is also thought to play a role in increasing the population of *Azotobacter* spp. According to Suba-Rao [24], the rhizosphere environment is a good growth place for microbes because there are root exudates in the form of amino acids, sugars, and organic acids released by the roots, which become stimulants that can increase microbial population and activity.

3.6. Tomato Yield Component

Table 6. revealed the effect of the combination of N-fixing isolate consortium with NPK on the yield components of the Amala variety of tomato plants. The results of statistical analyses demonstrate that the application of two Azotobacter isolates in the form of a consortium culture combined with NPK has a significant effect on yield components, which include weight per fruit, fruit weight per plant, and number of fruit per plant in Amala variety tomato plants. Yield components indicate the quality of the fruit produced by the tomato plant.

The component data of Tomato yield is displayed in Table 6. The results reveal that the weight per fruit ranges from 104 - 110 g. According to the description, the Amala variety tomato plant has the potential weight per fruit ranging from 101 g to 117 g. Doe to C (N-fixing+ ¼ NPK) treatment resulted the significantly highest tomato weight per fruit, namely 110.56 g/ fruit.

According to the statistical analysis, the treatment of N-fixing + 1/4 NPK (C) resulted also in significantly higher fruit weight per plant and number of plants, which was 2356.67 g/plant and 68.33 fruits, respectively, compared to other treatments. On the other hand, Treatment B had lower yields with 1895.00 g/plant and 41 fruits. The Amala variety tomato plant is known to have the potential to produce several fruits ranging from 19 to 33 fruits per plant during harvest. However, applying a combination of Azotobacter isolate fertilizer combined with NPK application increased the number of fruits beyond the potential of the Amala tomato.

Table 6 Effect of the combination of N-fixing isolate consortium with NPK on the yield components of the Amala variety of tomato plants

Code	Treatment	Weight per Fruit (g)	Fruit Weight per plant (g/plant)	Number of Fruits per Plant
A	Control	105.19a	1768.33a	52.33a
B	N-fixing culture	109.70a	1895.00a	41.00a
C	N-fixing + ¼ NPK	110.56b	2356.67b	68.33b
D	N-fixing + ½ NPK	109.19a	2193.33a	51.67a
E	N-fixing + ¾ NPK	106.07a	2073.33a	52.33a
F	N-fixing + 1 NPK	107.78a	2120.00a	55.67a
G	1 NPK	105.22a	1840.00a	46.67a

Note: numbers followed by the same letter are not significantly different based on Duncan's Multiple Range Test at the 5% level

The data on yield components of fruit weight per plant were obtained from a total of 5 harvests. The resulting averages were taken for each repetition. Treatment C (N-fixing + ¼ NPK) resulted the highest yield in the fruit weight per plant component, producing 2356.67 g/plant, while treatment A (control treatment) gave lower yields of 1768.33 g/plant. The Amala tomato can produce a potential yield ranging from 2100-3070 g/plant. If the average population of tomato plants per hectare is 20,000, then the fruit weight of the plant can be converted from kg/plant to tons/ha with a correction factor of 15%. This correction factor is used to adjust the ideal conditions to actual conditions for a specific variable. The conversion results of fruit weight from kg/pot to tons/ha are shown in table 7.

The results of the study shows that N-fixing + ¼ NPK + ¼ NPK (C) treatment tends to produce higher crop yields compared to other treatments. Treatment C is also efficient because it requires a low NPK dose (¼ NPK dose) yet still provides better results than a full dose of NPK. This indicates that the use of *Azotobacter* sp. and *Azotobacter vinelandii* in mixed culture can be effective at low doses of NPK fertilizer. The activity of the Azotobacter consortium used in the research showed have potent in increasing crop yields. Ramakrishnan and Selvakumar [18] have reported that Azotobacter can enhance the availability of nitrogen in the soil, leading to increased plant yields. Renuka and Ravishankar [20] found that Azotobacter and Azospirillum play a crucial role in nitrogen fixation from the atmosphere and the production of phytohormones like IAA, GA3, and cytokinins. These hormones are important for fruit formation. Furthermore, some strains of Azotobacter can produce amino acids when grown in culture media with different carbon and nitrogen sources. These amino acids, which are involved in different processes that promote plant growth, can help explain the plant-growth-promoting properties of rhizobacteria [13] The use of Azotobacter inoculated resulted in higher biochemical analysis of chlorophyll, nitrogen, phosphorous, potassium, and protein content, leading to increased tomato yield.

Table 7 Results of Conversion of Fruit Weight Units per Plant to tonnes/ha

Code	Treatment	Results Conversion g/plant to tonnes/ha
A	Control	30.06
B	N-fixing culture	32.22
C	N-fixing + ¼ NPK	40.06
D	N-fixing + ½ NPK	37.29
E	N-fixing + ¾ NPK	35.25
F	N-fixing + 1 NPK	36.04
G	1 NPK	31.28

Note: numbers followed by the same letter are not significantly different based on Duncan's Multiple Range Test at the 5% level

4. Conclusion

Lembang Andisol has an acidic pH, moderate available nitrogen, and high phosphorus retention. However, it contains high organic matter but has a low indigenous *Azotobacter* spp. population, specifically $0.5x10^3$ CFU/g soil. The study showed that applying *Azotobacter* sp. and *Azotobacter vinelandii* (N-fixing bacteria) in combination with a single dose of NPK can enhance plant height and total soil nitrogen content. Similarly, N-fixing inoculation combined with 1/4 NPK, 1/2 NP, and 3/4 NPK can improve plant nitrogen uptake. Additionally, using N-fixing + 1/4 NPK significantly increased tomato yield, including fruit weight, number of fruits, and yield per hectare of tomatoes compared to using 1 NPK without N-fixing inoculation. When *Azotobacter* sp. and *Azotobacter vinelandii* were inoculated in mixed culture, it was found that NPK usage can be reduced by 75% with higher tomato yields. Further research should examine different crops and test the extent of these findings in various ecological zones and soil conditions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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