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Effectivity of borate micro fertilizer on yield of cucumber (*Cucumis sativus* L.)

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Abstract

Boron (B) is one of the most essential nutrients for fertilization and the production of fruits and seeds, however the availability of boron in soil is very limited. The aim for this experiment is to test the borate micro fertilizer to improve the growth and production of cucumber (*Cucumis sativus*). The fertilizer used in this experiment is borate micro fertilizer which contain 46% or 460 g.kg^{-1} B_2O_3. The experiment was conducted at Cibadak Village, Sukaresmi District, Cianjur Regency, West Java Province. Treatments in this experiment were arranged within five rates of fertilizer, which are: without fertilizer (P0); 0.5 rate of Borate fertilizer (0.5 B) (P1); 1.0 rate of Borate fertilizer (1.0 B) (P2); 1.5 rate of Borate fertilizer (1.5 B) (P3); and 2.0 rate of Borate fertilizer (2.0 B) (P4). The result showed that the treatment of 0.5 to 2.0 rate of borate micro fertilizer can produce growth characteristics and plants that are better compared to the control treatment. Applicating 0.5 rate of borate micro fertilizer even has the capacity of yielding production up to 48.960 kg.ha^{-1}. The 0.5 rate of Borate micro fertilizer treatment was concluded as the most effective one compared to other treatments, due to its capacity to produce the highest relative agronomical effectivity value, which is 152%. The recommended rate of Borate fertilizer is 25 kg.ha^{-1} given by soil drench at 15 and 30 DAP (days after planting) with the concentration is 1.5 g.L^{-1} and the volume is 250 ml/plant.

Keywords: horticulture, micro fertilizer, plant nutrient, productivity

Introduction

Cucumber is a popular fruit vegetable in Indonesia and in the world, commonly served fresh as pickles, salad, or juice. Cucumber nutritional content includes 0.65% protein, 0.1% fat, 2.2% carbohydrates, and essential minerals and vitamins such as calcium, iron, magnesium, phosphorous, and vitamins A, B1, B2, and C (Abbey et al., 2017). Additionally, cucumbers contain 35,100 – 486,700 ppm of linoleic acid (Gustia, 2016). These diverse components contribute to its health benefits, leading to its frequent use in cosmetics and medicine.

Despite its popularity, the availability of cucumbers in Indonesia has been unstable over the past decade. According to the Indonesian Center of Statistics (BPS), cucumber production experienced a decline from 2011 to 2017 but saw an increase from 2018 to 2021. In 2021, production reached 471,941 tons, a 6.95% increase compared to the previous year. However, it still fell short of the 2011 production levels. Rahma and Masrury (2021) attributed this fluctuation to factors such as seed quality and insufficient knowledge of optimal harvesting practices.

Cultivation methods, including fertilization, play a crucial role in enhancing cucumber quality. Fertilization aims to improve soil fertility and provide essential nutrients for plant growth. Soepardi (1985) emphasized the importance of organic materials in soil, which not only serve as a nutrient source but also enhance soil properties and microbial activity. Macronutrients and micronutrients, such as boron (B), are vital for plant growth and development. Boron, primarily located in cell walls, influences nutrient uptake and plant metabolism (Hu and Brown, 1994). Its application enhances fruit quality and improves growth parameters in various crops, including tomatoes (Xu et al., 2021).

Boron deficiency is prevalent worldwide and can adversely affect plant growth and development. Symptoms include inhibited leaf expansion and root elongation (Day and Aasim, 2020). Addressing boron deficiency in agriculture poses challenges due to the narrow margin between deficiency and toxicity (Arunkumar et al., 2018). Proper management, including precise application of boron fertilizers, is crucial for optimizing fruit growth and quality in crops like cucumbers (Nemeata-Alla, 2017). The objective of this experiment is to evaluate the efficacy of borate

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micro fertilizer in enhancing the growth and production of cucumber.

Material and Methods

The experiment was conducted at Cibadak Village, Sukaresmi District, Cianjur Regency, West Java within 4 months starting from May until August of 2023. Materials that were used in this experiment were the seeds of cucumber (*Cucumis sativus*) and borate micro fertilizer (46% or 460 g.kg^{-1} B_2O_3 borate), manure, dolomite, NPK fertilizer, MKP and $CaCO_3$ also insecticide and fungicide according to field necessity.

Soil fertility was analysed after land preparation and before planting. The treatment used to evaluate borate micro fertilizer by comparing the fertilizer's effect in different rates on the growth and production variables of the cucumber. Rate treatments for fertilizer evaluation are based on Indonesian Ministry of Agriculture. Five levels of fertilization were tested: without fertilizer as control treatment (P0), 0.5 rate of borate fertilizer (0.5 B) (P1), 1.0 rate of borate fertilizer (1.0 B) (P2), 1.5 rate of borate fertilizer (1.5 B) (P3), and 2.0 rate of borate fertilizer (2.0 B) (P4).

and 21 DAP (days after planting). NPK fertilizer was given by soil drench at a rate of 100 kg.ha^{-1}, while potassium fertilizer (kg.ha^{-1}) and calcium fertilizer (0.75 kg.ha^{-1}) were given by foliar spray. There were 10 representative plants chosen randomly as model plants in each plot for observation. The variables observed in this experiment are number of flowers observed at 25 DAP, number of fruits observed at 30 DAP before the first harvest, fruit length and fruit diameter observed in each harvest, yield and phototoxicity. Yield of cucumber measured by counting the total weight of cucumber from the first to the last harvest. Phototoxicity observed by looking for the symptoms of plant phototoxicity on the 3rd day after treatment.

The data were analysed with the SAS statistical analysis program using analysis of variance (F-test) and the significant variables were further analyzed using Duncan Multiple Range Test (DMRT) at the level of 5%. The borate fertilizer considered effective if the RAE value equal or greater that 95% and there is no phototoxicity observed. Relative agronomic effectiveness (RAE) of the borate fertilizer was measured using an equation as follows (Machay et al., 1984).

$$RAE = \frac{\text{Cucumber production from standard fertilizer + rate of borate fertilizer}}{\text{Cucumber production from standard fertilizer}} \times 100\%$$

Table 1. The details of borate fertilizer treatments in cucumber

Code of treatment	Treatment	Borate concentration (g.L^{-1})	Volume per plant (ml)	Volume per plot (L)	Fertilizer rates (kg.ha^{-1})
P0	Control	0	250	0	0
P1	0.5 B	1.5	250	20	25
P2	1.0 B	3.0	250	20	50
P3	1.5 B	4.5	250	20	75
P4	2.0 B	6.0	250	20	100

The experiment was designed in five repetitions so that there were 25 experimental units (plot) with an area of each plot is 5 m x 5 m with 4 beds. Each bed was planted with 20 cucumber seeds with planting distance is 60 cm x 50 cm, so that there were 80 populations of cucumber per square. Application of manure at a rate of 15 t.ha^{-1} and dolomite at a rate of 2 t.ha^{-1} were conducted before planting. Borate fertilizer application was set 2 times by soil drench at 15 and 30 DAP. The amount of borate fertilizer applied based on the treatment as shown in Table 1. Compound fertilizer (NPK), potassium fertilizer (MKP) and calcium fertilizer ($CaCO_3$) were given at 7

Result and Discussion

Fertilizer Quality Analysis

As plants constitute the foundation of the food chain, there are some concerns about the possibility of toxic concentrations of heavy metal elements being absorbed to a plant and then transported from plants to the other consumer (Peralta-Videa, 2009). It is important to prove that fertilizer used contain nutrients that have been claimed and fulfilled the minimum standard of heavy metals. Fertilizer quality analysis showed that the quality of borate micro fertilizer has

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fulfilled the minimum technical requirements from Indonesian Ministry of Agriculture (Table 3). Borat micro fertilizer used in this experiment contain 46% B_2O_3. This fertilizer has passed the maximum standard of heavy metal.

Soil Analysis Before Treatment

The soil analysis was done before treatment by acquiring soil samples from every plot of treatment which then composited. The soil test was aimed for understanding the level of soil fertility which will be used before the experiment. The soil analysis result can be seen in Table 4. The soil in the experiment location tends to be acidic with average C-organic content. The N-total, P-potential and K-potential contents tend to be high according to Balittanah (2005). Based on the soil analysis result, application of manure and dolomite were conducted before planting to improve the acidity value and organic matter of the soil.

Growth and Production of Cucumber

Borate fertilizer significantly affected the number of flowers, number of fruits and yield of cucumber (Table 5). The cucumber fruits showed significant increases in fruit length and fruit diameter at 8 and 10 WAP (weeks after planting).

Our results demonstrated a significant increase in the number of flowers and fruits of cucumber with borate micro fertilizer treatment compared to the control (Table 6). Particularly, the application of a 0.5 rate of borate micro fertilizer resulted in the highest number of flowers and fruits compared to other treatments. Specifically, the 0.5 rate borate fertilizer treatment yielded an average of 7.48 flowers and 5.32 fruits per plant. This represents a notable enhancement, with a 38% increase in the number of flowers and a 66% increase in the number of fruits compared to the control group.

Previous research has also highlighted the positive effects of boron fertilizer application on flower and fruit development in various crops. For instance, Naz et al. (2012) found that boron fertilizer application led to increased flower cluster per plant and fruit set percentage in tomatoes, while Rajakumar and Lal (2014) observed increased flower and fruit retention in guava. Hegazi et al. (2018) reported that boron tends to accumulate more in reproductive organs than vegetative organs in olive trees, potentially leading to improved fruit set and yield through balanced endogenous hormone regulation, such as auxin, gibberellin, and abscisic acid.

Table 3. Components and composition of borate micro fertilizer.

Parameters	Value
B_2O_3	46.88 %
Na_2O	20.76 %
SO_4	0.001 %
Moisture content	0.47 %
As	<0.002 ppm
Pb	<0.002 ppm
Cd	25.08 ppm
Hg	<0.001 ppm

Table 4. Soil analysis result before treatment

Parameters	Value
pH H2O	5.11
C-Organic (%)	2.47
Total N (%)	0.35
Dissolve P (ppm P_2O_5)	140.52
CEC ($cmol.kg^{-1}$)	22.08
Exchangeable K (cmol $K.kg^{-1}$)	1.57
P-potential (mg $P_2O_5.100g^{-1}$)	254.96
K-potential (mg $K_2O.100g^{-1}$)	42.44

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Table 5. Recapitulation of variance analysis on the growth and production variables of cucumber

Variables	Fertilization	Pr>F	CV (%)
Number of flowers	**	<0.0001	4.98
Number of fruits	**	<0.0001	10.77
Fruit length			
week 2	*	0.0453	4.35
week 4	ns	0.3876	2.65
week 6	ns	0.0678	2.21
week 8	**	0.0003	1.17
week 10	**	0.0033	1.49
Fruit diameter			
week 2	ns	0.0901	3.22
week 4	ns	0.3594	6.11
week 6	**	0.0077	2.62
week 8	**	0.0031	3.48
week 10	**	0.0045	3.43
Yield per plot	**	0.0004	11.19
Yield per ha	**	0.0004	11.27

CV = Variance Coefficient of variation, ** = significant at α=0.01, * = significant at α=0.05, ns = not significant.

Table 6. Effect of borate micro fertilizer application on the number of flowers and fruits of cucumber

Treatment	Flower number	Fruit number
Control	5.40 d	3.20 d
0.5 B	7.48 a	5.32 a
1.0 B	6.50 b	4.30 b
1.5 B	6.36 b	4.18 bc
2.0 B	5.86 c	3.60 cd

Note: Values within the same column followed by the different letter are significantly different based on the DMRT at α=0.05.

Fruit length observation was done on the harvesting day of 2,4,6,8, and 10 with 5 samples of cucumber fruits. Results of 0.5 – 2.0 rate of borate micro fertilizer was significant on the 2nd day of harvest and very significant on the 8th and 10th. In the application of 0.5 rate borate micro fertilizer showed length of fruit significant statistically and in terms of length in comparison to the control and other treatments. The average length of cucumber fruit with 0.5 rate of borate micro fertilizer from the 2nd – 10th day of harvest was within the range of 15.22 – 15.96 cm (Table 7).

The application of borate micro fertilizer at rates ranging from 0.5 to 2.0 demonstrated significant effects on fruit diameter, particularly noticeable on the 6th, 8th, and 10th day of harvest. Addition of the fertilizer led to a significantly larger fruit diameter compared to the control group (Table 8). The fruit diameter resulting from the application of the 0.5 rate of the fertilizer surpassed that of other fertilization rates, showing a consistent trend. The mean cucumber fruit diameter with the 0.5 rate of borate fertilizer ranged from 3.30 to 3.46 cm from the 2nd to the 10th day of harvest.

Application of 0.5 rate of borate micro fertilizer resulted in a higher yield per square compared to the control treatment (Table 9). Additionally, when considering the potential yield per hectare based on land area measurement, the 0.5 to 1.5 rate of borate micro fertilizer treatments exhibited higher potential yields compared to the control. Among these, the 0.5 rate of borate micro fertilizer treatment consistently yielded the highest results both per square and per hectare compared to other treatments. Specifically, the yield obtained from the 0.5 rate of borate fertilizer was approximately 122.4 kg per plot or approximately 48,960 kg.ha^{-1}.

However, it's worth noting that the yields from the

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Tabel 7. Effect of borate micro fertilizer application on the length of cucumber fruits

Treatment	Fruit length on the -n harvesting day				
	2	4	6	8	10
Control	13.98 b	15.62	15.16	14.97 b	15.28 b
0.5 B	15.22 a	15.96	15.83	15.69 a	15.87 a
1.0 B	14.82 ab	15.67	15.46	15.37 b	15.84 a
1.5 B	15.02 a	16.06	15.30	15.37 b	15.50 b
2.0 B	14.35 b	15.69	15.50	15.39 b	15.44 b

Note: Values within the same column followed by the different letter are significantly different based on the DMRT at α=0.05.

Tabel 8. Effect of borate micro fertilizer application on the diameter of cucumber fruits

Treatment	Fruit diameter on the -n harvesting day				
	2	4	6	8	10
Control	3.18	3.30	3.10 b	3.17 b	3.07 b
0.5 B	3.30	3.38	3.32 a	3.46 a	3.36 a
1.0 B	3.14	3.13	3.18 b	3.18 b	3.22 ab
1.5 B	3.11	3.28	3.15 b	3.19 b	3.09 b
2.0 B	3.16	3.19	3.16 b	3.19 b	3.14 b

Note: Values within the same column followed by the different letter are significantly different based on the DMRT at α=0.05.

1.0 to 2.0 rate of borate fertilizer treatments were significantly lower than those from the 0.5 rate treatment. This discrepancy may be attributed to the potential toxicity of boron, despite the absence of visible symptoms based on phototoxicity analysis. Boron, being a micronutrient required in small amounts by plants, has a narrow threshold between deficiency and toxicity (Arunkumar et al., 2018). Studies by Yau et al. (1994) and Cikili et al. (2013) highlight the sensitivity of plants to boron levels, with deficiencies or excesses adversely affecting plant growth and yield.

The analysis of relative agronomical effectivity (RAE) values revealed variability across the different rates of borate micro fertilizer application. The highest RAE value was associated with the 0.5 rate of borate micro fertilizer, indicating its superior effectiveness in enhancing cucumber plant productivity compared to other rates. The RAE value for the 0.5 rate of borate micro fertilizer was calculated at 153%, signifying that this treatment could potentially increase cucumber yield by 1.53 times compared to the control treatment.

Nitrogen (N), phosphorus (P), and potassium (K) fertilization are macro elements essential for plant growth and development as they are essential for photosynthesis and the production of photosynthate (Subhan et al., 2009). Additional fertilization is often required to optimize the effectiveness of NPK fertilizers in supporting plant growth and production. Boron (B) supplementation is one such addition, as it is typically limited in soil and essential for various physiological processes in plants.

Boron plays a crucial role in RNA synthesis, cell division, cell maturation, respiration, and growth (Sutiyoso, 2003). It also maintains the health of conductive tissue and parenchyma, facilitating the transport of water, nutrients, and organic compounds to actively growing parts of the plant (Rio, 2022). Studies by Bommesh et al. (2017) have shown that boron application can enhance cucumber dry matter production by increasing chlorophyll levels, leaf area, and photosynthetic activity.

In borate micro fertilizer treatments, boron significantly affects cucumber growth and production, influencing parameters such as flower and fruit numbers, fruit length and diameter, as well as yield per square and potential yield. This aligns with findings from Sarwar et al. (2021), who reported that boron supplementation can enhance flower and fruit production in cucumbers by improving flower production and retention, pollen tube elongation and germination, seed, and fruit growth.

Boron deficiency during the reproductive growth phase can lead to bud and flower withering, resulting in reduced seed and fruit formation and compromised fruit quality (Wang et al., 2015). Application of boron fertilizer, particularly at a 0.5 rate, has been shown to increase flower and fruit production compared to other rates. Boron also plays a role in carbohydrate

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Tabel 9. Effect of borate micro fertilizer application on cucumber production

Treatment	Yield (kg per plot)	Potential yield ($kg.ha^{-1}$)	RAE (%)
Control	80.70 b	32.28 c	-
0.5 B	122.40 a	48.96 a	152
1.0 B	97.90 b	39.15 b	121
1.5 B	103.20 b	41.28 b	128
2.0 B	92.30 bc	36.91 bc	114

Note: Values within the same column followed by the different letter are significantly different based on the DMRT at α=0.05. RAE: relative agronomical effectivity.

transport from photosynthesis, thereby improving photosynthetic efficiency and ultimately increasing fruit production (Ai, 2022). The fruit production is indicated by fruit weight, which is determined by fruit diameter and flesh width (Rahma et al., 2015). Therefore, the addition of boron at various rates can lead to increased cucumber fruit production due to its multiple effects on plant physiology and metabolism.

As can be seen from Figure 1, the diameter and width of cucumber fruit on different fertilizer rates are apparent. The largest fruit diameter is from the application of 0,5 rate borate micro fertilizer. On Figure 2, it shows that the length of cucumber fruit with 0.5 rate borate micro fertilizer is also higher compared to other rates. Phytotoxicity observation did not show any symptoms after 3 days of application. All cucumber plants appeared to be normal as shown by Figure 3. Based on RAE measurement, adding 0.5 borate micro fertilizer is very effective on cucumber plants which is it can increase yield of cucumber 1.53 higher than control treatment (without boron fertilizer). Nevertheless, application of boron fertilizer must be done by considering the boron availability in the soil to prevent boron toxicity which can be detrimental for plants. On the other hand, it is important to study the responsiveness of other crops and other varieties of cucumber to boron fertilizer.

Figure 1. Diameter and width of cucumber fruit flesh; P0: without fertilizer as control treatment, P1: 0.5 rate of borate fertilizer (0.5 B), P2: 1.0 rate of borate fertilizer (1.0 B), P3: 1.5 rate of borate fertilizer (1.5 B), P4: and 2.0 rate of borate fertilizer (2.0 B), U1: replicate 1, U2: replicate 2, U3: replicate 3, U4: replicate 4.

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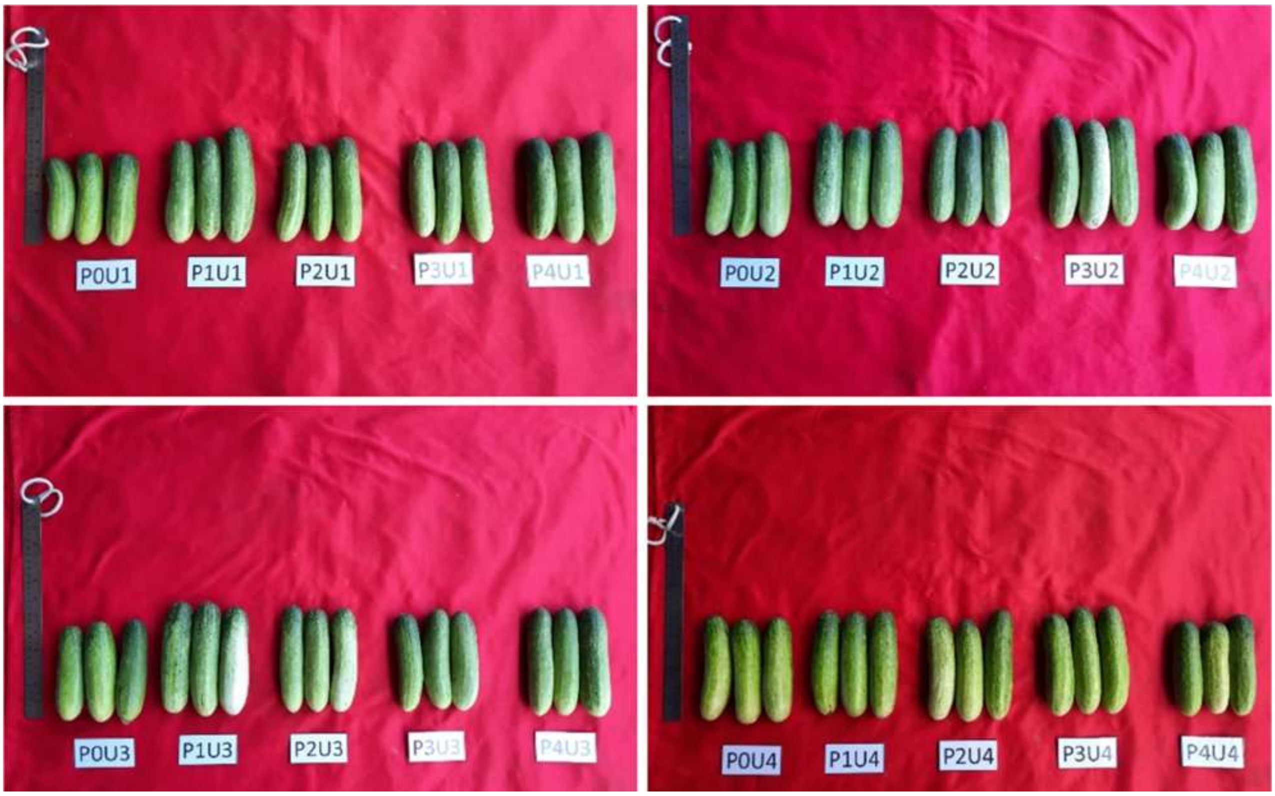

Figure 2. Cucumber fruit length with varying rates of borate micro fertilizer. P1: 0.5 rate of borate fertilizer (0.5 B), P2: 1.0 rate of borate fertilizer (1.0 B), P3: 1.5 rate of borate fertilizer (1.5 B), P4: and 2.0 rate of borate fertilizer (2.0 B), U1: replicate 1, U2: replicate 2, U3: replicate 3, U4: replicate 4.

Figure 3. Cucumber plants after application of borate micro fertilizer at 15 DAP (A) and 30 DAP (B)

Conclusion

Addition of borate micro fertilizer at rates ranging from 0.5 to 2.0 significantly improves cucumber growth characteristics and yield compared to the control group. The application of the 0.5 rate of borate micro fertilizer can yield up to 48,960 $kg.ha^{-1}$ and exhibits the highest relative agronomical effectivity value at 152%, making it the most effective among the treatments assessed. Visual inspection did not reveal any signs of phototoxicity throughout the experimental period for treatments ranging from 0.5 to 2.0 rates of borate micro fertilizer. Based on its effectiveness in enhancing cucumber plant growth and yield, it is recommended to apply borate micro fertilizer at a rate of 25 $kg.ha^{-1}$ via soil drenching at 15 and 30 days after planting (DAP). The recommended concentration of the borate fertilizer solution is 1.5 $g.L^{-1}$, with a volume of 250 ml per plant.

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