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Growth and Yield Responses of Red Chili to Various Foliar Fertilizers

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ABSTRACT

Red chili production in certain areas of Central Java, including Sendangijo Village, Wonogiri Regency, remains relatively low. One alternative to improve its growth and yield is foliar fertilization. This study aimed to determine the most effective type of foliar fertilizer for enhancing the growth and yield of red chili. The study was conducted from May to September 2023 in Sendangijo Village using a Randomized Complete Block Design with a single factor consisting of four treatments: no foliar fertilizer, foliar fertilizer A. NPK 11-8-6, B. NPK 20-15-15, and C. NPK 10-2-7, each with six replications. Observed variables included plant height, number of dichotomous branches, number of leaves, leaf area, fresh and dry weight of biomass, number of fruits, fresh weight of fruits per plant, and productivity per hectare. The result showed that the leaf area of red chili pepper given foliar fertilizer NPK 20-15-15 was larger than the foliar fertilizer NPK 11-8-6, NPK 10-2-7, and without foliar fertilizer. Foliar fertilizer NPK 20-15-15 also gave a heavier dry weight of biomass compared to foliar fertilizer NPK 11-8-6, NPK 10-2-7, and without foliar fertilizer. However, foliar fertilizer application did not significantly affect the number of fruits, the fresh weight of fruits per plant, or productivity per hectare.

Keywords: *Capsicum annuum;* Foliar application; Leaf area; Macronutrient; Vertisol

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INTRODUCTION

Red chili (*Capsicum annuum* L.) is one of the fruit and vegetable horticultural crops with high economic value due to its diverse benefits, so the demand for it by the community continues to increase (Nurvitasari et al., 2018). The level of consumption is high and is growing relatively every year, along with population growth, particularly in Central Java. The production of curly red chili in Central Java in some areas is still relatively low, for example, Wonogiri Regency, which in 2020 contributed only 1.3% of the total chili production in Central Java (Statistics-Central Java Indonesia 2021). The low production is presumed to be caused by the suboptimal use of vacant land in Sendangijo Village, Wonogiri Regency, which is characterized as Vertisol soil based on its physical and chemical properties.

Initial soil physical analysis revealed that the study site had a clayey-textured soil with poor drainage and developed cracks during the dry season. This soil exhibits physical properties of swelling and shrinking, a heavy texture, and a low water infiltration rate, resulting in slow drainage (Bani and Neonbeni 2022). This is due to the soil texture of Vertisols, which is rich in clay and clay minerals, resulting in high bulk density (Rahman et al. 2017). Chemically, Vertisols generally have a high organic matter content and an alkaline pH. Nonetheless, the initial soil chemical analysis results showed that the soil pH value of 6.53 was classified as slightly acidic, with a moderate organic C content of 2.83%. This difference can be caused by land conditions that are not intensively cultivated or a lack of organic matter input over time.

Curly chili plants can grow in almost all types of soil suitable for agricultural cultivation (Taufani et al. 2019), including Vertisols. However, based on the initial soil chemical analysis, it was found that, in addition to the slightly acidic soil pH, the phosphorus content was also relatively low (19.68 ppm). This is a key constraint in the growth and development of chili plants at the study site. Phosphorus plays a crucial role in enhancing the yield and intensity of red color in fruits, such as chili peppers (Hunde 2020). Moderate organic C and nitrogen contents also indicate that soil fertility at the study site remains suboptimal. This limitation in organic C content can be attributed to the lack of organic matter input and the characteristics of Vertisol, which has a clay texture with high density and tends to exhibit low decomposition activity (Sari et al., 2017). Therefore, foliar fertilization is necessary as a complementary nutrient, especially to support the limited availability of nutrients resulting from these soil conditions.

Foliar fertilization is a method of applying nutrients to plants through the leaves using foliar fertilizers. This fertilization method is generally complementary and does

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not entirely replace root fertilization. In this study, foliar fertilization was employed as a treatment to evaluate the effectiveness of different foliar fertilizer types. In contrast, basal fertilization was applied uniformly throughout the soil to all treatments, meeting the plants' initial nutrient requirements. However, foliar fertilization can serve as a supporting alternative when root fertilization is hindered or less effective (Sembiring and Maghfoer 2018).

Foliar fertilization is also a strategy to enhance nutrient uptake efficiency and reduce negative environmental impacts (Otálora et al. 2018). This is due to the fertilizer being applied directly to the plants, without contaminating the soil. Plants receive nutrients through leaf adsorption, beginning with penetration of foliar fertilizer through the cuticle, aqueous pores, and stomata, until reaching the leaf apoplast. Then, nutrients are absorbed by leaf cellular compartments, such as chloroplasts, mitochondria, and vacuoles, before being transported to other plant parts, including stems, flowers, and seeds (Malhotra et al. 2020).

Foliar fertilizers are classified into various types based on their nutrient content and form. Foliar fertilizers contain essential macro-nutrients in the form of nitrogen (N), phosphorus (P), and potassium (K), with varying percentages for each type. The application of NPK fertilizer at a dose of 300 kg.ha^{-1} has been shown to increase plant height, number of leaves, and leaf area of red chili at 60 DAT (Abdillah and Laude 2023). In addition, foliar fertilizers are enriched with essential micronutrients such as Boron (B), Calcium (Ca), Iron (Fe), and Sulfur (S), which are considered effective in increasing plant growth, yield, and quality. Some types of foliar fertilizers also contain vitamins and organic materials such as proteins and fats. Based on their form, foliar fertilizers are available in liquid and powder forms. The determination of the type and formulation of foliar fertilizer is related to soil nutrient conditions and the interaction between foliar-applied nutrients and soil-applied fertilizer uptake (Wang et al. 2019). This study aimed to determine the most effective type of foliar fertilizer for enhancing the growth and yield of red chili.

MATERIALS AND METHODS

The study was conducted on chili fields in Kedung Banteng Hamlet, RT 01/RW 04, Sendangijo Village, Selogiri Sub-district, Wonogiri Regency, Central Java. The study field is located at coordinates 7°45'47" SL 110°53'56" EL with an altitude of 145 meters above sea level (masl) from May to September 2023. The materials used were curly red chili seeds of TM 999, seedling polybags, basal fertilizers consisted of cattle manure at a dose 6 t.ha^{-1} and NPK Compound 16-16-16 at a dose 60 g, profenofos-based insecticide 500 gL^{-1}, supplementary fertilzers consisted of leaf fertilizer A. NPK 11-8-6), enriched with micronutrients such as Iron (Fe), Boron (B), Molybdenum (Mo), Copper (Cu), Cobalt (Co), Manganese (Mn), and Zinc (Zn); B. NPK 20-15-15, which contained Magnesium (Mg), B, Zn, Mn, Co, and Cu as well as vitamin B1, and foliar fertilizer; and C. NPK 10-2-7, which included Calcium (Ca), Fe, Mn, Cu, Mg, Zn, B, and Co along with organic compounds such as protein, fat and other organic substances.

This study used an experimental method with a Randomized Complete Block Design single factor with four treatments (no foliar fertilizer, foliar fertilizer A, foliar fertilizer B, foliar fertilizer C). Each treatment was repeated six times to obtain 24 experimental units, and each experimental unit consisted of eight plants, resulting in 16 samples collected by simple random sampling. The area of land used was 31 m^2 with a plot area of 100 cm x 800 cm for each experimental unit.

The variables observed in this study included plant height, number of dichotomous branches, number of leaves, leaf area, fresh and dry biomass weights, cumulative fruit number per plant, cumulative fruit weight per plant, and fruit weight per hectare. The data obtained were analyzed by analysis of variance (ANOVA) at the 5% level. Data that were significantly different were further tested with the Least Significant Difference (LSD) test at the 5% level.

The study stages consisted of initial soil chemical analysis, tillage and mulching, seeding, transplanting, maintenance, foliar fertilization treatment, and harvesting. Chili plants were planted at a spacing of 40 x 50 cm. Foliar fertilization was applied 6 times between 35 and 77 Days After Transplanting (DAT). The fertilizer concentration used was 3 mL.L^{-1} of water, with an application rate of 322.58 L.ha^{-1}. Foliar fertilization was conducted at 14-day intervals from 35 to 63 DAT, and subsequently increased at 7-day intervals until 77 DAT. The fertilizer was sprayed onto the underside of the leaves in the morning (07:00–09:00 WIB), when the stomata were open.

RESULTS AND DISCUSSIONS

Growth of chili crops

The application of various foliar fertilizers showed results that were not significantly different in the height of curly red chili plants (Table 1). Plants that were not given foliar fertilizer showed a plant height of 95.19 cm. The application of foliar fertilizers B, C, and A, respectively, showed a plant height of 92.23, 85.54, and 83.93 cm. The reason is thought to be caused by a suboptimal fertilization interval. Foliar fertilization should be applied at appropriate intervals, as excessively short intervals may lead to waste, while prolonged intervals may lead to nutrient deficiencies. This is because the interval is related to the frequency of nutrient levels supplied to plants. A low frequency causes the amount of nutrients applied to be insufficient to meet the plants' needs.

Plants sprayed with foliar fertilizer B and the control showed a height that was already within the height range of curly red chili varieties, which was 90-120 cm. Plant height under treatment with foliar fertilizer B was slightly higher than the other treatments. This is thought to be related to the content of vitamin B1 (Thiamin) within foliar fertilizer B, which, according to Nurul et al. (2023), can increase plant height better than without vitamin application. However, because the difference in height between treatments was not very pronounced, the genetic factor of the variety is thought to be more influential on plant height growth in this study. Sayekti et al. (2021) state that quantitative characters, such as plant height, are influenced by a combination of genetic and environmental factors, where genetic influences can be more dominant, especially when diversity is low.

The application of various types of foliar fertilizers resulted in a relatively similar number of dichotomous branches in chili peppers (Table 1). Dichotomous branches are the main branches of the chili plant stem, which is fork-shaped. The spraying of foliar fertilizer B resulted in the number of dichotomous branches of 125.02, followed by no foliar fertilizer, foliar fertilizer C, and foliar fertilizer A, with 121.30, 116.79, and 110.42 branches, respectively. The low number of branches is thought to be caused by the nutrient supply that does not meet the plants' needs. Plants require nutrient levels according to their age, in agreement with the statement of Rahayu et al. (2021) that as plants age, their nutritional requirements for growth and development also increase.

A similar number of dichotomous branches under foliar fertilizer treatments during crop growth and development can also be influenced by plant pests. This is because during the study, the plants were attacked by aphids and whiteflies, which were mechanically eradicated. Pest management was carried out by cutting or pruning the branches along with the infested leaves, followed by burning or burying them outside the field to prevent the spread to nearby plants (Wisdawati et al. 2022). Therefore, indirectly, the application of foliar fertilizer has not affected the number of dichotomous branches.

The type of foliar fertilizer applied to chili plants has not resulted in a significantly different number of leaves (Table 1). The application of foliar fertilizer B resulted in 108.85 leaves. Plants under the treatment of no foliar fertilizer, foliar fertilizer C, and foliar fertilizer A resulted in the number of leaves of 106.06, 92.06, and 84.33, respectively. The increase in the number of leaves is correlated with various factors, including plant height. Based on the statement by (Panthi et al. 2019), taller plants generally have more leaves, as their height increase is influenced by the rise in photosynthate production by the leaves. The application of various foliar fertilizers has not increased the number of leaves due to the low plant height.

Environmental factors such as drought can reduce the number of leaves as they wither and fall off. In this study, monthly rainfall during the vegetative phase, according to Selogiri Agricultural Extension Agency (2024)The range of leaf numbers, which ranged from 0 to 41 mm, indicated dry conditions, with no rainfall recorded in the final month of measurement. Okunlola et al. (2017) added that drought and high temperatures can affect fundamental physiological and biochemical processes such as photosynthetic metabolism and reduced stomatal function, thus indirectly leading to a decline in leaf production. Aphids in the study area also affect the number of chili leaves. Wibowo et al. (2022) explain that the curling of chili leaves due to aphids can cause nutrients to be improperly processed, thereby hindering vigorous growth and reducing plant productivity.

The application of various foliar fertilizers has a significant effect on the leaf area of chili (Table 1). Chili leaves treated with foliar fertilizer B showed the largest leaf area, 85.94 cm^2. The application of foliar fertilizer C was also significantly different from the application of foliar fertilizer A and the control, with a value of 75.00 cm^2. However, the application of foliar fertilizer A was not significantly different from the control or without foliar fertilizer treatment at 61.56 cm^2 and 62.81 cm^2, respectively. Plant leaf area is generally influenced by the number of leaves, namely, when the number of plant leaves increases, the leaf area becomes larger (Wijiyanti et al. 2019).

Plants sprayed with foliar fertilizer B have the largest area due to its nutrient content. Foliar fertilizer B contains higher N content than other fertilizers, which supports an increase in leaf area. Micronutrients in foliar fertilizers, such as Zn and B, also affect leaf area. According to research by Ghosh et al. (2020) the application of Zn ($ZnSO_4$) and B (H_3BO_4) can significantly increase the leaf area of chili. This is due to the role of Zn in auxin biosynthesis, which supports plant growth, including an increase in leaf area through cell elongation. The application of foliar fertilizer A has not increased the leaf area compared to the control, due to the nutrient content of foliar fertilizer A, which lacks enrichment with the micro-nutrient Mg, unlike fertilizers B and C. Kii et al. (2018) reported that adequate N and Mg nutrients can increase the leaf area of chili plants.

Table 1. Growth of red chili crops with various foliar fertilizers

Foliar Fertilizers	Plant height (cm)	Number of dichotomous branches	Number of leaves	Leaf area (cm^2)	Fresh weight of biomass (g)	Dry weight of biomass (g)
No foliar fertilizer	95.19±5.40	121.30±16.36	106.06±19.02	62.81±1.72 c	87.57±5.22 b	25.85±1.86 b
A. NPK 10-8-6	83.93±7.61	110.42±17.30	84.33±13.15	61.56±2.14 c	93.53±7.03 b	27.10±2.90 b
B. NPK 20-15-15	92.23±5.37	125.02±18.49	108.85±12.70	85.94±3.24 a	119.68±8.98 a	35.57±1.99 a
B. NPK 10-2-7	85.54±5.69	116.79±24.40	92.06±17.30	75.00±4.49 b	88.77±4.41 b	28.78±2.31 b
Sig. (*p*)	0.52	0.96	0.66	<0.05	<0.05	<0.05
CV (%)	19	39	33	22	27	27

Remarks: Sig: Significance. CV (%): Coefficient of Variation

The type of foliar fertilizer applied to chili plants has a significant effect on the fresh weight of biomass (Table 1). The fresh weight of curly red chili biomass under foliar fertilizer B treatment showed the highest value of 119.68 g. Applications of foliar fertilizer A, foliar fertilizer C, and control produced fresh weights of 93.53, 88.77, and 87.57 g, respectively, which were not significantly different. Research by Nugroho et al. (2022) reported that the application of NPK produced a fresh weight of 103.45 g and was able to increase by 233.71% compared to without NPK application. The fresh weight of plant biomass is related to the simultaneous results of plant growth, as evident from the previous growth parameters, namely, plant height and the number of branches.

The fresh weight of biomass under foliar fertilizer B treatment has the highest value compared to other treatments. This is because chili plants under the foliar fertilizer B treatment showed numerically higher plant height and a greater number of branches compared to other treatments, resulting in better photosynthate production. According to Hapsoh et al. (2019), the better vegetative growth of the plants can further increase the amount of photosynthate in these plants. This increase in photosynthate is influenced not only by nutrients but also by water. As supported by the research of Ceunfin and Bere (2022), the fresh weight of biomass reflects the metabolic activity of a plant because better plant growth results in more water uptake and increased cell division.

Foliar fertilizer application also has a significant effect on the dry weight of chili plant biomass (Table 1). The dry weight of curly red chili plant biomass under foliar fertilizer B treatment showed the highest value of 35.57 g. Applications of foliar fertilizer C, foliar fertilizer A, and control resulted in relatively the same dry weight of 28.78, 27.10, and 25.85 g, respectively. This dry weight is influenced by the fresh weight of biomass and the activity of plant growth. Fitria et al. (2021) in their research, they state that significant increases in the fresh weight and growth of chili plants affected the dry weight of the chili plants.

The application of foliar fertilizer B showed the highest dry weight of biomass due to the higher macronutrient content in foliar fertilizer B compared to other foliar fertilizers. According to Pratama et al. (2022), the value of the dry weight of plant biomass reflects the amount of nutrients taken up by plants, with higher dry weight indicating greater nutrient uptake, particularly phosphorus (P). Dry weight of plant biomass can also increase as a result of photosynthesis, which involves the uptake of CO_2, in contrast to respiration, which in fact releases CO_2 (Rahmanda et al. 2017). Therefore, the number of leaves has an indirect effect on the dry weight of biomass.

Yield of chili crops

The application of various types of foliar fertilizers has not been effective in increasing the yield of curly red chili (Table 2). Plants that were not given foliar fertilizer produced a total of 150.00 fruits, while the application of foliar fertilizers B, A, and C, respectively, produced 143.67, 143.00, and 141.50 fruits. Based on the research by Maulani (2018), the application of foliar fertilizer B with a concentration of 3 g.L^{-1} was able to produce 119.99 chili fruits, but was able to increase 71.4% more fruits than the control. Foliar fertilizer application in this study did not increase the number of fruits, which is thought to be caused by the dose of nutrients not meeting the plant's needs. The dose was set based on a general reference (3 mL.L^{-1}), but the volume of solution received per plant may still be lower than the optimal requirement. This is one of the technical limitations that need to be considered in future research.

Several factors, including the number of dichotomous branches and the presence of plant pests and diseases, can influence the number of fruits. These dichotomous branches or productive branches are where the chili fruits appear, and according to (Ganefianti et al. 2024), the more the number of dichotomous branches, the more fruit will be produced. The application of foliar fertilizer B numerically produced more dichotomous branches than the application of other foliar fertilizers, which led to the production of more fruits. Plant pests and diseases are also known to limit the effectiveness of foliar fertilization in increasing fruit number. Pests such as fruit flies and anthracnose disease were identified to reduce the number of fruits.

The type of foliar fertilizer sprayed yielded results that were not significantly different in terms of fresh weight cumulative fruits per plant (Table 2). Plants that were not given foliar fertilizer produced chili fruit weight of 490.50 g. The application of foliar fertilizer B produced chili fruit weights of 450.83 g, foliar fertilizer C of 445.00 g, and foliar fertilizer A of 424.00 g. The cumulative fresh weight of chili fruit per plant treated with various types of foliar fertilizers may also be affected by the amount of photosynthate produced by plants. This is supported by Kramchote and Suwor (2022), who state that fruit weight has a dependence or relationship with the ability of plants to produce and translocate photosynthate.

The application of various types of foliar fertilizers had no significant effect on productivity per hectare (Table 2). Plants that were not given foliar fertilizer showed productivity per hectare of 7.60 t.ha^{-1}. Foliar fertilizers B, C, and A showed productivity per hectare of 7.21, 6.89, and 6.57 t.ha^{-1}, respectively. The resulting productivity was found to be lower than the yield potential stated in the official description of chili varieties used, which should reach 23 t.ha^{-1}. The main factor affecting fruit weight per hectare is the weight of chili fruit per plant. Plants that produce more chili fruit weight per plant cumulatively will produce more chili fruit weight per hectare. This is in line with the statement of Ghosh et al. (2020) that chili plants producing greater fruit weight per plant can also increase fruit weight per hectare.

Table 2. Yield of red chili crops with various foliar fertilizers

Foliar Fertilizers	Number of fruits	Fresh weight of fruits per plant (g)	Productivity per hectare ($t.ha^{-1}$)
No foliar fertilizer	150.00±16.17	490.50±73.36	7.60±73.36
C. NPK 10-8-6	143.00±31.86	424.00±123.11	6.57±123.11
B. NPK 20-15-15	143.67±16.24	450.83±50.88	7.21±50.88
D. NPK 10-2-7	141.50±32.64	445.00±126.29	6.89±126.29
Sig. (*p*)	0.99	0.97	0.97
CV (%)	22	27	27

Remarks: Sig: Significance. CV (%): Coefficient of Variation

The application of essential microelements through foliar fertilization has also been unable to increase productivity. According to Shahrekizad et al. (2015), foliar fertilizer spraying should be accompanied by soil improvement to produce better plant growth and production. The reason is that foliar fertilizer application generally targets micronutrient supply for plants. This statement is in line with the research of Chowdhury et al. (2020) that the application of fertilizer solutions consisted of N_2 1.4%, K_2O 0.1%, Mg 0.71%, S 1.5%, Zn 0.12%, B 0.34%, Mo 50 ppm, Mn 200 ppm produced fruit weight per hectare of 15.1-19.6 $t.ha^{-1}$ and increased 14.57-24.05% better than the control. The application of this fertilizer composition also resulted in optimal weight compared to other fertilizer compositions that had higher macronutrient concentrations but lower micronutrient concentrations. The solution consisted of N_2 8.0%, K_2O 6.0%, S 0.9%, Zn 0.005%, B 0.01%, Cu 0.007%, Mn 0.013%, Mau 0.001%, Fe 0.015%, Cl 0.9%.

Environmental conditions during the study, which took place in the dry season, also showed suboptimal temperature and humidity levels for chili plants. High temperatures and low humidity caused the plants to suffer from water stress. Cherni et al. (2019) reported that plants that suffered water stress experienced disruptions in the generative phase, specifically flowering, which subsequently led to a reduction in fruit yield. Rajeswari et al. (2020), in their research proved that 40% watering and an increase in ambient temperature of 5 °C above ideal conditions can reduce the weight of chili fruit by approximately 23% lower than the weight of chili fruit under those ideal conditions.

CONCLUSIONS AND SUGGESTIONS

Application of NPK 20-15-15 foliar fertilizer on red chili plants increased leaf area by 39.60, 14.59, and 36.83% compared to NPK 11-8-6, NPK 10-2-7, and no foliar fertilizer, respectively. Dry biomass weight was also higher by 23.60, 31.25, and 37.60% compared to NPK 10-2-7, NPK 11-8-6, and control. Yield was unaffected. Further studies should optimize application timing and dosage according to growth stages, and consider integrating foliar and continuous root fertilization, particularly organic fertilizers. As this study applied only basal root fertilization during early growth, the results need to be interpreted in light of its limitations and are insufficient for practical recommendations.

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