

Influence of Fertilizer and Mulch Types on Growth and Yield of Curly Chili (*Capsicum annuum* L.)

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ABSTRACT

*Application of fertilizers and mulches can potentially improve crop productivity. However, the effectiveness and sustainability of these inputs depend on how they are managed. The objective of this study is to evaluate the effects of organic and chemical fertilizers, and plastic and bamboo leaf mulches, on the physiological growth and productivity of curly chili (*Capsicum annuum* L.). Experiment was performed according to a randomized block design with two factors. First factor was fertilizer (P) types consisting of three levels, namely: P0 (no fertilizer), P1 (ecoenzyme organic fertilizer), and P2 (NPK fertilizer). The second factor is the type of mulch (M) consisted of three levels, including M0 (without mulch), M1 (bamboo leaf mulch), and M2 (plastic mulch). Independent parameters included plant height, leaf number, and fruit weight. Results showed that fertilizer type had no significant effect, while plastic mulch significantly improved all parameters. No interaction was observed. These results suggest that plastic mulch effectively enhances chili growth and yield, particularly in the vegetative stage, but its long-term effects warrant further research.*

1. INTRODUCTION

According to recent data, Indonesia's curly chili pepper production reached 1.55 million tons in 2023, highlighting its great potential and competitiveness in the national agricultural sector (BPS, 2023). This high production reflects the vital role of curly chili as a leading commodity that must be managed sustainably to ensure supply availability, price stability, and farmer welfare. The increasing demand for chili has led to challenges in improving productivity, due to especially suboptimal cultivation techniques and environmental factors (Gulo *et al.*, 2024; Winarto *et al.*, 2024). Fertilizers and mulches are critical inputs that influence physiological growth (Juhaeni & Priyadi, 2023; Tulak *et al.*, 2022). While chemical fertilizers provide rapid nutrient availability, they pose environmental risks. In contrast, organic fertilizers enhance long-term soil health. Similarly, plastic mulch offers effective microclimate control but contributes to pollution, whereas organic mulches like bamboo leaves are environmentally friendly but decompose faster.

In the Special Region of Yogyakarta, chili production especially curly chili reached 441,985 quintals in 2023, with Sleman District contributing 58,416 quintals (BPS, 2024). This region stands out as a major production center due to its consistent implementation of agribusiness strategies and agricultural innovations (Saputro & Kruniasih, 2017). To meet productivity targets, the application of fertilizers and mulches has become a common practice. However, the effectiveness and sustainability of these inputs depend on how they are managed.

Fertilizers are vital for fulfilling plant nutrient requirements. Chemical fertilizers are advantageous because they deliver nutrients rapidly and in measurable amounts to support vegetative and reproductive growth (Yeritsyan *et al.*,

2022). However, overuse of chemical fertilizers can lead to adverse environmental consequences, such as reduced soil fertility and water pollution (Gokul *et al.*, 2020; Rashmi *et al.*, 2020). Organic fertilizers, such as ecoenzym, offer an environmentally friendly alternative by improving soil structure, increasing nutrient availability over time, and enhancing microbial activity (Arfa *et al.*, 2024), though their effects are generally slower.

Similarly, the type of mulch applied plays a vital role in modifying the soil microclimate. Plastic mulch is widely used because it effectively retains soil moisture, controls weed growth, and improves water use efficiency (Zhao *et al.*, 2023; Salama & Geyer, 2023). Despite these benefits, plastic residues pose long-term environmental concerns. In contrast, natural mulches such as bamboo leaves are biodegradable and contribute positively to the ecosystem by adding organic matter and reducing pollution.

Given the complementary roles of fertilizers and mulches, their integrated use is essential to optimize plant physiological responses such as height, leaf number, and fruit weight. Therefore, this study seeks to evaluate the combined effects of organic and chemical fertilizers with plastic and bamboo leaf mulches on chili growth. The findings are expected to provide valuable insights into efficient, sustainable, and environmentally friendly cultivation strategies suitable for chili farmers.

2. RESEARCH MATERIALS AND METHODS

2.1. Research Location and Materials

The research site is located at Pakem, Sleman Regency (-7.6542385 S, 110.4028019 E), with an altitude of 450 meters above sea level and soil texture consisting of 72.06% sand, 15.38% dust, and 12.56% clay (Figure 1). The materials used in this research include curly chili seeds (*Capsicum annuum* L.) Electra variety, organic fertilizer in the form of ecoenzyme, and NPK chemical fertilizer which will be used as a comparison. The mulch used consists of organic mulch from bamboo leaves, and inorganic mulch from silver-colored plastic. The tools used are hoes, shovels, bamboo, paranet, marker boards, paddles, scales, rulers, books, pens, scissors, cell phones and laptops.

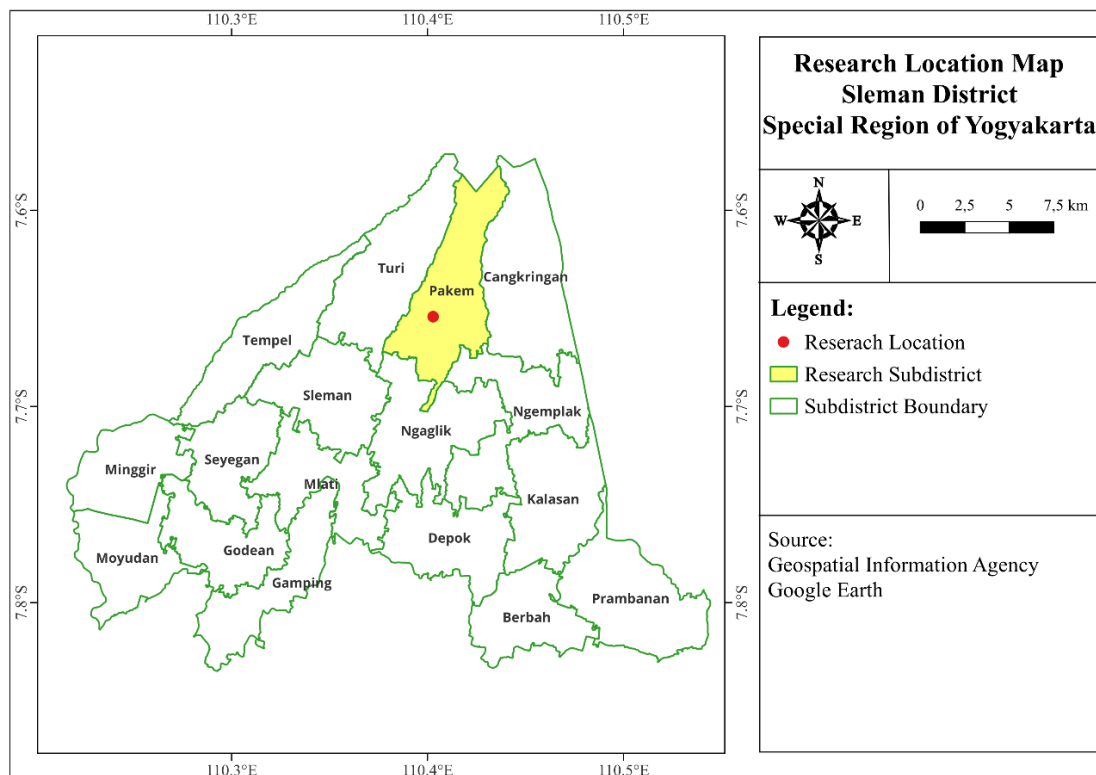


Figure 1. Research location

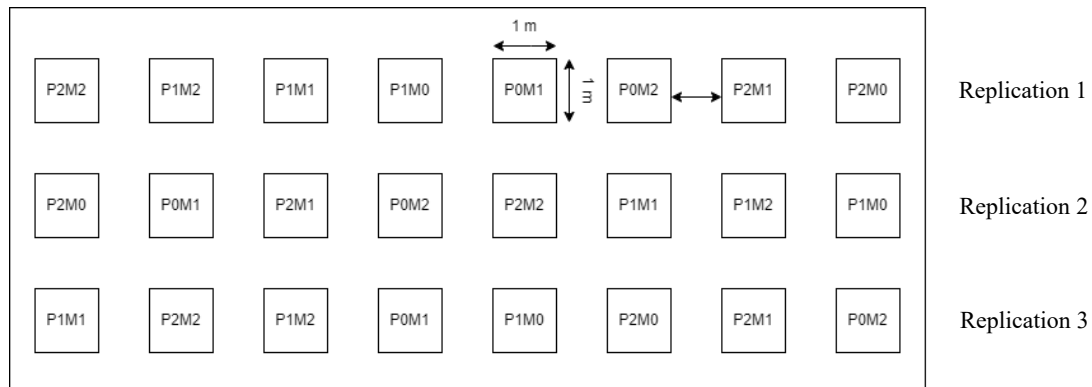


Figure 2. Layout of research plot

2.3. Research Design

This research was conducted using a randomized group design with two treatment factors, namely the type of fertilizer and the type of mulch. The first factor is the type of fertilizer (P) which consists of three levels, namely: P0 (no fertilizer), P1 (ecoenzyme organic fertilizer), and P2 (NPK fertilizer). The second factor is the type of mulch (M) which consists of three levels which included M0 (without mulch), M1 (bamboo leaf mulch), and M2 (plastic mulch). All treatment combinations were performed in triplicates. Figure 2 presented field layout.

There were 8 treatment combinations with three replications, resulting in a total of 24 experimental units performed in plots of 1 m². In this study, only 8 treatment combinations were used, because the P0M0 treatment (no fertilizer and no mulch) was eliminated with the consideration that the treatment did not reflect cultivation practices oriented towards increasing productivity and input efficiency. Parameters observed included plant height and number of leaves measured every two weeks, and chili production in the form of fruit weight per experimental plot measured at harvest. This study utilized only 8 treatment combinations with 3 replications, resulting in a total of 24 experimental units, as the P0M0 treatment (no fertilizer and no mulch) was intentionally excluded based on the consideration that such a treatment does not reflect cultivation practices aimed at improving productivity and input use efficiency. Data were processed using the analysis of variance (ANOVA) method at the 5% confidence level to determine the effect of treatment, then continued with the Duncan test at the 5% confidence level to see differences between treatments. According to [Darma et al. \(2024\)](#), the Duncan test formula is as follows:

$$DMRT = r\alpha.p.v \sqrt{(KTG/r)} \quad (1)$$

where KTG is mean error square value, r is total replicates, $r\alpha.p.v$ is Duncan's significance area value, α is significance level, p is Relative distance between treatments with the next rank, and v is error free degree

3. RESULT AND DISCUSSION

The data obtained from measurements and observations in the field were then processed with ANOVA analysis of variance (5% level). The Analysis of Variance (ANOVA) test is a statistical technique employed to assess and determine significant differences among the means of three or more groups ([Kumar, 2024](#)). Based on the results of ANOVA analysis presented in the table (Table 1), information was obtained on the effect of fertilizer treatment, mulch, and their interaction on the observation variables. In the parameter of plant height, fertilizer treatment did not have a significant effect on all weeks of observation. Mulch treatment gave a significant effect (n) on plant height at 2 to 8 weeks of planting, but not significant at 10 and 12 weeks of planting. The interaction between fertilizer and mulch showed insignificant results in all weeks of observation.

Plastic mulch significantly improved plant height, leaf number, and fruit yield compared to bamboo leaf mulch or no mulch. Fertilizer type did not significantly influence any observed parameters. These findings emphasize the importance of environmental conditions -especially soil moisture and temperature- in determining plant performance.

While fertilizer ensures nutrient availability, mulch modifies the microclimate more effectively, resulting in enhanced vegetative growth and yield.

3.1. Plant Height

Plant height was measured at 2, 4, 6, 8, 10, and 12 weeks after planting. Based on the ANOVA and Duncan tests at the 5% level (Table 1), fertilizer treatment showed no significant effect throughout the observation period. In contrast, mulch treatment significantly affected plant height during the early to mid-growth stages (2 to 8 weeks after planting). Table 2 shows that fertilizer treatments did not have a significant effect on plant height at all weeks of observation. This result indicates that differences in nutrient sources from each type of fertilizer were not enough to statistically affect plant height growth during the observation period. In contrast, the use of mulch had a more significant effect on plant height growth (Figure 3). The treatment with plastic mulch (M2) showed better results compared to bamboo leaf mulch (M1) and no mulch (M0).

The effect of mulch use on plant height at the age of 2 weeks after planting showed the highest results in the M2 treatment (plastic mulch) with plant height reaching 12.75 cm, while the treatment without mulch (M0) produced the lowest plant height of 10.21 cm. At the age of 4 weeks after planting, the plastic mulch treatment (M2) again showed the highest results with an average plant height reaching 24.77 cm, while the bamboo leaf mulch treatment (M1) produced the lowest plant height, which was 21.62 cm. The use of mulch also had a significant effect at week 6, with the highest result in the M2 treatment at 48.43 cm and the lowest in the M0 treatment at 41.01 cm. At week 8, the plastic mulch treatment (M2) produced the highest growth with an average plant height of 62.91 cm, while the bamboo leaf mulch treatment (M1) produced lower growth, which was 54.48 cm. These results indicate that plastic mulch has a significant impact on increasing plant height compared to bamboo leaf mulch (M1) and no mulch.

Table 1. Results of ANOVA at the 5% level of the effect of the use of types of fertilizers and mulches on the growth of curly chili.

No	Observed Variables	Fertilizer	Mulch	Fertilizer × Mulch
1.	Plant height 2 WAP (cm)	ns	s	ns
2.	Plant height 4 WAP (cm)	ns	s	ns
3.	Plant height 6 WAP (cm)	ns	s	ns
4.	Plant height 8 WAP (cm)	ns	s	ns
5.	Plant height 10 WAP (cm)	ns	ns	ns
6.	Plant height 4 WAP (cm)	ns	ns	ns
7.	Number of leaves 2 WAP	ns	s	ns
8.	Number of leaves 4 WAP	ns	s	ns
9.	Number of leaves 6 WAP	ns	ns	ns
10.	Number of leaves 8 WAP	ns	s	ns
11.	Number of leaves 10 WAP	ns	s	ns
12.	Number of leaves 12 WAP	ns	ns	ns
13.	Weight of chili (kg)	ns	s	ns

Table 2. The results of DMRT at the 5% level of the effect of the use of fertilizers and mulches on the height of the plants.

Treatment	Plant Height (cm)					
	2 WAP	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Fertilizer						
No Fertilizer	12.53a	23.68a	45.81a	58.50a	61.50a	61.16a
Organic fertilizer	11.45a	22.34a	45.98a	59.68a	60.11a	61.22a
Chemical fertilizer	10.65a	22.68a	42.37a	55.82a	62.78a	64.00a
HSD 5%	not significant	not significant	not significant	not significant	not significant	not significant
Mulch						
No Mulch	10.21b	21.63b	41.01b	55.66ab	57.85a	59.33a
Bamboo leaf mulch	10.90b	21.62b	43.13b	54.48b	58.22a	58.88a
Plastic mulch	12.75a	24.77a	48.43a	62.91a	67.11a	67.55a
HSD 5%	3.28	5.69	5.19	3.81	ns	ns

Notes: Values followed by different lowercases in the same column are significantly different at the 5% level according to DMRT.

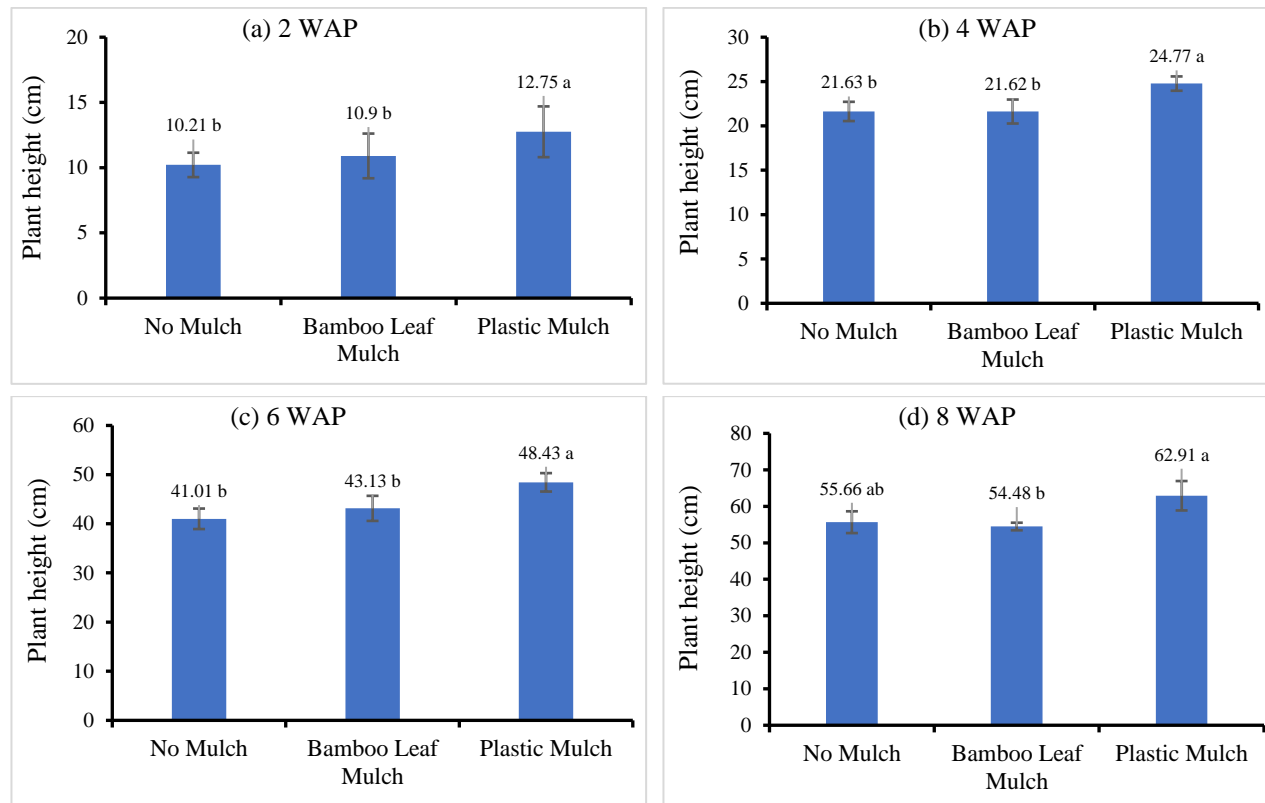


Figure 3. Effect of mulch use on plant height: (a) 2 WAP, (b) 4 WAP, (c) 6 WAP, (d) 8 WAP

The significant difference in plant height only occurred in weeks 2 to 8 weeks after planting, while in weeks 10 and 12 weeks after planting, the difference was not significant. This phenomenon can be explained by several physiological and environmental factors. In the early weeks, plants are in the active vegetative phase, where height growth, leaf formation and biomass accumulation take place intensively. Entering weeks 10 and 12 WAP, chili plants may have entered the transition phase or the beginning of the generative phase (flower and fruit formation), so that more plant energy and resources are allocated to the reproductive process rather than high growth (Darko *et al.*, 2022; Poethig & Fouracre, 2024). In addition, the significant positive effects of mulching in the early phase begin to decline in the late phase. The use of mulch, especially organic types such as bamboo leaves, tends to lose its ability to maintain soil moisture and temperature stability as it decomposes. Onovo *et al.* (2016) mentioned that the effect of mulch is more dominant in the early phase of plant growth. On the other hand, competition for resources between plants also increases at weeks 10 and 12 WAP, such as competition for water, light, and nutrients, which makes plant growth more homogeneous. Thakur *et al.* (2021) emphasized that competition between plants is more significant in the advanced growth phase, so that treatment differences become less visible.

Another influencing factor is photosynthetic efficiency, which began to decline in the final weeks due to the dense plant canopy. This condition causes shading, which reduces the photosynthetic capacity of the lower leaves. Cutolo *et al.* (2023) explained that a dense canopy can reduce the efficiency of light capture, thus affecting plant height growth. Thus, noticeable differences in plant height were more pronounced in the early phase of growth, whereas at weeks 10 and 12 WAP, physiological changes in plants, decreased effects of mulch treatment, and increased competition between plants led to higher homogeneity.

3.2. Number of Leaves

The results of the ANOVA test (5% level) showed that fertilizer application did not have a significant impact on the number of plant leaves in all weeks of observation. In contrast, the use of mulch showed a significant effect on the

number of leaves. This finding indicates that mulch treatment plays a crucial role in influencing plant growth. Further analysis was conducted to understand the mechanism behind the effect of mulch on the number of leaves and its potential in supporting sustainable agricultural practices. The results of Duncan's further test analysis at the 5% level are presented in Table 3.

Table 3. Results of Duncan's further test at the 5% level of fertilizer and mulch use on the number of leaves

Treatment	Plant Height (cm)					
	2 WAP	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Fertilizer						
No Fertilizer	12.53a	23.68a	45.81a	58.50a	61.50a	61.16a
Organic fertilizer	11.45a	22.34a	45.98a	59.68a	60.11a	61.22a
Chemical fertilizer	10.65a	22.68a	42.37a	55.82a	62.78a	64.00a
HSD 5%	ns	ns	ns	ns	ns	ns
Mulch						
No Mulch	10.21b	21.63b	41.01b	55.66ab	57.85a	59.33a
Bamboo leaf mulch	10.90b	21.62b	43.13b	54.48b	58.22a	58.88a
Plastic mulch	12.75a	24.77a	48.43a	62.91a	67.11a	67.55a
HSD 5%	3.28	5.69	5.19	3.81	ns	ns

Notes: Values followed by different lowercase letters in the same column are significantly different at the 5% level according to Duncan's Multiple Range Test (DMRT). HSD 5% indicates the minimum difference required for significance. "ns" denotes non-significant differences.

Table 3 shows that the fertilizer treatments did not have a significant effect on the number of plant leaves in all weeks of observation. This indicates that although there were variations in the types of fertilizers applied, the differences in nutrient sources were not large enough to significantly affect the growth of plant leaf number within the observation period. The type of fertilizer applied, whether organic, inorganic or no fertilizer, did not result in a considerable difference in plant leaf growth.

In contrast, the use of mulch gave a clearer and more significant effect on the number of plant leaves, as shown in Figure 4. The plastic mulch treatment (M2) showed better results compared to the bamboo leaf mulch treatment (M1) and without mulch (M0). This indicates that plastic mulch is more effective in increasing the number of plant leaves. Its ability to maintain soil moisture and stable temperature may be the main factor supporting better leaf growth compared to other types of mulch.

Based on DMRT at the 5% level, the use of mulch showed a significant effect on the number of plant leaves at weeks 2, 4, 8, and 10 after planting. At week 2, treatment M2 (plastic mulch) produced the highest average number of leaves, which was 17.89 leaves, while treatment M1 (bamboo leaf mulch) produced the lowest number of leaves, which was 10.44 leaves. This difference indicates that mulch has a significant effect on the growth of the number of plant leaves, where plastic mulch (M2) gives better results than bamboo leaf mulch (M1). This suggests that more intensive use of mulch (M2) tends to increase the number of leaves, while treatments with less mulch (M1) show lower results. Therefore, a more in-depth analysis is needed to understand other factors that may affect these results.

At the age of 4 weeks after planting, the M2 treatment again showed the highest results with an average number of leaves reaching 52.44. In contrast, the M1 treatment produced the lowest number of leaves, which amounted to 38.56 leaves. The positive effect of plastic mulch on the number of leaves continued until week 8, where the M2 treatment obtained an average number of leaves of 383.44 strands, much higher than the M1 treatment which only produced 269.56 strands. At week 10, the plastic mulch treatment (M2) also continued to show the highest results with an average leaf number of 289.33 leaves, while the treatment without mulch (M0) produced the lowest number of leaves, which was 226.5 leaves.

Overall, these results indicate that the use of plastic mulch consistently has a positive effect on the number of leaves of chili plants in each observation period. In contrast, the treatment with bamboo leaf mulch (M1) showed lower results in all weeks of observation. Therefore, the use of plastic mulch is considered more effective in

supporting the growth of plant leaves, while bamboo leaf mulch shows lower effect in increasing the number of leaves. The significant difference in the number of leaves of chili plants at 2, 4, 8, and 10 weeks of planting with mulch treatment can be explained through the effect of mulch on microclimate conditions and nutrient uptake. Plastic mulch is proven to be effective in maintaining soil moisture and temperature stability, thus creating an optimal environment for plant vegetative growth, especially in the early stages of environmental adaptation (2 and 4 weeks after planting) (Zhang *et al.*, 2022). At 8 and 10 weeks after planting, which is the active phase of leaf formation, the soil stability produced by plastic mulch supports increased water and nutrient availability, resulting in a higher number of leaves compared to other types of mulch (Wang *et al.*, 2017).

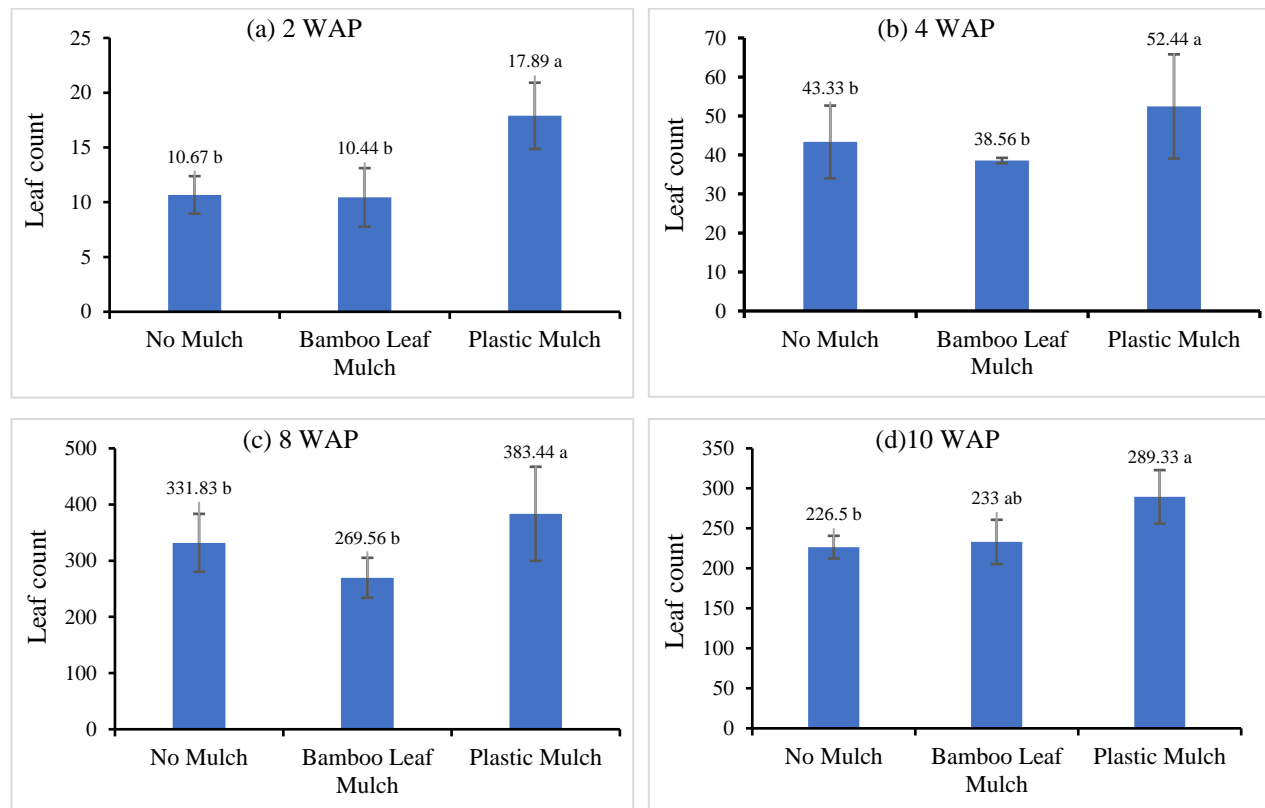


Figure 4. The effect of the use of mulch on the number of leaves: (a) 2 WAP, (b) 4 WAP, (c) 8 WAP, (d) 10 WAP

However, at 6 and 12 weeks after planting, there was no significant difference between mulch treatments. At 6 weeks after planting, plants enter the transition phase from vegetative growth to the formation of generative organs, so that plant energy is focused on the process of organ differentiation. As a result, the response to different mulch treatments is minimal (Dryha *et al.*, 2023). At 12 WAP, plants begin to enter the generative stage with a focus on flower and fruit formation, so that leaf growth slows down, and the effect of mulch treatment on the number of leaves becomes less significant (Jung *et al.*, 2017).

Meanwhile, in the fertilizer treatment, no significant differences were found in all weeks. This indicates that the nutritional needs of plants have been fulfilled in all treatments. Both organic (ecoenzyme) and inorganic (NPK) fertilizers provide adequate nutrients, especially nitrogen, which plays an important role in vegetative growth. This nutrient may not have been a limiting factor in this study, resulting in no significant differences. In addition, organic fertilizers tend to improve soil structure in the long term, while inorganic fertilizers provide rapid nutrient availability, but both have relatively similar impacts on leaf number growth in the short term (Liu *et al.*, 2024; Wang *et al.*, 2024).

Table 4. Results of DMRT at the 5% level of fertilizer and mulch use on fruit weight

Treatment	Weight of Chili (kg)
Fertilizer (P)	
No fertilizer	0.37a
Organic fertilizer	0.22a
Chemical fertilizer	0.30a
HSD 5%	ns
Mulch (M)	
No mulch	0.16b
Bamboo leaf mulch	0.22b
Plastic mulch	0.46a
HSD 5%	18.04

Notes: Values followed by different lowercase letters in the same column are significantly different at the 5% level according to DMRT. HSD 5% indicates the minimum difference required for significance; “ns” denotes non-significant differences.

3.3. Weight of Chili

The results of ANOVA test at 5% ($p\text{-value} \leq 0.05$) level on fruit production from the effect of fertilizer and mulch showed a significant effect on mulch treatment, while there was no significant effect on fertilizer use. The combination of fertilizer and mulch treatments also showed no significant interaction. Further analysis was conducted to understand the mechanism behind the effect of mulch on fruit weight by conducting DMRT at the 5% level. The results of Duncan's further test analysis at the 5% level are presented in Table 4. Table 4 shows the results of the Duncan test at the 5% level, where fruit weight in the no fertilizer, organic fertilizer, and chemical fertilizer treatments had values that were not significantly different, which were 0.37 kg, 0.22 kg, and 0.30 kg per plot, respectively, all marked with the same lowercase letter (a). In contrast, the mulch treatment had a significant effect on fruit weight. The highest fruit weight was produced in the plastic mulch treatment, which amounted to 0.46 kg per plot, compared to the treatment without mulch (0.16 kg per plot) and bamboo leaf mulch (0.22 kg per plot), as indicated by the difference in lowercase letters (a and b) in the Duncan test results.

Compared to previous studies, the fruit weight under plastic mulch in this study aligns with findings by (Saikia *et al.*, 2022), who reported improved microclimatic conditions and moisture retention as key factors for yield enhancement under mulch. Integrated nutrient management significantly influenced crop yield, with the optimal combination resulting in yields of up to 13.3 tons per hectare, whereas lower yields were recorded under fully organic applications (Rani *et al.*, 2015). The relatively low yield may be attributed to suboptimal soil fertility, climatic conditions during the study period, or possible nutrient competition in plots with organic amendments not yet fully decomposed. Additionally, differences in chili cultivar, plant density, and management practices could also contribute to yield variation.

Figure 5 shows that Plastic Mulch (M2) gives the highest chili fruit weight, which is 0.46 kg per plot. This indicates that plastic mulch provides the best conditions for chili plant growth, possibly due to its ability to retain soil moisture and regulate soil temperature effectively. Bamboo Leaf Mulch (M1) showed a more moderate increase, with chili fruit weight of 0.22 kg per plot, while No Mulch (M0) produced the lowest fruit weight of 0.16 kg per plot. These results indicate that the use of mulch has a significant effect on yield, with plastic mulch being the most effective in increasing chili fruit weight compared to bamboo leaf mulch and no mulch.

The insignificant difference in fruit weight in the fertilizer treatment but significant in the mulch treatment can be explained by several factors. The use of fertilizer aims to increase the availability of nutrients in the soil, but if the soil used in the experiment already has sufficient nutrient content, then additional fertilizer does not have a significant effect on plant yield. In addition, plants can only absorb nutrients to a certain extent according to their physiological capacity, so excess fertilizer does not always increase crop yield (Francis *et al.*, 2023). The effect of fertilizer also depends on its type and quality. Organic fertilizers, for example, take longer to break down into a form that can be absorbed by plants, while chemical fertilizers tend to be faster but do not always provide long-lasting effects (Priya *et al.*, 2024).

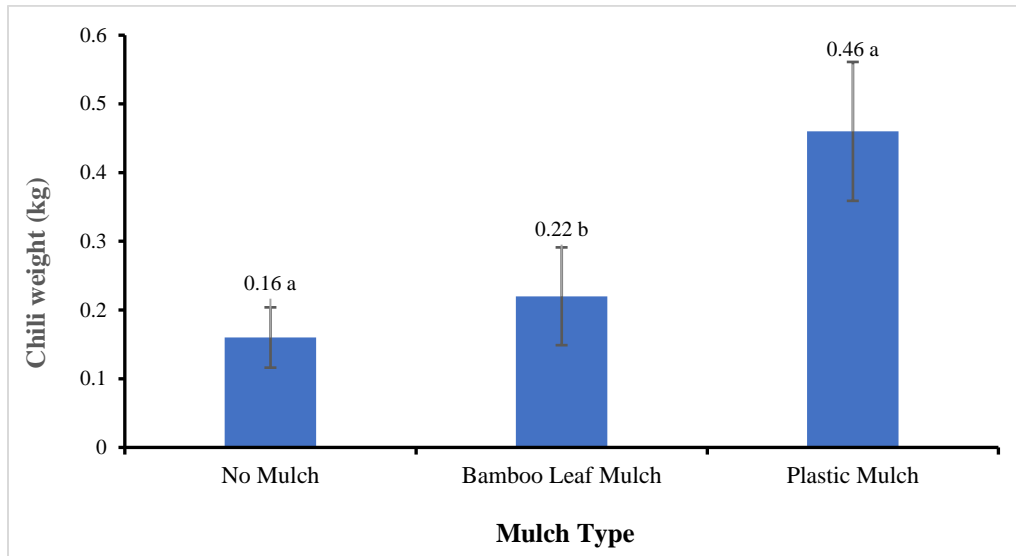


Figure 5. Effect of mulch use on chili weight

In contrast, mulch treatments have a significant effect because mulch affects the microenvironment of plants. Plastic mulch, for example, is able to reduce soil moisture loss through evaporation, maintaining optimal soil moisture for plant growth (Bai *et al.*, 2022). In addition, mulch also stabilizes soil temperature, which is important for microorganism activity and nutrient uptake. Research shows that stable soil temperature can increase the activity of microorganisms in the soil, which in turn supports the availability of nutrients for plants (Husna *et al.*, 2021). Mulch is also effective in inhibiting weed growth, so the main crop does not need to compete for water, light and nutrients (Somanathan *et al.*, 2022).

Under these conditions, fertilizer may not be the main limiting factor. Instead, environmental factors such as soil moisture and temperature, which are more influenced by the mulch, have a more dominant role in supporting crop growth and yield. Therefore, even when fertilizers are applied, their effects are not apparent in the absence of treatments that optimize the environment, such as the use of mulch. With mulch, the soil environment becomes more conducive, which in turn contributes significantly to the increase in fruit weight.

4. CONCLUSION

The use of plastic mulch significantly enhanced chili growth and yield, making it a valuable tool for improving productivity. Fertilizer application showed no significant effect in this study, indicating that mulch may play a more dominant role in growth optimization. Future studies should address the long-term environmental impact of plastic mulch and investigate biodegradable alternatives for sustainable agriculture.

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REFERENCES

Arfa, A., Akhtar, K., Yousaf, R., Misbah, M., Shahzadi, N., Iqbal, H., & Shahid, M.U. (2024). Exploring diverse biological fertilizers (micronutrients) for sustainable soil fertility: A review. *Preprint*. <https://doi.org/10.20944/preprints202410.1140.v1>

- Bai, Y., Zhang, H., Jia, S., Huang, C., Zhao, X., Wei, H., Yang, S., Ma, Y., & Kou, R. (2022). Plastic film mulching combined with sand tube irrigation improved yield, water use efficiency, and fruit quality of jujube in an arid desert area of Northwest China. *Agricultural Water Management*, **271**, 107809. <https://doi.org/10.1016/J.AGWAT.2022.107809>
- BPS (Badan Pusat Statistik). (2024). *Indikator Pertanian*. Badan Pusat Statistik, Jakarta. Accessed on July 10, 2024 from: <https://www.bps.go.id/id/publication/2024/10/14/8a17b449f72bcd692f99c4ec/indikator-pertanian-2023.html>
- BPS (Badan Pusat Statistik). (2023). *Produksi Tanaman Sayuran*. Badan Pusat Statistik, Jakarta. Accessed on July 10, 2024 from: <https://www.bps.go.id/id/statistics-table/2/NjEjMg==/production-of-vegetables.html>
- Cutolo, E.A., Guardini, Z., Dall'Osto, L., & Bassi, R. (2023). A paler shade of green: engineering cellular chlorophyll content to enhance photosynthesis in crowded environments. *New Phytologist*, **239**(5), 1567-1583. <https://doi.org/10.1111/nph.19064>
- Darko, E., Hamow, K.A., Marček, T., Dernovics, M., Ahres, M., & Galiba, G. (2022). Modulated light dependence of growth, flowering, and the accumulation of secondary metabolites in chilli. *Frontiers in plant science*, **13**, 801656. <https://doi.org/10.3389/fpls.2022.801656>
- Darma, N.F., Muzaifa, M. & Widayat, H.P., 2024. Karakteristik fisiko kimia water kefir menggunakan cascara dari tiga jenis pengolahan kopi arabika. *Seminar Nasional Penelitian dan Pengabdian Teknologi Hasil Pertanian*, **4**, 11-19.
- Dryha, V., Doronin, V., Sinchenko, V., Karpuk, L., Mykolaiko, V., & Topchii, O. (2023). Formation of generative organs of switch-grass (*Panicum virgatum* L.) depending on cultivation conditions. *Ecological Engineering & Environmental Technology*, **24**(4), 210-215. <https://doi.org/10.12912/27197050/162706>
- Francis, B., Aravindakumar, C.T., Brewer, P.B., & Simon, S. (2023). Plant nutrient stress adaptation: A prospect for fertilizer limited agriculture. *Environmental and Experimental Botany*, **213**, 105431. <https://doi.org/10.1016/J.ENVEXPBOT.2023.105431>
- Gokul, D., Poonkodi, P., & Angayarkanni, A. (2020). Effect of integrated nutrient management on the growth and nutrient content of chilli (*Capsicum annuum* L.). *Int J Chem Stud*, **8**(4), 2647-2651. <https://doi.org/10.22271/chemi.2020.v8.i4ae.10040>
- Gulo, N.A., Mendrofa, A.I.P., Lase, B.V.L., Mendrofa, C.F., Telaumbanua, I.V., & Laia, I.S. (2024). Kurangnya unsur hara pada tanaman cabai merah serta pemeliharaannya. *Tumbuhan: Publikasi Ilmu Sosiologi Pertanian Dan Ilmu Kehutanan*, **1**(3), 13-20. <https://doi.org/10.62951/tumbuhan.v1i3.112>
- Husna, H., Bakhtiar, B., & Ichsan, C. N. (2021). Pengaruh suhu, pemupukan K dan N terhadap pertumbuhan tanaman padi Inpari 30 (*Oryza sativa* L.). *Jurnal Ilmiah Mahasiswa Pertanian*, **6**(4), 81-90.
- Juhaeni, A.H., & Priyadi, R. (2023). The productivity of red chili (*Capsicum annum* L.) improvement using inorganic fertilizer and biofertilizer: implications for sustainable agriculture. *Jurnal Biologi Tropis*, **23**(3), 63-69. <https://doi.org/10.29303/jbt.v23i3.4933>
- Jung, C., Pillen, K., Staiger, D., Coupland, G., & Von Korff, M. (2017). Recent advances in flowering time control. *Frontiers in Plant Science*, **7**, 2011. <https://doi.org/10.3389/fpls.2016.02011>
- Kumar, N.K. (2024). F-Test and analysis of variance (ANOVA) in economics. *Mikailsys Journal of Mathematics and Statistics*, **2**(3), 102-113. <https://doi.org/10.58578/mjms.v2i3.3449>
- Liu, Y., Lan, X., Hou, H., Ji, J., Liu, X., & Lv, Z. (2024). Multifaceted ability of organic fertilizers to improve crop productivity and abiotic stress tolerance: Review and perspectives. *Agronomy*, **14**(6), 1141. <https://doi.org/10.3390/agronomy14061141>
- Onovo, C.J., Mowobi, G.G., Osuji, C., Salisu, A., & Adama, O.N. (2016). Effect of mulching on early development of beans (*Phaseolus vulgaris* L.) seeds, in keffi, Nasarawa state. *Journal of Environment and Life Sciences*, **1**(1), 66-70.
- Poethig, R.S., & Fouracre, J. (2024). Temporal regulation of vegetative phase change in plants. *Developmental Cell*, **59**(1), 4–19. <https://doi.org/10.1016/J.DEVCEL.2023.11.010>
- Priya, E., Sarkar, S., & Maji, P.K. (2024). A review on slow-release fertilizer: Nutrient release mechanism and agricultural sustainability. *Journal of Environmental Chemical Engineering*, **12**(4), 113211. <https://doi.org/10.1016/J.JECE.2024.113211>
- Rani, P.L., Balaswamy, K., Rao, A.R., & Masthan, S.C. (2015). Evaluation of integrated nutrient management practices on growth, yield and economics of green chilli cv pusa jwala (*Capsicum annum*L.). *International Journal of Bio-Resource and Stress Management*, **6**(1), 76–80. <https://doi.org/10.5958/0976-4038.2015.00007.X>
- Rashmi, I., Roy, T., Kartika, K.S., Pal, R., Coumar, V., Kala, S., & Shinoji, K.C. (2020). Organic and inorganic fertilizer contaminants in agriculture: Impact on soil and water resources. *Contaminants in Agriculture: Sources, Impacts and Management*, 3-41. https://doi.org/10.1007/978-3-030-41552-5_1

- Saikia, U.S., Das, S., Pradhan, R., Goswami, B., Wungleng, V.C., Rajhkowa, D.J., & Ngachan, S.V. (2022). Effect of mulching on microclimate, growth and yield of mustard (*Brassica juncea*) under mid-hill condition of Meghalaya. *Journal of Agrometeorology*, **16**(1), 144–145. <https://doi.org/10.54386/jam.v16i1.1502>
- Salama, K., & Geyer, M. (2023). Plastic mulch films in agriculture: Their use, environmental problems, recycling and alternatives. *Environments*, **10**(10), 179. <https://doi.org/10.3390/environments10100179>
- Saputro, J., & Kruniasih, I. (2017). Analisis pendapatan dan efisiensi usahatani cabai merah di Kecamatan Minggir Kabupaten Sleman. *Agros*, **15**(1), 111–122.
- Somanathan, H., Sathasivam, R., Sivaram, S., Mariappan Kumaresan, S., Muthuraman, M. S., & Park, S. U. (2022). An update on polyethylene and biodegradable plastic mulch films and their impact on the environment. *Chemosphere*, **307**, 135839. <https://doi.org/10.1016/J.CHEMOSPHERE.2022.135839>
- Thakur, M.P., van der Putten, W.H., Wilschut, R.A., Veen, G.F.C., Kardol, P., van Ruijven, J., Allan, E., Roscher, C., van Kleunen, M., & Bezemer, T.M. (2021). Plant–soil feedbacks and temporal dynamics of plant diversity–productivity relationships. *Trends in Ecology & Evolution*, **36**(7), 651–661. <https://doi.org/10.1016/J.TREE.2021.03.011>
- Tulak, A., Inrianti, I., Maulidiyah, M., & Nurdin, M. (2022). The impact of using a mixture of organic fertilizers (compost and liquid organic) and plastic mulch, on the development of cayenne pepper plants. *Journal of Applied Agricultural Science and Technology*, **6**(2), 98–106. <https://doi.org/10.55043/jaast.v6i2.60>
- Wang, J., Yang, X., Huang, S., Wu, L., Cai, Z., & Xu, M. (2024). Long-term combined application of organic and inorganic fertilizers increases crop yield sustainability by improving soil fertility in maize-wheat cropping systems. *Journal of Integrative Agriculture*, **24**(1), 290–305. <https://doi.org/10.1016/J.JIA.2024.07.003>
- Wang, L., Li, X.G., Lv, J., Fu, T., Ma, Q., Song, W., Wang, Y.P., & Li, F.M. (2017). Continuous plastic-film mulching increases soil aggregation but decreases soil pH in semiarid areas of China. *Soil and Tillage Research*, **167**, 46–53. <https://doi.org/10.1016/J.STILL.2016.11.004>
- Winarto, B., Susila, A., Triastono, J., Pramono, J., Supriyo, A., Cempaka, I.G., Sihombing, D., & Handayati, W. (2024). Chili growth-yield improvement under different experience-creativity farmer levels, agronomical components, and their partial economic analysis. *International Journal on Advanced Science, Engineering & Information Technology*, **14**(2). <https://doi.org/10.18517/ijaseit.14.2.18830>
- Yeritsyan, S.K., Gasparian, G.H., Yeritsyan, L.S., & Martirosyan, G.S. (2022). Increasing the efficiency of chili pepper cultivation through an effective fertilization system. *AgriScience and Technology*, **2**(78). <https://doi.org/10.52276/25792822-2022.2-154>
- Zhang, S., Zhang, G., Xia, Z., Wu, M., Bai, J., & Lu, H. (2022). Optimizing plastic mulching improves the growth and increases grain yield and water use efficiency of spring maize in dryland of the loess plateau in China. *Agricultural Water Management*, **271**, 107769. <https://doi.org/10.1016/J.AGWAT.2022.107769>
- Zhao, Y., Mao, X., Li, S., Huang, X., Che, J., & Ma, C. (2023). A review of plastic film mulching on water, heat, nitrogen balance, and crop growth in farmland in China. *Agronomy*, **13**(10), 2515. <https://doi.org/10.3390/agronomy13102515>