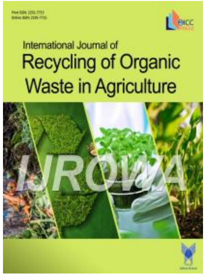

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Research Article

Rabbit Manure and Burnt Rice Husk Boosts Shallot Growth, Yield, and Soil Chemical Properties Over NPK Fertilizers

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Abstract

Purpose: Dependency on chemical fertilizers in shallot production has increased farmers' production expenses and resulted in several environmental issues. Using organic fertilizers and soil amendments can help reduce reliance on chemical fertilizers.
Method: The three shallot cultivars utilized in this study were Bawang BAW1 (MARDI) (BM), Bawang India (BI), and Bawang Siam (BS). The experiment was arranged in three different randomized complete block designs according to the other cultivars with four replications and treated with five fertilizer treatments which were (a) control, (b) NPK fertilizer (NPK) of 15:15:15 at 450 kg/ha (CF), (c) Rabbit manure (RM) + burnt rice husk (BRH) (organic fertilizer (OF)), (d) 225 kg/ha NPK + OF (OCF1), and (e) 112.5 kg/ha NPK + OF (OCF2). Growth performance, yield and soil properties after harvest were recorded.
Results: OF treatment resulted in the best outcomes in terms of total weight, bulb diameter, bulb weight, marketable yield, and macronutrient content across the three shallot cultivars, compared to the other treatments. The combination of OF with NPK fertilizer (OCF1 and OCF2) consistently ranked second in growth, yield and macronutrient content while also leading to notable improvements in various soil chemical properties, particularly the availability of essential nutrients and cation exchange capacity (CEC).
Conclusion: The application of OF showed great promise as an organic alternative for shallot production, as it gave the highest yield and macronutrient content across the three cultivars.

Keywords: Plant height, Marketable yield, Bulb diameter, Cation exchange capacity, Nutrient uptake

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1. Introduction

Allium ascalonicum, commonly known as shallot, is a widely cultivated vegetable belonging to the Amaryllidaceae family (Basir et al., 2024). In 2022, Malaysia imported 38.6 thousand metric tons of shallots, valued at RM81.0 million, primarily from India (62%), the Netherlands (15%), and China (9%) (DOSM, 2023; Basir et al., 2024). However, since 2020, the reliability and affordability of these imports have declined due to global issues and adverse weather conditions (Mahmood et al., 2024). For instance, India's export ban on onions in September 2020, following severe flooding, significantly affected the shallot supply to Malaysia. This led to a rise in the market price of shallots in Malaysia, of over 30%, from USD 1.35 (MYR 6) to USD 1.80 (MYR 8) per kilogram in 2020. To reduce reliance on imports, the Malaysian government initiated large-scale shallot production in lowland areas through the Malaysian Agricultural Research and Development Institute (MARDI) in 2021 (Fadzil et al., 2023; Basir et al., 2023). MARDI recommends applying NPK green fertilizer (15:15:15) at 450 kg/ha, along with an initial chicken manure application of 1 t/ha as a soil amendment, nine days before transplanting of shallot bulbs or seedlings (Basir et al., 2024).

As shallot production relies heavily on chemical fertilizers to enhance yield, the increased cost of chemical fertilizers directly affects farmers' profitability. According to Vos et al. (2025) and findings by Jalaluddin et al. (2022), fertilizer prices have surged due to reduced supplies from major exporting countries like China and Russia. China's export halt in 2021, caused by a significant increase in domestic prices, led to a 26.3% drop in exports, while geopolitical tensions between Ukraine and Russia have further strained global fertilizer supplies (Jalaluddin et al., 2022; Jones & Nti, 2022).

Given Malaysia's dependence on imported fertilizers, these shortages and price hikes pose serious challenges for farmers.

Using organic amendments alongside chemical fertilizers could help lower production costs and improve farmers' incomes (Durham &Mizik, 2021).

Numerous studies have proven the efficacy of organic amendments and chemical fertilizer combinations in boosting shallot production (Kadafi et al., 2022; Sugiono et al., 2021).

Organic amendments include various materials such as livestock manures, compost, plant residues, and biochar (Garbowski et al., 2023). Kadafi et al. (2022) found that the right dosage of chicken manure alongside chemical fertilizers promotes shallot growth and nutrient availability. The addition of organic fertilizers improves soil aeration, which enhances nutrient absorption by plants (Hapsoh et al., 2023; Kadafi et al., 2022). Sugiono et al. (2021) stated that combined composted cow manure and chemical fertilizer treatments resulted in positive increments in plant height, number of plantlets, number of tubers, and yield of shallot. Despite extensive research having been done on the effects of organic fertilizers from animal manure on shallot production, there is limited research on the effects of rabbit manure (RM) on shallot growth in Malaysia.

RM has gained popularity among farmers due to its low moisture and heavy metal content, as well as its higher nutritional value compared to other animal manures (Bastos et al., 2022; Li et al., 2022b). RM contains nitrogen (N) ranging from 1.6-2.0% dry matter (DM), 6.5-8.2% DM phosphorus (P), and 1.2-1.4% DM potassium (K) (Li et al., 2022a). Yunus et al. (2018) found that a 40% application of RM positively affected the growth of *Artemisia annua*. Prajanti et al. (2023) also stated that using RM and urine as organic fertilizer on *Arabica* and *Robusta* seedlings resulted in positive effects that included improved plant height, leaf count, and seedling diameter.

These findings highlight the possibility of RM being a viable and efficient organic amendment as it enhances overall plant growth and development.

Burnt rice husk (BRH) is another effective soil amendment that increases soil cation exchange capacity (CEC) and nutrient availability (Idwar et al., 2024; Asadi et al., 2021).

Idwar et al. (2024) reported that the combination of five tons per hectare of BRH, in combination with guano-based phosphate fertilizer, significantly increased the number of bulbs per clump of shallots.

The combination of RM and BRH could reduce dependency on chemical fertilizers in shallot production, offering a cost-effective and environmentally friendly alternative.

However, relying solely on organic amendments may not be practical due to their slow nutrient release and labour-intensive production. This study, therefore, aims to determine the effects of RM, BRH, NPK fertilizers, and their combinations on the growth and yield of three *Allium ascalonicum* cultivars.

2. Methodology

2.1. Planting materials preparation

BAW-1 shallot bulbs were provided by MARDI, while other shallot cultivar bulbs were purchased from the Selangor Wholesale Market, Selangor. Only healthy bulbs were selected as planting material. The upper third part of

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the bulbs were cut to ensure uniform shoot growth (Basir et al., 2024).
To prevent and reduce fungal infections, the bulbs were thoroughly coated with Kencozeb M45® fungicide (a.i 80% w/w Mancozeb) powder one day before planting.

2.2. Establishment of the experimental plot

Land preparation and initial soil sampling for its characterization commenced one and a half months before transplanting, as described in Table 1. Primary tillage, aimed at loosening the soil, was performed one month before transplanting. Secondary tillage was conducted 2 weeks before transplanting to enhance soil pulverization and to build up the planting bed for each block (Gondal et al., 2021).
Following the secondary tillage, 60 planting beds were prepared manually, each measuring 1 m × 1 m with a height of 20 cm (Basir et al., 2024). There was a 1.0 m gap between blocks and 0.5 m between beds within each row. Each bed was covered with silver shine sheets featuring 25 pre-made holes for easy bulb planting. A weed mat was laid between blocks to minimize weeding needs. A ground sprinkler irrigation system with eight-unit sprinklers was installed along the vertical borders of the plot to irrigate the plants.

2.3. Experimental design and application of the fertilizer treatments

The experiment comprised three randomized complete block design (RCBD), with four blocks as replications. The fertilizer treatments, consisted of five levels, namely: control (C), 450 kg/ha of 15:15:15 NPK fertilizer (CF), Organic fertilizer (OF), 225 kg/ha NPK + OF (OCF1), and 112.5 kg/ha NPK + OF (OCF2).
The OF comprised RM and BRH, as outlined in Table 2. The shallot cultivars included were Bawang BAW-1 (MARDI) (BM), Bawang Merah India (BI), and Bawang Siam (BS). Each shallot cultivar was planted in a different RCBD plot within the same area. Each block consisted of five plots with 1 m^2 (1 m × 1 m) square beds.
The CF was applied at the recommended rate specified by Basir et al. (2024), while BRH was used at the rate of 5 t/ha as recommended by Idwar et al. (2024), all of which are outlined in Table 3.
The chemical composition of the RM, BRH, and CF used in this experiment are listed in Table 3.
The soil's physical and chemical properties were measured before (Table 1) and after harvest, while the fertilizer content was recorded before the treatment application.

2.4. Bulb's transplanting and cultural practices

The bulbs were planted at a depth equal to three-quarters of their height, with 15 cm × 15 cm spacing between plants and rows.
Each planting bed contained 25 bulbs and were planted in the late evening from 5 to 7 p.m. to reduce transplant shock and water loss due to higher temperatures. Replanting was done for any bulbs that failed to germinate in the first two weeks. Pesticide application was carried out only when pest and disease presence was observed, in line with safety and environmental guidelines. Specifically, Kencozeb M45® fungicide (a.i 80% w/w Mancozeb) was applied at early detection of basal rot signs (43 days after planting) at a rate of 25 g/10 litres of water, as described on the pesticide label.
Next, handpicking of visible pests, particularly tobacco cutworm (with an infestation rate of less than 5%), was employed to minimise crop damage and reduce chemical use. Hand weeding was implemented every 3-5 days to reduce competition for nutrients, water, and light, promoting better plant growth in the plot (Sebayang & Prasetyo, 2020). Irrigation through the sprinkler system was twice daily at 7 a.m. and 4 p.m. and was stopped one week before harvesting time to reduce the bulb's moisture content during harvesting (Basir et al., 2024).

Table 1. Initial soil properties before experimentation

Property	Value
Sand (%)	37.87
Silt (%)	8.05
Clay (%)	53.98
Textural class	Sandy clay
Bulk density (g cm^{-3})	1.371
Particle density (g cm^{-3})	1.852
Porosity (%)	25.97
Air dry moisture (%)	8.07
Available water content (m^3/m^3)	0.12
pH (water)	4.72
Electrical conductivity (mS/cm)	0.09
C:N ratio	9.13
Organic matter (%)	1.297
Total organic carbon (%)	1.10
C (%)	1.46
N (%)	0.16
S (%)	0.02
Available P (mg kg^{-1})	4.993
Exchangeable K ($cmol_c$ kg^{-1})	0.1531
Exchangeable Ca ($cmol_c$ kg^{-1})	0.7110
Exchangeable Mg ($cmol_c$ kg^{-1})	0.1770
Cation exchange capacity ($cmol_c$ kg^{-1})	3.1538

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Table 2. Type of fertilizer with rate and time of application

Type of fertilizer	Rate	Time of application
Control (C)	Unfertilized	-
NPK of 15:15:15 at 450 kg/ha (CF)	0.45 t/ha	NPK was applied in three equal splits, including 7 days before transplanting, 15 and 35 days after transplanting.
RM + BRH (Organic fertilizer (OF))	RM = 14.464 t/ha BRH = 5.232 t/ha	14 days before transplanting
225 kg/ha NPK + OF (OCF1)	NPK = 0.225 t/ha RM = 7.232 t/ha BRH = 2.616 t/ha	RM and BRH were applied 14 days before transplanting. NPK was applied in three equal splits, including 7 days before transplanting, 15 and 35 days after transplanting.
112.5 kg/ha NPK + OF (OCF2)	NPK = 0.125 t/ha RM = 10.848 t/ha BRH = 3.924 t/ha	RM and BRH were applied 14 days before transplanting. NPK was used in three equal splits, 7 days before and 15 and 35 days after transplanting.

Table 3. Chemical composition of burnt rice husk, rabbit manure and NPK fertilizer

Property	Burnt rice husk	Rabbit manure	NPK 15:15:15
pH (water)	7.8	6.6	
Electrical conductivity (mS/cm)	0.56	3.64	
C:N ratio	52.78	9.24	
Organic matter (%)	59.09	33.55	
C (%)	45.59	25.88	
N (%)	0.864	2.80	15
S (%)	0.014	0.352	
P (%)	0.28	1.39	15
K (%)	0.73	1.80	15

2.5. Harvesting and data collection

The harvesting process was carried out 75 days after bulb transplanting as it takes 75-85 days post-transplanting time to mature (Basir et al., 2024). Growth performance metrics, including the number of leaves per plant, leaf length, and plant height, were recorded 75 days after transplanting.

Measurements were taken from five randomly selected plants per plot.

Leaf counts were done manually, while leaf length (from neck to tip) and plant height (from the soil surface to the tallest leaf) were measured using a 30 cm ruler (Faber-Castell, Malaysia). Yield parameters were assessed at harvest, including bulb diameter, bulb numbers per clump, fresh and dry weight of the bulbs, total fresh and dry weight of shallots per plot, and marketable bulb yield (Gererufael et al., 2020). Bulb diameter was measured using a digital calliper (IP54 Waterproof Digital Caliper 1104-150 (6”), Germany) and bulb counts were done manually for five clumps per plot. Total and bulb fresh weight were recorded on harvest day, while dry weight was measured after 14 days of sun-drying at 32–36 °C. Total fresh and dry weights per plot were measured in kg/plot and converted to t/ha. Marketable yield was measured based on bulbs that were free from disease, decay, and splitting.

The total weight of marketable bulbs was recorded at t/ha after 14 days of sun-drying.

2.6. Plant tissue analysis for N, P, K, Ca, and Mg content

The macronutrient content of the plant tissues was analyzed using a wet digestion method (Jones, 2001). Aliquots of the stock solution were then prepared for N, P, K, calcium (Ca), and magnesium (Mg) analyses. K, Ca, and Mg were measured using a PinAAcle 900T Atomic Absorption Spectrometer (PerkinElmer, USA), while N and P were analyzed using the AA500 AutoAnalyzer (SEAL, Germany). Results were calculated using standard formulas.

2.7. Chemical analysis of BRH and RM

BRH and RM were analysed for their nutrient content before treatment determination. The samples were analyzed via combustion using the LECO CNS928 Analyzer (LECO Corporation, USA) to determine C, N, S, CN ratio, and organic matter content. The dry ashing method by Peters et al. (2003) was used to analyze P and K in the BRH and RM. P was measured with an AA500 AutoAnalyzer (SEAL, Germany) and K with a PinAAcle 900T AAS (PerkinElmer, USA). The results were calculated using standard formulas.

2.8. Soil physical and chemical properties

Soil samples were collected before land preparation and after the experiment. Sampling was done using a soil auger at a depth of 0-15 cm. Samples were collected from six locations per bed and then composited to form a representative sample.

The samples were analyzed for chemical properties, including pH, electrical conductivity (EC), N, available P, K, Ca, Mg, sodium (Na), C, S, CEC, carbon-to-nitrogen ratio (C:N), organic matter (OM), and total organic carbon (TOC).

Soil pH and EC were analyzed via a 1:2.5 soil-to-water dilution method using the respective meters (Hanna Instruments, Romania). Available P was determined by the Bray II method (Bray and Kurtz, 1945; FAO, 2021) and analyzed with an AA500 AutoAnalyzer (SEAL, Germany).

Exchangeable cations (K, Ca, Mg) and CEC were measured using the NH_4OAc leaching procedure and analyzed with a PinAAcle 900T AAS (PerkinElmer, USA). Soil C, N, S, C:N, OM and TOC were evaluated using a LECO CNS928 Analyzer (LECO Corporation, USA).

Data from instrument readings were processed using standard formulas for nutrient concentrations and CEC calculations.

2.9. Data analysis

Statistical analysis was subsequently performed to evaluate the collected data. The normality of the data was assessed using the Shapiro-Wilk test to ensure compliance with the assumptions of the parametric analysis. All data were subjected to ANOVA using R statistical software (Version 4.4.2).

When the F-test indicated significance, means were compared and separated using the least significant difference (LSD) method at a significance level of $p \leq 0.05$. The results are presented in bar graphs and tables to clearly distinguish the differences among treatments, thereby enhancing clarity and interpretability.

3. Results and discussion

The results obtained provide valuable insights into the effects of the varied fertilizer treatments on the growth and yield of the three shallot cultivars, particularly in relation to macronutrient content in plant tissue, nutrient uptake, and soil chemical properties. These findings also provide a key understanding of sustainable nutrient management practices for shallot production, highlighting the interplay between organic and inorganic fertilizers.

3.1. Plant height, leaf length, and number of leaves

The effects of the different fertilizer treatments on plant height (Figure 1A) and leaf length (Figure 1B) were more pronounced in the BM cultivar (Figure 2A), whereas no substantial differences were observed in the BI and BS cultivars across treatments. A similar trend was observed for leaf number, with significant differences noted in the BM (Figure 1C) and BI (Figure 1D) cultivars. The highest leaf numbers in the BM shallots were observed under OCF1, OF, and OCF2 treatments, though no significant difference was observed between OCF2, OF and the control. For the BI cultivar, OCF1 showed the highest leaf number, however, this difference was not statistically significant compared to the control.

3.2. Total fresh and dry weight per plot

BM (Figure 3A), BI (Figure 3C), and BS (Figure 3E) shallots treated with OF produced the highest total fresh weight compared to the control and NPK fertilizer. Meanwhile, the OF, OCF1, and OCF2 treatments yielded equivalent total dry weights in the BM (Figure 3B) shallots and total fresh weights in the BI shallots, with no significant differences observed (Figure 3C). However, in terms of total dry weight (Figure 3D), the OF treatment produced significantly higher values than all other treatments, while no significant differences were observed between OCF1 and OCF2.

In BS shallots, the highest total dry weight (Figure 3F) was recorded in the OCF2 treatment, although the difference was not statistically significant when compared to OF and OCF1.

Across all three cultivars, CF and control treatments consistently resulted in the lowest total fresh and dry weights, which were significantly lower than those obtained from OF, OCF1, and OCF2 treatments.

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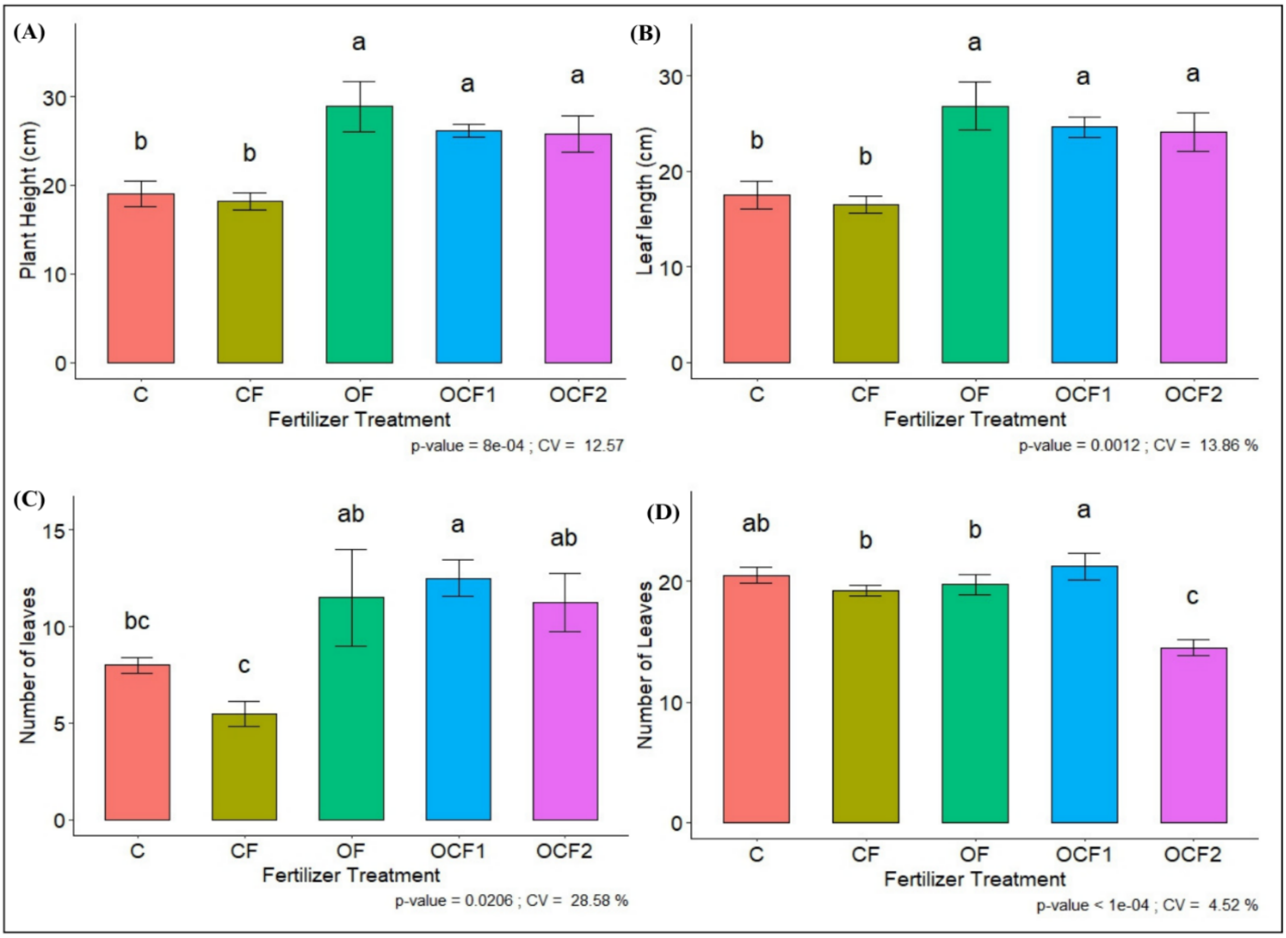

Figure 1. Effects of different fertilizer treatments on plant height (A), leaf length (B), number of leaves in Bawang BAW-1 (MARDI) (C), and number of leaves in Bawang India (D) at 75 days after planting. Means with different alphabets are significantly different at $p \leq 0.05$ using the LSD test. Error bars indicate the standard error of the mean.

Treatments: C = Control; CF= NPK fertilizer (NPK) of 15:15:15 at 450 kg/ha; OF= Organic fertilizer (Rabbit manure (RM) + Burnt rice husk (BRH)); OCF1= 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

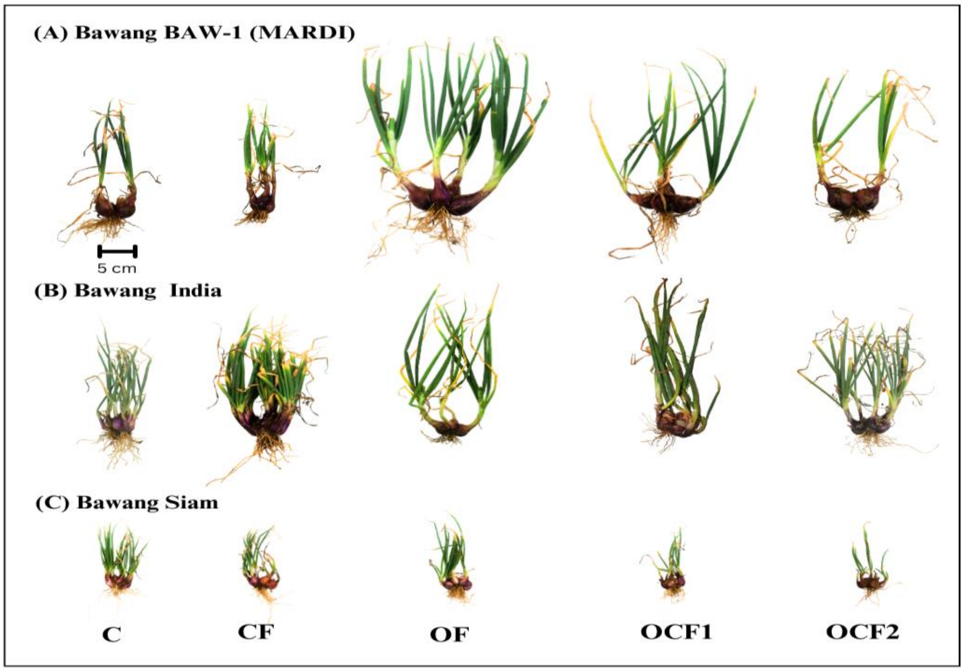

Figure 2. Growth performance of three shallot varieties under different fertilizer treatments: (A) Bawang BAW-1 (MARDI), (B) Bawang India, and (C) Bawang Siam, harvested at 75 days after planting. Treatments: C = Control; CF= NPK fertilizer (NPK) of 15:15:15 at 450 kg/ha; OF= Organic fertilizer (Rabbit manure (RM) + Burnt rice husk (BRH)); OCF1= 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

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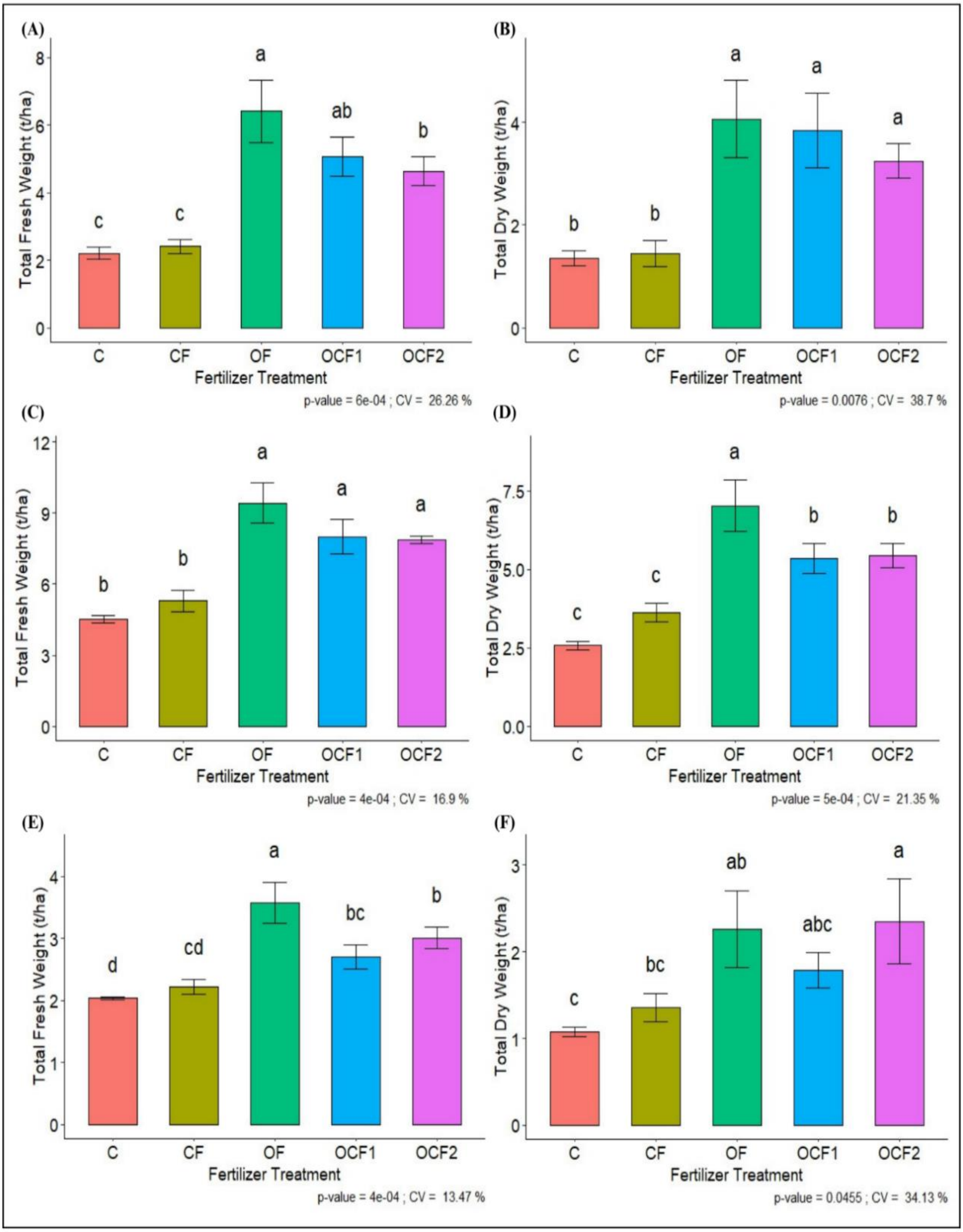

Figure 3. Effects of different fertilizer treatments on total fresh weight at 75 days after planting and total dry weight at 14 days after harvest.
(A–B) Bawang BAW-1 (MARDI); (C–D) Bawang India; (E–F) Bawang Siam. Means with different alphabets are significantly different at $p \leq 0.05$ using the LSD test. Error bars indicate the standard error of means.
Treatments: C = Control; CF= NPK fertilizer (NPK) of 15:15:15 at 450 kg/ha; OF= Organic fertilizer (Rabbit manure (RM) + Burnt rice husk (BRH)); OCF1= 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

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3.3. Bulb diameter and bulb numbers per clump

The different fertilizer treatments significantly influenced the bulb diameter across all shallot cultivars (Figures 4A and 5A, 5C and 5E). In particular, the application of OF resulted in the largest bulb diameters for BM (Figures 4A and 5A) and BS (Figures 4C and 5E) cultivars, significantly outperforming all other treatments. Notably, the bulb diameter of BM shallots treated with OF was approximately 47% greater than that of those treated with CF, highlighting the superior effect of organic amendments on bulb expansion in this cultivar. For the BI cultivar (Figures 4B and 5C), no significant differences in bulb diameter were observed among the OF, OCF1, and OCF2 treatments, suggesting comparable efficacy of full and partial organic-based inputs. However, treatments with CF and the untreated C resulted in significantly smaller bulb diameters, indicating the limitations of inorganic fertilizers and nutrient deficiency in promoting bulb growth. In contrast, bulb number per clump did not differ significantly among the fertilizer treatments in any of the cultivars (Figures 5B, 5D, and 5F), as indicated by $p \leq 0.05$. This suggests that while fertilizer inputs influence bulb enlargement, they have a limited effect on the initiation of bulb numbers.

3.4. Bulb fresh and dry weight

The application of OF resulted in the highest bulb fresh and dry weight of the BM shallot cultivars, outperforming all other treatments ($p \leq 0.05$, Figures 6A and 6B). In contrast, the combined fertilizer treatments (OCF1 and OCF2) produced significantly lower bulb fresh and dry weights than OF but were still superior to the CF and C treatments. For the BI cultivar, there were no significant differences in bulb dry weight among the OF, OCF1, and OCF2 treatments (Figure 6C), suggesting that all three fertilizer treatments were similarly effective. However, both CF and C treatments consistently resulted in lower dry weights.

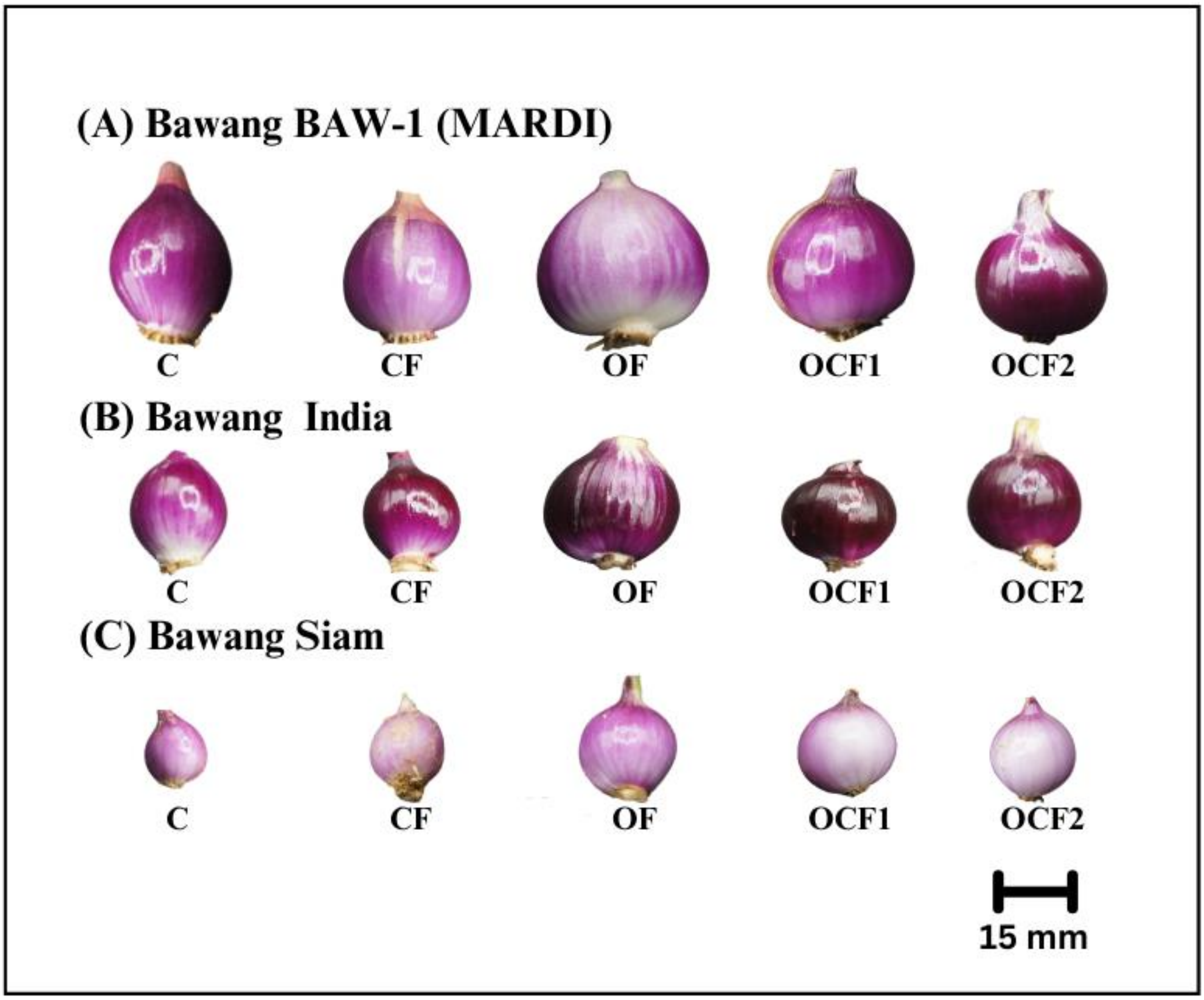

Figure 4. Effects of Different Fertilizer Treatments on Bulb Morphology of Three Shallot Cultivars. *Treatments*: C = Control; CF= NPK fertilizer (NPK) of 15:15:15 at 450 kg/ha; OF= Organic fertilizer (Rabbit manure (RM) + Burnt rice husk (BRH)); OCF1= 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

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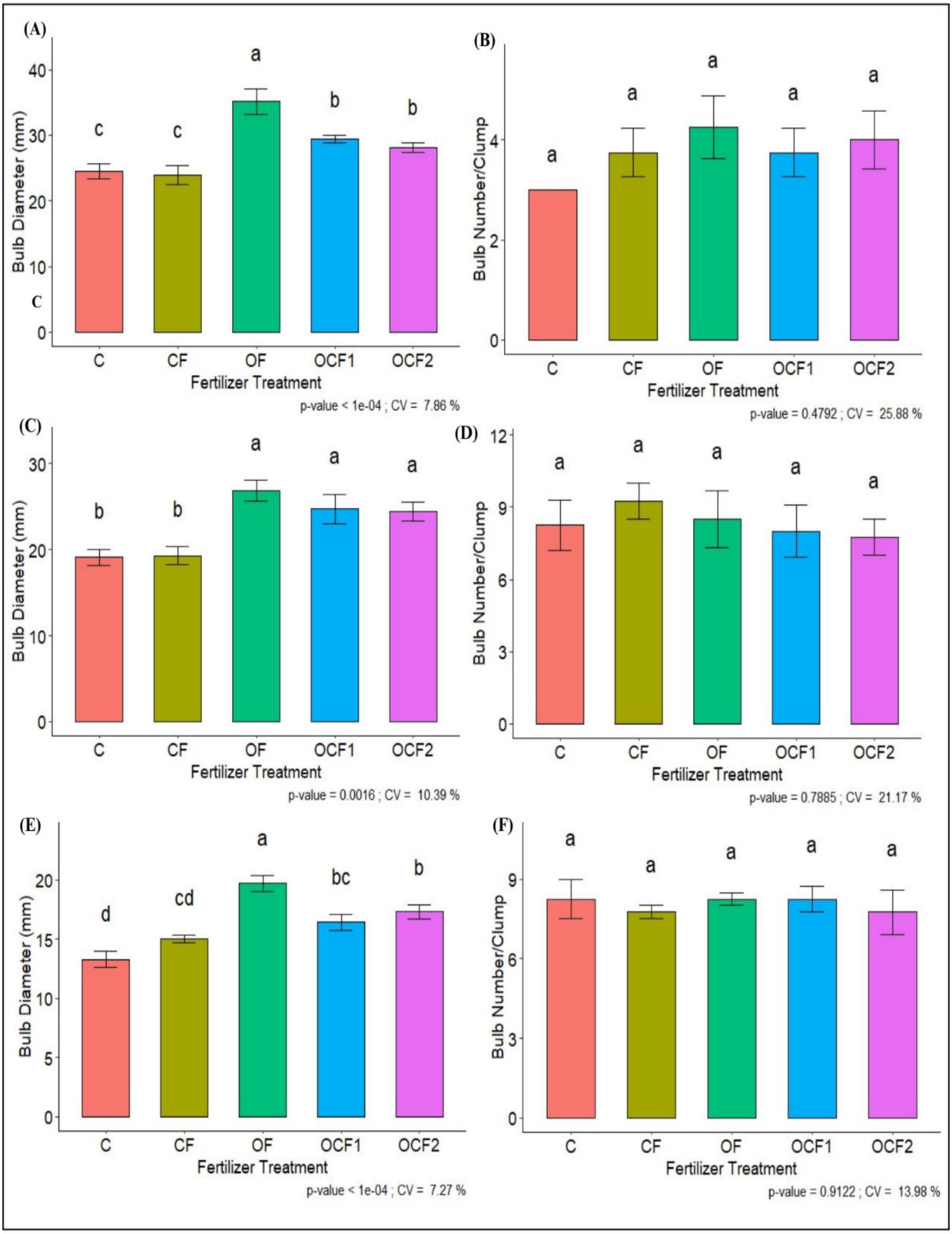

Figure 5. Effects of different fertilizer treatments on bulb diameter and bulb number/clump at 75 days after planting. (A–B) Bawang BAW-1 (MARDI); (C–D) Bawang India; (E–F) Bawang Siam.

Means with different alphabets are significantly different at $p \leq 0.05$ using the LSD test. Error bars indicate the standard error of means.

Treatments: C = Control; CF= NPK fertilizer (NPK) of 15:15:15 at 450 kg/ha; OF= Organic fertilizer (Rabbit manure (RM) + Burnt rice husk (BRH)); OCF1= 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

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In the BS shallot cultivar, the highest bulb fresh weights were recorded under OF and OCF2 treatments, with both significantly exceeding those of OCF1, CF, and C (Figure 6D). Additionally, the OF application produced the highest bulb dry weight in BS (Figure 6F). Although OCF1 and OCF2 also improved dry weights, the difference between them was not statistically significant. Generally, control and CF treatments yielded the lowest bulb weights across all cultivars.

However, exceptions were observed in the fresh weight of BS bulbs (Figure 6D), where CF performed better than the control.

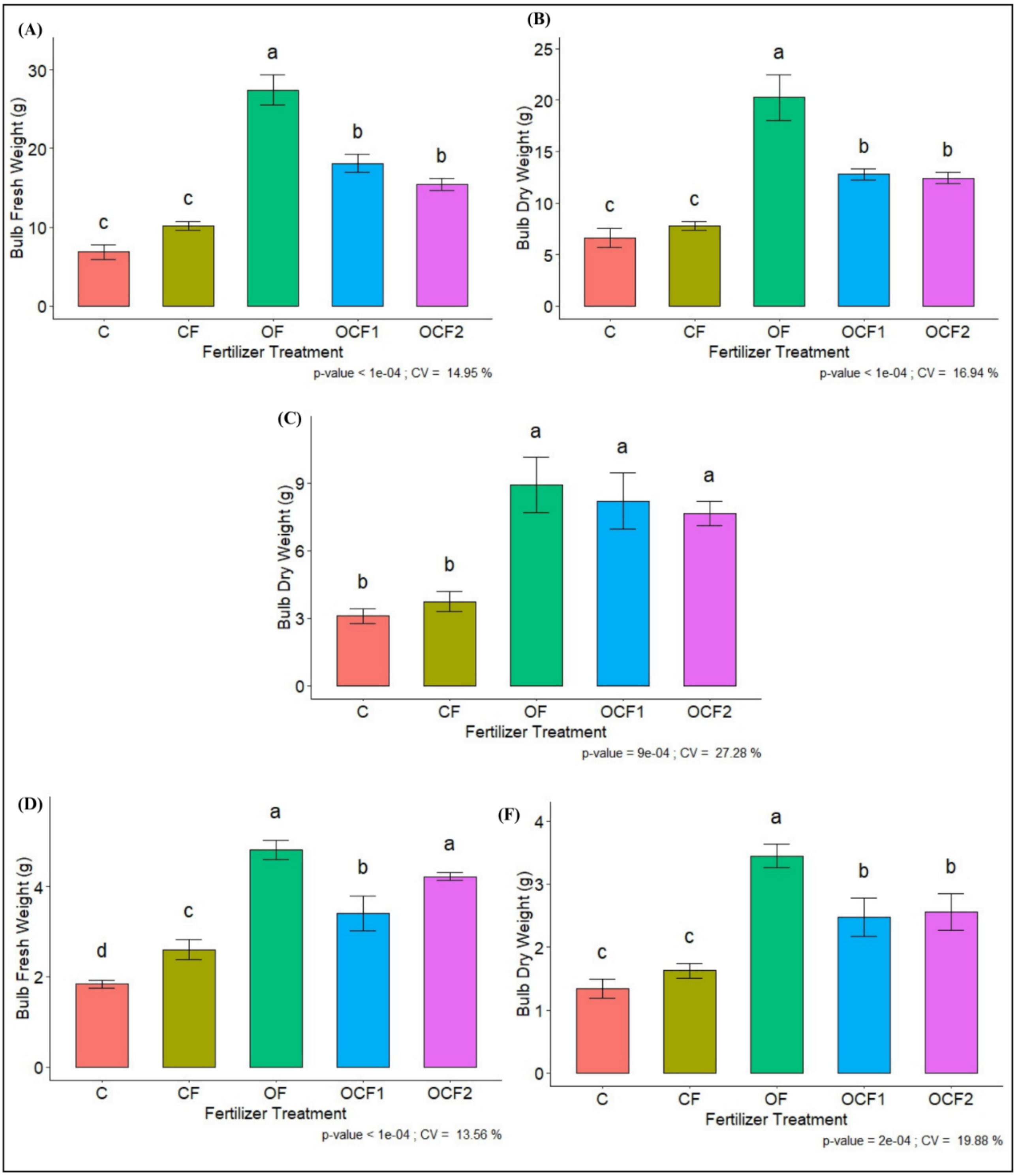

Figure 6. Effects of different fertiliser treatments on bulb fresh and dry weights of three shallot cultivars at 75 days after planting. (A–B) Bawang BAW-1 (MARDI); (C) Bawang India; (D-E) Bawang Siam. Means with different alphabets are significantly different at $p \leq 0.05$ using the LSD test. Error bars indicate the standard error of means.

Treatments: C = Control; CF = NPK fertilizer (15:15:15 at 450 kg/ha); OF = Organic fertilizer (Rabbit manure + Burnt rice husk); OCF1 = 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

3.5. Marketable yield

As illustrated in Figures 7B and 7C, the BI and BS shallot cultivars treated with OF produced the highest marketable yields, significantly surpassing all other treatments ($p \leq 0.05$).

For BI, the OF treatment yielded 7.55 t/ha, which was approximately three times higher than the control (2.47 t/ha), and notably greater than the CF, OCF1, and OCF2 treatments. A similar trend was observed for the BM cultivar (Figure 7A), where OF also resulted in the highest marketable yield. However, this increase was not statistically different from the yields obtained under the OCF1 and OCF2 treatments, indicating that partial substitution of OF with NPK still maintained high productivity in BM.

In the BS cultivar, although OF achieved the highest marketable yield, both OCF1 and OCF2 produced statistically similar yields to CF, and all were significantly lower than OF but higher than the control (Figure 7C).

The control consistently recorded the lowest yields across all cultivars, particularly in BI and BS.

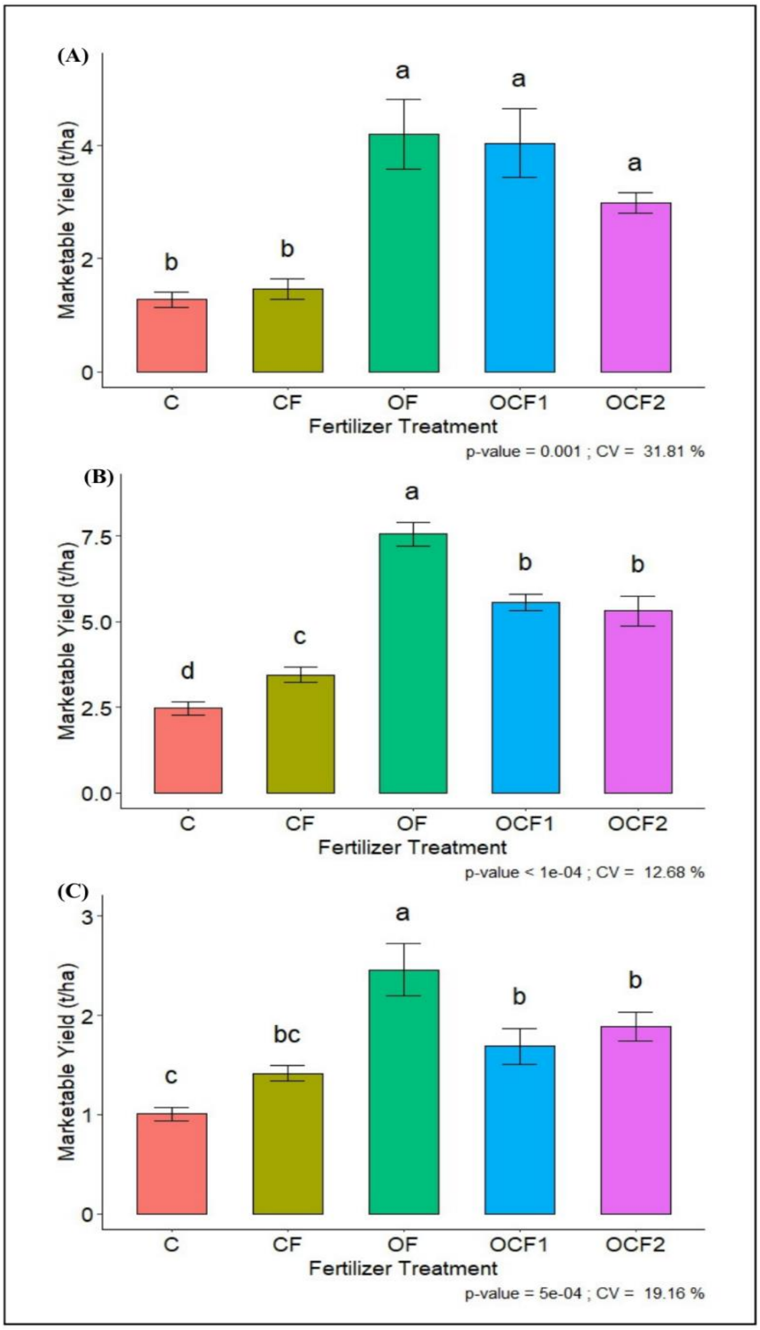

Figure 7. Effects of different fertiliser treatments on marketable yield of three shallot cultivars at 75 days after planting. (A) Bawang BAW-1 (MARDI); (B) Bawang India; (C) Bawang Siam. Means with different alphabets are significantly different at $p \leq 0.05$ using the LSD test. Error bars indicate the standard error of means. *Treatments:* C = Control; CF = NPK fertilizer (15:15:15 at 450 kg/ha); OF = Organic fertilizer (Rabbit manure + Burnt rice husk); OCF1 = 225 kg/ha NPK + OF; OCF2 = 112.5 kg/ha NPK + OF.

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3.6. Plant growth and yield parameters

This study demonstrates that fertilizer treatments, particularly the application of OF, had a substantial positive effect on both vegetative growth and yield-related parameters of shallot cultivars. Notable enhancements were observed in plant height, leaf length, number of leaves, total fresh and dry weights, bulb fresh and dry weights, bulb diameter, and marketable yield, with the OF treatment consistently outperforming other treatments.

The variation in growth performance among cultivars may be partly attributed to their differing nutrient requirements and nutrient uptake efficiencies. Teklehaimanot et al. (2024) reported that the number of leaves in Bombay red onions did not differ significantly across vermicompost and mineral fertilizer (NPSZn) treatments in the Kilte Awulaelo District, but significant differences were observed in the Raya Azobo District, suggesting that soil conditions play a major role in nutrient availability and uptake. Similarly, in the current study, differences in growth response, especially in plant height and leaf traits, may reflect the interaction between cultivar-specific nutrient demands and the soil environment. For example, the growth performance of the BM cultivar in this study aligns with the findings of Shimelis et al. (2020), who showed that increasing N application significantly affected plant height, leaf number, and leaf length in the Improved Huruta shallot variety. This suggests that the BM cultivar was likely more responsive to N and overall fertilizer application compared to the BI and BS cultivars. Furthermore, the lack of significant difference in leaf number observed in the BS cultivar is consistent with findings by Basir et al. (2023), who found that applying 300–600 kg/ha of NPK 15:15:15 combined with 1 t/ha chicken manure did not significantly influence leaf numbers in shallots. This points to the possibility that certain growth parameters, such as leaf number, may be less responsive to nutrient variation and more genetically regulated.

In support of this, Buda et al. (2018) observed that N application did not significantly influence bulb number/plant, and Yeshiwas et al. (2023) further emphasized that bulb number per clump is generally unaffected by interactions between variety, environment, or season. Instead, genetic differences were identified as a more likely factor influencing bulb initiation. These findings align with the current study's observation that bulb number per clump remained relatively stable across treatments, indicating that while bulb development may be nutrient-sensitive, bulb initiation is more genetically driven.

These results collectively affirm the role of organic fertilizer in improving overall plant growth and productivity. Priyadi et al. (2023) similarly found that applying chicken manure at 10 t/ha significantly enhanced plant height, biomass accumulation, and yield in shallots. Ruedas & Ruedas (2022) also showed that Red Pinoy onions fertilized with fresh RM produced larger bulbs with higher fresh and dry weights than those treated with commercial fertilizers or vermicompost. Moreover, Wirajaya et al. (2022) demonstrated that applying 15 t/ha of rabbit or cow manure resulted in the highest chilli yields per hectare, reinforcing the yield-enhancing potential of organic fertilizers.

The superior performance of OF in this study is largely attributed to the synergistic effects of its components, RM and BRH. RM provided a consistent source of N and other nutrients through gradual mineralization, ensuring sustained availability throughout the crop cycle (Sajar et al., 2024; Zhang et al., 2019). Nitrate, the primary form of N taken up by plants, was easily mobilized in the soil solution, facilitating rapid uptake by roots (Sajar et al., 2024). Supriyadi et al. (2022) and Wysokinski & Kożuchowska (2024) both emphasized that animal manure decomposes steadily, providing a prolonged nutrient release that supports continued vegetative and reproductive development. BRH, as a source of biochar, enhanced this effect by improving soil structure and nutrient retention. Its porous nature facilitated the retention of nutrients and water while contributing to improved soil porosity and reduced bulk density (Supriyadi et al., 2022). This created a more favorable environment for root development and enhances nutrient use efficiency.

While OF alone produced the highest values across most parameters, the combined organic and chemical fertilizer treatments (OCF1 and OCF2) also yielded favorable outcomes. In several instances, including the marketable yield and total dry weight of the BM cultivar and the bulb diameter and fresh weight of the BI and BS cultivars, there were no significant differences between OF and OCF treatments. These results are consistent with Priyanshu et al. (2020), who demonstrated that combining 50% NPK with 50% farmyard manure improved shallot growth and yield. Likewise, EL-Sayed et al. (2022) reported that a combination of 12 t/ha RM and 170 kg/ha K_2O maximized potato tuber yield under alternate furrow irrigation. Similar findings were reported by Qodarrohman et al. (2024), where a mixture of 10 t/ha coconut shell biochar, biofertilizer, and 400 kg/ha NPK significantly enhanced red shallot fresh and dry weights. Additionally, a study by Zhang et al. (2019) in China revealed that partial substitution of synthetic N with animal manure increased crop yields in both upland and paddy systems.

The success of these combined treatments can be attributed to the complementary release patterns of nutrients. Inorganic fertilizers provide immediate availability of nutrients, especially N during early growth stages, while organic fertilizers supply a sustained nutrient release throughout the crop cycle (Wysokinski & Kożuchowska, 2024). This combination ensures optimal nutrient availability across critical developmental phases. Furthermore, the interaction between mineral fertilizers and organic amendments such as FYM improves soil's physical and biological properties. These include enhanced water retention, improved aeration, greater microbial activity, better nutrient buffering, and increased aggregation, conditions that favor root proliferation and nutrient absorption (Priyanshu et al., 2020). As a result, nutrient use efficiency was optimized, and environmental losses such as leaching and denitrification were reduced (Liu et al., 2021; Supriyadi et al., 2022). The application of organic fertilizer significantly enhanced plant growth and yield across all shallot cultivars. However, the integrated use of organic and chemical fertilizers (OCF1 and OCF2) also demonstrated strong potential, making them a suitable alternative in scenarios where organic resources are limited. Their ability to combine rapid nutrient availability with long-term soil improvement supports a sustainable and productive shallot cultivation strategy.

3.7. Plant macronutrient content

The analysis of macronutrient content in the three different shallot cultivars subjected to five different fertilizer treatments revealed significant variations between treatments, with the exception of the K concentration in the BI cultivar (Table 4). As shown in Table 4, the highest N concentration in the BM plant tissue was observed under the CF treatment, while BI had the highest N concentration with the OF treatment, and BS had the highest N under the OCF2 treatment. For P concentration, OF treatment stands out as it resulted in the highest P concentration for both the BM (2.32%) and B1(2.21%) cultivars. However, the P concentration in BI under the C treatment was not significantly different from that with the OF treatment. For the BS shallot, the P concentrations under the C, OF, and CF treatments were similar, with no significant differences. Further, the K content in BM treated with OF was not significantly different from that of BM treated with OCF1 and OCF2. In the case of the BS cultivar, treatment with OCF2 and OF resulted in the highest K concentrations. Nevertheless, it was noted that the K content in BS with the OF treatment did not significantly differ from that with the OCF2 and C treatments.

This indicates that while OF and OCF2 can enhance K levels, the difference may not be sufficiently substantial to warrant a preference for one treatment over the other in terms of K concentrations. For all the shallot cultivars studied, treatment with OF demonstrated superior Ca and Mg content compared to the other treatments. Only the BM shallots treated with OCF1 recorded Ca content that was not significantly different from that with OF. This finding highlights the effectiveness of organic fertilization in enhancing Ca and Mg content across the three different shallot cultivars studied. Notably, with the exception of the BM cultivar, N uptake was the highest in both BI and BS cultivars treated with OF, as compared to all other treatments. The BS cultivar treated with OCF2 exhibited a similar level of N uptake, making it statistically not significantly different from that with the OF treatment.

3.8. Effects of RM, BRH and NPK on soil chemical properties

The effectiveness of the RM, BRH and NPK fertilizers were further observed through the differences in the availability of various macronutrients, CEC and the C:N of the soils (Table 5). The results shown in Table 5 indicate that the fertilizer treatments did not significantly affect pH, EC, Ca, S, OM, and TOC in the plots planted with the three different shallot cultivars as its measurements were all statistically similar across the different fertilizer treatments. Both combination fertilizers OCF1 and OCF2 demonstrated the highest total available N in soil for the three shallot cultivars. In soil planted with BI, the total available N resulting from the OF treatment was not significantly different from that of soil treated with OCF1 and OCF2. This aligns with the findings on N uptake, where BI shallots treated with OF showed the highest N uptake, while the highest N uptake in BM was observed under the OCF1 treatment. Additionally, the application of OF treatment led to notably higher P in the soils than that with the other treatments.

CEC is a crucial indicator of soil fertility, reflecting the soil's ability to retain and supply essential nutrients to plants. The OCF2 treatment recorded the highest soil CEC values across the three plots cultivated with different shallot cultivars, measuring 6.85 $cmol_c\ kg^{-1}$ for BM, 7.12 $cmol_c\ kg^{-1}$ for BI and 8.01 $cmol_c\ kg^{-1}$ for BS (Table 5). However, the CEC values with the OCF2 treatment were not significantly different from those with the OCF1 and OF treatments in the BM and BS soils. This suggests that while on the whole OCF2 demonstrated the highest CEC values, the differences in nutrient retention capacity among treatments in the BM and BS soils may not have been substantial enough to impact plant growth significantly. Soil treated with OF, OCF2, and OCF1 also exhibited a significantly lower C:N compared to soil fertilized with NPK or soil that was left untreated. This can be attributed to the higher OM content in soil treated with OF, OCF1, and OCF2.

Fertilization is a crucial field management practice that significantly impacts plant tissue nutrient content, soil nutrient availability, and soil chemical properties in shallot cultivation (Rahayu et al., 2019; Sutardi et al., 2022). In this study, the use of combination fertilizers, namely OCF1 and OCF2, resulted in relatively higher N content in the soil compared to that with the single OF treatment, chemical fertilizer, and no fertilizer. Meanwhile, on average, shallots treated with OF had higher N uptake, followed by those treated with combination fertilizers and those treated with CF and C, respectively. This is consistent with the findings of Wysokinski & Kożuchowska (2024), who reported that N uptake by maize increased when RM application was increased. In contrast, Zhang et al. (2019) noted that N-use efficiency improved with a moderate level of manure substitution (substitution rate < 40%) but declined when synthetic N fertilizer was completely replaced. The larger bulb diameter, increased bulb weight, and enhanced marketable yield of shallots treated with OF, OCF1, and OCF2 can be attributed to the higher P content in the soil associated with each treatment. P is a vital nutrient that supports root and leaf development and is essential for overall plant health and productivity (Yali et al., 2021; Tekeste et al., 2018). Chen et al. (2021) observed that adding organic amendments significantly increased the P content in soil. Alternatively, Tekeste et al. (2018) found that higher applications of Triple Super Phosphate (P_2O_5) significantly affected leaf numbers, leaf length, bulb diameter, total yields, and marketable yields of onion, although it did not have a significant impact on other growth and yield parameters.

While soil pH, Ca, C, S, OM, and TOC increased after harvesting compared to the initial levels, these changes were not significantly influenced by the fertilization treatments, as the values were consistent across all treatments.

This aligns with the findings of Rahayu et al. (2019), who observed that soil pH and EC did not differ significantly with the application of 20 t/ha biochar, or a combination of 10 t/ha compost + 5 t/ha biochar and the control treatment. Alternatively, Chen et al. (2021) found contrasting soil pH and EC results when comparing organic amendments to chemical fertilizers. Their research indicated that soils treated with a combination of chemical fertilizers and organic amendments exhibited significantly lower pH and EC levels than when treated with chemical fertilizers or left unfertilized. The lower C:N values in the OF, OCF1, and OCF2 treatment plots suggest a more favourable environment for nutrient release, potentially contributing to higher plant yields as well as increased N and OM content in the soil. Li et al. (2022a) observed that over time, C: N of RM decreased due to the degradation of organic matter such as organic acids, phenols, cellulose, and hemicellulose through the humification process. This reduction in C: N reflects improved nutrient availability resulting from the microbial activity.

Table 4. Macronutrients content and N uptake of the three shallot cultivars under different fertilizer treatments

	Shallot Cultivar	Treatment C	CF	OF	OCF1	OCF2
N (%)	BM	1.60 ± 0.17c[z]	2.31 ± 0.07a	1.89 ± 0.02b	1.80 ± 0.03bc	1.61 ± 0.11c
	BI	2.07 ± 0.03b	1.86 ± 0.08c	2.35 ± 0.09a	2.07 ± 0.06b	2.08 ± 0.03b
	BS	2.10 ± 0.04b	1.82 ± 0.02bc	1.67 ± 0.02c	1.72 ± 0.16c	2.65 ± 0.17a
P (%)	BM	1.47 ± 0.07c	2.22 ± 0.09ab	2.32 ± 0.07a	1.44 ± 0.10c	2.04 ± 0.08b
	BI	2.14 ± 0.12a	1.47 ± 0.10c	2.21 ± 0.10a	1.67 ± 0.10bc	1.72 ± 0.09b
	BS	2.58 ± 0.16a	2.31 ± 0.04a	2.37 ± 0.08a	1.81 ± 0.11b	1.87 ± 0.16b
K (%)	BM	13.28 ± 0.96b	14.34±0.51b	19.47 ± 0.25a	18.82 ± 0.86a	17.24 ± 0.81a
	BI	12.22 ± 0.78a	19.94 ± 4.46a	18.81 ± 0.51a	16.45 ± 0.58a	15.26 ± 0.99a
	BS	15.28±1.17bc	14.35 ± 0.93c	17.90±0.87ab	14.61±1.13bc	19.59 ± 0.38a
Ca (%)	BM	2.62 ± 0.31b	1.21 ± 0.01c	4.69 ± 0.47a	3.82 ± 0.36a	1.40 ± 0.18c
	BI	1.50 ± 0.09c	2.08 ± 0.27bc	4.68 ± 0.44a	2.60 ± 0.42b	3.02 ± 0.13b
	BS	1.01 ± 0.14bc	1.68 ± 0.05b	2.70 ± 0.35a	0.72 ± 0.18c	1.45 ± 0.24b
Mg (%)	BM	1.97 ± 0.08b	1.21 ± 0.09c	2.42 ± 0.20ab	2.92 ± 0.17a	2.48 ± 0.26ab
	BI	1.78 ± 0.08b	1.08 ± 0.16c	2.66 ± 0.13a	2.17 ± 0.24b	1.97 ± 0.19b
	BS	1.15 ± 0.08b	1.06 ± 0.15b	1.94 ± 0.04a	1.30 ± 0.07b	2.26 ± 0.15a
N uptake (kg/plot)	BM	0.22 ± 0.04d	0.35 ± 0.05cd	0.58 ± 0.03b	0.86 ± 0.07a	0.46 ± 0.06bc
	BI	0.52 ± 0.04c	0.71 ± 0.08c	1.81 ± 0.07a	1.20 ± 0.10b	1.21 ± 0.06b
	BS	0.11 ± 0.01b	0.14 ± 0.01b	0.23 ± 0.01a	0.15 ± 0.01b	0.20 ± 0.02a

[z]Means ± standard error (n = 3). Different letters indicate significant difference levels among the five fertilizer treatments at $p \leq 0.05$ using the LSD test.

Table 5. Soil chemical properties in soil planted with three shallot cultivars under different fertilizer treatments

	Shallot Cultivar	Treatment				
		C	CF	OF	OCF1	OCF2
pH	BM	5.66 ± 0.06a[z]	5.54 ± 0.25a	6.10 ± 0.08a	5.42 ± 0.05a	5.73 ± 0.28a
	BI	5.14 ± 0.23a	5.84 ± 0.29a	5.79 ± 0.09a	5.56 ± 0.15a	5.84 ± 0.28a
	BS	5.26 ± 0.18a	5.43 ± 0.11a	5.67 ± 0.41a	6.06 ± 0.10a	5.82 ± 0.18a
EC (mS/cm)	BM	0.11 ± 0.05a	0.10 ± 0.01a	0.09 ± 0.00a	0.10 ± 0.01a	0.08 ± 0.02a
	BI	0.07 ± 0.02a	0.11 ± 0.01a	0.12 ± 0.00a	0.10 ± 0.02a	0.10 ± 0.03a
	BS	0.05 ± 0.01a	0.10 ± 0.03a	0.14 ± 0.06a	0.10 ± 0.02a	0.13 ± 0.01a
N (%)	BM	0.14 ± 0.01c	0.22 ± 0.07bc	0.40 ± 0.06b	0.84 ± 0.09a	0.90 ± 0.00a
	BI	0.18 ± 0.03c	0.48 ± 0.05b	0.66 ± 0.02a	0.67 ± 0.05a	0.63 ± 0.01a
	BS	0.17 ± 0.01d	0.38 ± 0.04c	0.67 ± 0.10b	0.81 ± 0.06ab	0.92 ± 0.10a
P (mg/kg)	BM	7.08 ± 0.87c	20.86 ± 9.23bc	57.98 ± 3.63a	41.37 ± 8.76ab	35.22 ± 4.58b
	BI	8.04 ± 0.47c	12.86 ± 0.84c	74.19 ± 5.43a	49.58 ± 4.43b	56.54 ± 0.41b
	BS	4.48 ± 0.42d	12.50 ± 1.44c	25.27 ± 0.99b	43.29 ± 3.52a	30.82 ± 2.73b
K ($cmol_c\ kg^{-1}$)	BM	0.83 ± 0.51a	0.47 ± 0.11a	0.40 ± 0.03a	0.52 ± 0.03a	0.45 ± 0.11a
	BI	0.34 ± 0.07b	0.34 ± 0.02b	0.36 ± 0.08b	0.56 ± 0.12ab	0.70 ± 0.07a
	BS	0.25 ± 0.03b	0.40 ± 0.08ab	0.58 ± 0.14a	0.59 ± 0.08a	0.40 ± 0.01ab
Ca ($cmol_c\ kg^{-1}$)	BM	1.84 ± 0.39a	1.54 ± 0.14a	2.23 ± 0.12a	1.39 ± 0.21a	1.65 ± 0.58a
	BI	1.37 ± 0.37a	2.32 ± 0.23a	1.26 ± 0.46a	1.79 ± 0.49a	2.07 ± 0.20a
	BS	1.02 ± 0.11a	1.51 ± 0.10a	2.18 ± 1.30a	2.76 ± 0.18a	1.21 ± 0.21a
Mg ($cmol_c\ kg^{-1}$)	BM	0.85 ± 0.23b	0.57 ± 0.09b	1.58 ± 0.03a	0.70 ± 0.14b	0.99 ± 0.20b
	BI	0.46 ± 0.09a	1.20 ± 0.19a	0.79 ± 0.35a	1.02 ± 0.30a	1.38 ± 0.16a
	BS	0.45 ± 0.06b	0.56 ± 0.06b	1.91 ± 0.43a	1.84 ± 0.22a	1.56 ± 0.20a
C (%)	BM	2.25 ± 0.06a	2.25 ± 0.11a	2.47 ± 0.11a	2.38 ± 0.06a	2.48 ± 0.03a
	BI	2.30 ± 0.04a	2.26 ± 0.03a	2.59 ± 0.12a	2.38 ± 0.07a	2.41 ± 0.12a
	BS	2.16 ± 0.13a	2.29 ± 0.09a	2.45 ± 0.10a	2.43 ± 0.03a	2.54 ± 0.05a
S (%)	BM	0.08 ± 0.00a	0.08 ± 0.01a	0.07 ± 0.00a	0.08 ± 0.01a	0.13 ± 0.04a
	BI	0.08 ± 0.00a	0.07 ± 0.01a	0.08 ± 0.01a	0.09 ± 0.01a	0.07 ± 0.00a
	BS	0.07 ± 0.00a	0.08 ± 0.01a	0.09 ± 0.01a	0.08 ± 0.00a	0.08 ± 0.01a
CEC ($cmol_c\ kg^{-1}$)	BM	3.81 ± 0.33b	3.07 ± 0.21b	6.17 ± 0.40a	6.27 ± 1.20a	6.85 ± 0.16a
	BI	4.21 ± 0.23c	3.63 ± 0.36c	5.93 ± 0.52b	6.86 ± 0.24ab	7.12 ± 0.36a
	BS	4.00 ± 0.21b	3.74 ± 0.31b	8.06 ± 0.49a	7.27 ± 0.11a	8.34 ± 0.43a
C:N	BM	11.70 ± 0.32a	9.18 ± 2.12a	4.93 ± 0.29b	2.20 ± 0.29b	2.06 ± 0.03b
	BI	11.60 ± 2.82a	6.86 ± 2.41ab	4.19 ± 0.51b	3.90 ± 0.37b	3.81 ± 0.20b
	BS	9.60 ± 0.23a	4.15 ± 0.27b	2.63 ± 0.27c	2.27 ± 0.17c	2.20 ± 0.14c
OM (%)	BM	2.92 ± 0.08a	2.92 ± 0.15a	3.20 ± 0.14a	3.08 ± 0.08a	3.22 ± 0.05a
	BI	2.98 ± 0.05a	2.94 ± 0.04a	3.35 ± 0.15a	3.09 ± 0.09a	3.13 ± 0.16a
	BS	2.80 ± 0.17a	2.96 ± 0.12a	3.18 ± 0.13a	3.14 ± 0.04a	3.29 ± 0.07a
TOC (%)	BM	1.69 ± 0.04a	1.68 ± 0.09a	1.85 ± 0.08a	1.79 ± 0.04a	1.87 ± 0.03a
	BI	1.73 ± 0.03a	1.70 ± 0.02a	1.95 ± 0.09a	1.79 ± 0.05a	1.82 ± 0.09a
	BS	1.63 ± 0.10a	1.72 ± 0.07a	1.85 ± 0.07a	1.82 ± 0.02a	1.91 ± 0.04a

[z]Means ± standard error ($n = 3$). Different letters indicate significant difference levels among the five fertilizer treatments at $p \leq 0.05$ using the LSD test

4. Conclusion

The application of RM, BRH, and CF fertilizer and their combinations across three different shallot cultivars was an effective method for improving plant growth, increasing yield, enhancing macronutrient content in plant tissues, and positively influencing soil chemical properties. The application of OF showed great promise as an organic alternative for shallot production as it gave the highest yield and macronutrient content across the three cultivars. The study findings revealed that incorporating RM and BRH as alternatives to reduce reliance on chemical fertilizers resulted in improved soil chemical properties, thereby promoting sustainable production of shallots. In light of the findings from this study, there is a need for further investigation of the long-term impacts of organic fertilizers on soil health and crop yield across different environmental conditions. Additionally, the effects on other shallot cultivars should be explored to confirm the consistency of these findings across differing genetic backgrounds.

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Authors Contribution

Conceptualization: Wan Muhamad, W. A. F., Nur Shahirah M. S., Azham, M. A., Munirah, M., Djuwansah, M. R., Citraresmini, A., and Tajidin, N. E; Data collection: Wan Muhamad, W. A. F., Nur Shahirah M. S., and Azham, M. A; Formal analysis: Wan Muhamad, W. A. F., Nur Shahirah M. S., Azham, M. A., Azman, E. A. and Tajidin, N. E.; Supervision: Tajidin, N. E., Azman, E. A., Baharudin, S. and Munirah, M.; Writing – original draft: Wan Muhamad, W. A. F., Nur Shahirah M. S., Azham, M. A., and Tajidin, N. E.; Writing – review and editing: Wan Muhamad, W. A. F., Nur Shahirah M. S., Baharudin, S., and Tajidin, N. E. All co-authors reviewed the final version and approved the manuscript before submission.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

The authors declare that they are no conflict of interest associated with this study.

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