*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

# Effects of POME Rates and NPK Fertilizer Combinations on Growth, Yield, Shelf Life, and Soil Chemical Properties of *Cucumis Sativus* L.

**Zafirah Zainal Abidin[1]; Muhammad Zhafiran Zamri[1]; Noorsuhaila Abu Bakar[3] & Mohd Hadi Akbar Basri[1,2]***

*[1]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, Selangor, Malaysia*
*[2]Laboratory of Sustainable Agronomy and Crop Protection, Institute of Plantation Studies, Selangor, Malaysia*
*[3]Pusat Penyelidikan Tanaman Industri, Ibu Pejabat MARDI, Persiaran MARDI-UPM, Selangor*

*Correspondence: hadiakbar@upm.edu.my*

## ABSTRACT

The oil palm industry generates substantial quantities of biomass waste, particularly palm oil mill effluent (POME), which poses significant environmental challenges due to its high organic load and pollutant content. Untreated POME may contribute to soil clogging and water pollution, whereas treated POME has potential as a nutrient-rich organic amendment capable of reducing dependence on inorganic fertilizers. However, the effectiveness of integrating treated POME with chemical fertilizers in vegetable production systems remains poorly understood.This study evaluated the combined effects of treated POME and NPK fertilizer on the growth, yield, postharvest quality, and soil chemical properties of cucumber (*Cucumis sativus* L.) using a randomized complete block design with nine treatments. Integrated POME–NPK applications significantly influenced stem diameter, root development, fruit yield, and postharvest weight loss. Notably, the treatment consisting of 3 g NPK combined with 300 ml POME achieved comparable performance to the conventional farmer practice of 6 g NPK while reducing inorganic fertilizer input by 50%. These findings demonstrate that treated POME can partially substitute inorganic fertilizers without compromising crop performance, highlighting its potential as a sustainable nutrient management strategy for cucumber production.

***Key words:*** *Cucumis sativus* L.*, palm oil mill effluent, NPK fertilizer*

## INTRODUCTION

Malaysia is the second-largest producer of palm oil globally after Indonesia, and the oil palm industry remains a major contributor to the national economy, accounting for approximately 2.7% of Malaysia's Gross Domestic Product (GDP) in 2020 (Ahmad *et al*., 2023). However, the rapid expansion of the palm oil industry has also generated substantial quantities of agro-industrial waste, particularly palm oil mill effluent (POME). During the milling process of fresh fruit bunches (FFB), POME constitutes nearly 28% of the total by-products produced (Onoja *et al*., 2019). This highly polluting liquid waste is composed predominantly of water, residual oil, and suspended organic solids (Wüstenhöfer, 2010). Owing to its high biochemical oxygen demand (BOD), chemical oxygen demand (COD), and organic load, untreated POME poses considerable environmental risks. Direct discharge onto land may cause soil clogging, waterlogging, and vegetation deterioration, while disposal into aquatic systems can result in oxygen depletion and severe water pollution (Abu Hassan & Puteh, 2020).

Increasing attention has been directed towards valorising treated POME as a resource within sustainable agricultural systems rather than viewing it solely as industrial waste.

*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

Several treatment and stabilization approaches, including biological digestion, composting with empty fruit bunches (EFB) and palm press fibre, and vermicomposting, have been shown to improve nutrient composition, stabilize organic matter, and reduce the carbon-to-nitrogen ratio of POME-derived products (Mohammad *et al*., 2012b; Rupani *et al*., 2013; Teow *et al*., 2022). These processes enhance nutrient availability and support the development of organic amendments suitable for soil conditioning and crop fertilization. Appropriate treatment prior to discharge or agricultural reuse is also essential to minimize environmental contamination and ensure sustainable utilization of POME (Okolie *et al*., 2020). The reutilization of treated POME as an alternative nutrient source is particularly relevant in intensive vegetable production systems that depend heavily on inorganic fertilizers. In Malaysia, cucumber cultivation relies extensively on synthetic nitrogen, phosphorus, and potassium (NPK) fertilizers to sustain high productivity. However, excessive application of inorganic fertilizers contributes to nutrient leaching, greenhouse gas emissions, soil degradation, and environmental pollution (Liu *et al*., 2021). Moreover, the increasing cost of chemical fertilizers imposes substantial economic pressure on farmers and threatens the long-term sustainability of crop production systems (Joneer & Sam, 2022). Recent studies have demonstrated that integrating organic amendments with reduced rates of inorganic fertilizers can maintain crop productivity while improving soil fertility and reducing environmental impacts. For example, integrated nutrient management practices combining organic materials with NPK fertilizers have enhanced cucumber growth and yield performance compared with sole inorganic fertilization (Marliah *et al*., 2020; Agbor *et al*., 2025). Similarly, reducing nitrogen application by 50% in greenhouse cucumber production significantly decreased nutrient losses and gaseous emissions without compromising yield (Liu *et al*., 2021).

Despite growing interest in circular bioeconomy approaches and sustainable nutrient management, the agronomic potential of treated POME as a partial substitute for inorganic fertilizers in cucumber cultivation remains insufficiently explored, particularly under Malaysian growing conditions. Current knowledge gaps persist regarding its effects on crop growth, yield performance, post-harvest quality, and soil chemical properties when combined with reduced rates of NPK fertilizer. Therefore, this study aimed to evaluate the combined effects of treated POME and NPK fertilizer on the growth, yield, shelf life, and soil chemical properties of cucumber (*Cucumis sativus* L.). The findings are expected to contribute towards the development of a more sustainable, cost-effective, and environmentally responsible fertilization strategy for vegetable production systems.

## MATERIALS AND METHODS

### Study site

This study was conducted at Shelter House, Ladang 15, Faculty of Agriculture, Universiti Putra Malaysia (2.986304°N, 101.736714°E) from 8 July to 27 August 2025 (**Figure 1**).




**Figure 1**. Location of the experiment plot.

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

**Planting materials and nursery establishment**

In this study, the cucumber seeds (Green Eagle variety, 138 F1 Hybrid Mini King) were sourced from Sin Seng Huat Seed Sdn. Bhd., Bandar Bukit Puchong, Selangor. To accelerate germination, the seeds were pre-treated by soaking in water for approximately eight hours. Following pre-treatment, the seeds were sown in seedling trays using peat moss as the growing medium. The trays were kept under a shading net for the first five days germination which then the net was removed to allow for full light penetration. After 10 days of germination, once the first true leaves had developed, the seedlings were transplanted into 36 polybags (16 × 16 inches), each containing 12 kg of soil. The initial physical and chemical properties of the soil used in this experiment are summarized in as in table (**Table 1**). To support vertical growth, the experimental plot was equipped with a trellis system (or staking and netting) to provide the necessary structural support for the cucumber vines (**Figure 2**).

**Table 1.** Initial soil properties before treatment

| Soil chemical parameters | Value |
|---|---|
| pH | 4.58 |
| EC (Ms/cm) | 0.04 |
| Total N (mg kg-1) | 60.00 |
| Available P (mg kg-1) | 5.506 |
| Exchangeable K (cmolc kg-1) | 0.73 |
| Exchangeable Ca (cmolc kg-1) | 0.07 |
| Exchangeable Mg (cmolc kg-1) | 0.01 |
| Cation exchange capacity (cmolc kg-1) | 0.72 |



**Figure 2**. Overview of the trellis system setup utilized in the experimental plots.

**Treatment and experimental design**

This experiment aimed to evaluate the synergistic effects of combining organic and inorganic nutrient sources. Inorganic fertilizer (NPK 15:15:15) was applied to supply nutrients in readily available forms and support rapid plant growth (Sutardi *et al*., 2025), while the organic fertilizer (POME), releases nutrients more gradually and contributes to improved soil structure, organic matter accumulation, and microbial activity (Chivenge *et al*., 2011). When applied together, organic amendments can enhance the efficiency of chemical fertilizers by reducing nutrient losses, while inorganic inputs ensure immediate nutrient availability, making Integrated Nutrient Management (INM) a balanced and sustainable strategy for high-demand crops such as cucumber. The experiment followed a Randomized Complete Block Design (RCBD) consisting of nine treatments and four blocks (**Figure 3**). Each treatment was

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

randomly allocated within each block, resulting in a total of 36 experimental units (**Table 2**). Treatment 0 (T0) served as the negative control, representing plants grown without any nutrient inputs. Treatments 1 (T1) and 2 (T2) acted as positive controls, where T1 represented the standard farmer practice using 6g NPK alone, and T2 represented POME application alone at 300 ml. The remaining treatments (T3–T8) consisted of various combinations of NPK and POME to determine the optimal input levels for cucumber production. POME was collected from commercial oil palm mill in Klang, Selangor, stored in airtight containers, and homogenized before application. Chemical analysis of the POME indicated a pH of 7.28 and an electrical conductivity (EC) of 7,881 ppm. POME was diluted to a fixed total volume of 1000 ml per treatment and applied 10 days before transplanting, followed by applications at 2 and 4 weeks after transplanting (WAT) (Zahrah & Fathurrahman, 2017). NPK Blue (15:15:15) fertilizer was applied around the root zone starting one week after transplanting and continued weekly for three weeks, following the standard recommendations of the Jabatan Pertanian Malaysia (1997). The ring placement method on the root zone was used to ensure efficient nutrient uptake.




**Figure 3**. Experimental layout for *Cucumis sativus* L.

**Table 2.** Description of treatments applied in the experiment

| Treatment | Description |
|---|---|
| Treatment 0 | 0 g NPK + 0 ml POME |
| Treatment 1 | 6 g NPK + 0 ml POME |
| Treatment 2 | 0 g NPK + 300 ml POME |
| Treatment 3 | 3 g NPK + 100 ml POME |
| Treatment 4 | 6 g NPK + 100 ml POME |
| Treatment 5 | 3 g NPK + 200 ml POME |
| Treatment 6 | 6 g NPK + 200 ml POME |
| Treatment 7 | 3 g NPK + 300 ml POME |
| Treatment 8 | 6 g NPK + 300 ml POME |

**Growth performance data collection**

Growth performance data were recorded at 14-day intervals from transplanting until 53 days after transplanting (DAT). The parameters measured included plant height (cm), number of leaves per plant and stem diameter (mm), which were used to evaluate vegetative growth development over time. In addition, reproductive growth data were collected by recording the number of staminate (male) and pistillate (female) flowers from the onset of flowering until 53 DAT. The total number of flowers per plant was calculated and used for analysis. Root

length (cm) was measured at the final harvest (53 DAT) by extracting the root system and measuring the length of the longest primary root using a measuring tape.

**Yield performance**

Yield performance was evaluated based on the number of fruits, fruit diameter, and fruit length. The number of marketable fruits harvested per plant was recorded, and fruit grading was conducted according to the Jabatan Pertanian Malaysia (1997) standard (10–15 cm length). Fruit diameter was measured using a digital vernier caliper at three positions, namely the apical, middle, and basal sections of the fruit. The mean value of these measurements was recorded in centimeters (cm). Fruit length was determined by measuring from the base to the tip of each fruit to the nearest 0.1 cm, and the mean fruit length per plant was calculated for analysis.

**Shelf-life evaluation**

Shelf-life evaluation of harvested cucumbers was conducted under room storage conditions with three replicates fruit per treatment. Three postharvest quality parameters were evaluated which are weight loss, firmness, and sensory quality, as these are critical indicators of quality and marketability for horticultural crops (Kader, 2002). Fruit weight loss was determined by recording the initial fresh weight of cucumbers immediately after harvest, followed by subsequent weights at Day 3 and Day 6. Percentage weight loss was calculated using the formula:

**Weight Loss (%) =Initial Weight – Final Weight×100**

Fruit firmness was determined using a handheld penetrometer, with measurements taken at three positions on each fruit (apical, middle, and basal), and the mean value was expressed in kilograms per square centimeter (kg $cm^{-2}$). Sensory quality was assessed periodically using a structured scoring scale, where visual freshness, colour, shrivelling, and overall fruit quality were evaluated to determine the progression of postharvest deterioration

**Soil chemical properties**

Soil samples were collected at the end of the experiment, with initial samples analysed prior to treatment application. Samples were air-dried, ground, and passed through a 2-mm sieve. Soil pH and electrical conductivity (EC) were measured using digital meters. Total nitrogen (N) was determined using the Kjeldahl method, while available phosphorus (P) was analysed using the Bray and Kurtz method. Exchangeable cations (K, Ca, Mg) and cation exchange capacity (CEC) were extracted using 1 M ammonium acetate ($NH_4OAc$), whereas exchangeable aluminium (Al) was extracted using 1 M KCl. Elemental concentrations were determined using AAS. Plant samples (0.5 g) were analysed for nutrient concentrations using AAS.

**Plant physiological measurement**

Plant physiological parameters were measured at the post-harvest growth stage using a portable photosynthesis system (LI-COR). The system was used to record the photosynthetic rate (µmol $CO_2$ $m^{-2}$ $s^{-1}$), transpiration rate (mmol $H_2O$ $m^{-2}$ $s^{-1}$), stomatal conductance to water vapour (mol $m^{-2}$ $s^{-1}$), and leaf vapour pressure deficit (kPa). Measurements were taken on fully expanded, healthy leaves under field light conditions to ensure consistent reading. Chlorophyll content was determined non-destructively using a SPAD chlorophyll meter, which provided an indirect estimation of leaf greenness and photosynthetic capacity without damaging the leaves.

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

**Statistical analysis**

Data was subjected to Analysis of Variance (ANOVA) based on RCBD using RStudio. Treatment means were separated using the Least Significant Difference (LSD) test at $p \leq 0.05$ to determine significant differences among treatments.

## RESULTS AND DISCUSSION

**Plant growth parameter**

Leaf number was significantly influenced by the interaction between POME and NPK applications over time (**Figure 4**). After transplanting (DAT), no significant differences were observed among treatments. However, by 25 DAT, fertilized treatments (T1, T3–T8) produced significantly higher leaf numbers compared to T2, indicating an early response to nutrient availability. This trend persisted at 39 DAT, where these treatments remained superior to the control (T0) and T2. By 53 DAT, differences were no longer statistically significant ($p > 0.05$). Consequently, T1 and the integrated treatments were placed in the same statistical group. This response can be attributed to complementary nutrient dynamics, where inorganic fertilizers provide readily available nutrients for early growth, while organic inputs such as POME release nutrients gradually through microbial decomposition (Jílková & Angst, 2022; Joshi *et al*., 2025).

Plant height was not significantly affected by treatments at 11 DAT (**Figure 5**). From 25 DAT onwards, fertilized treatments (T1, T3–T8) exhibited significantly greater height compared to T2. At 39 DAT, these treatments remained significantly taller than both T0 and T2. A significant Treatment × DAT interaction was observed, indicating that growth rates differed among treatments over time. Notably, T6 demonstrated a growth trend comparable to the farmer's practice (T1), maintaining steady increases in height as the experiment progressed. This pattern may be explained by synergistic effects between organic and inorganic fertilizers, which enhance soil microbial activity and nutrient cycling, thereby supporting plant growth (Luo *et al*., 2016)

Stem diameter was significantly affected by fertilizer treatments from 25 DAT onwards (**Figure 7**). At 25 and 39 DAT, treatments T1 and T3–T8 produced significantly larger stem diameters compared to T2, with no differences among the top-performing treatments. By 53 DAT, the combination treatments and T1 exhibited comparable performance, forming a superior group than T0 and T2. A significant interaction between treatment and time indicated that stem thickening was influenced by nutrient combinations throughout the growth period. Increased stem diameter under fertilized treatments may be associated with enhanced nitrogen availability, which supports vascular development and structural growth (Cai *et al*., 2017).

The male-to-female (M: F) flower ratio was significantly affected by the interaction between treatment and time (**Figure 8**). No flowers were observed at 11 DAT, reflecting the juvenile growth stage. As flowering progressed, clear treatment differences emerged. Treatment with nutrient inputs exhibited the significant M:F ratio, indicating a shift toward male flower production, whereas T0 and T2 showed lower ratios, reflecting a more balanced or female-biased expression. The M:F ratio generally peaked around 39 DAT before declining toward 53 DAT, indicating a transition from early male-dominant flowering to increased female flower production. Such shifts are typical in cucumber and are influenced by nutrient availability. Higher nutrient levels have been associated with increased female flower production and altered sex expression dynamics (Gao *et al*., 2021).

Root length was significantly influenced by fertilizer treatments with ($p = 0.015$) (**Table 3**). Treatments T2, T3, T4, T5, and T7 produced the greatest root lengths group than the control (T0) and the sole inorganic treatment (T1). The improved root growth under combined treatments may be attributed to the addition of organic matter from POME, which

enhances soil structure, porosity, and microbial activity, thereby facilitating root penetration and elongation (Siahaan *et al*., 2021). In contrast, the relatively shorter roots observed in T1 suggest that inorganic fertilization alone, while supplying readily available nutrients, does not contribute to improvements in soil physical properties. These findings are consistent with previous studies reporting that combined organic–inorganic fertilization improves root morphology and activity compared to sole inorganic inputs (Huang *et al*., 2021; Wang *et al*., 2022).

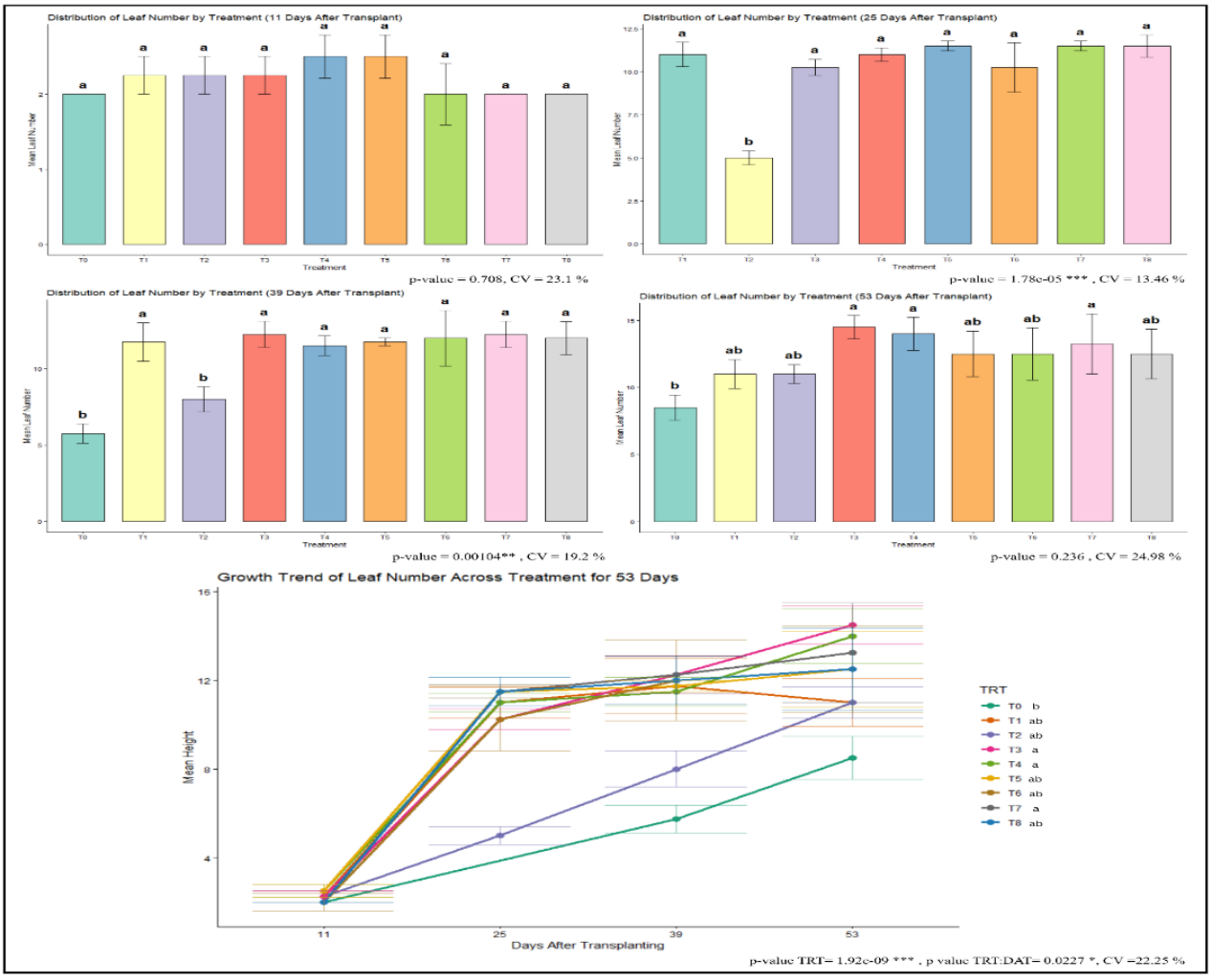



**Figure 4**. Leaf number of cucumber plants at 11, 25, 39, and 53 days after transplant

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

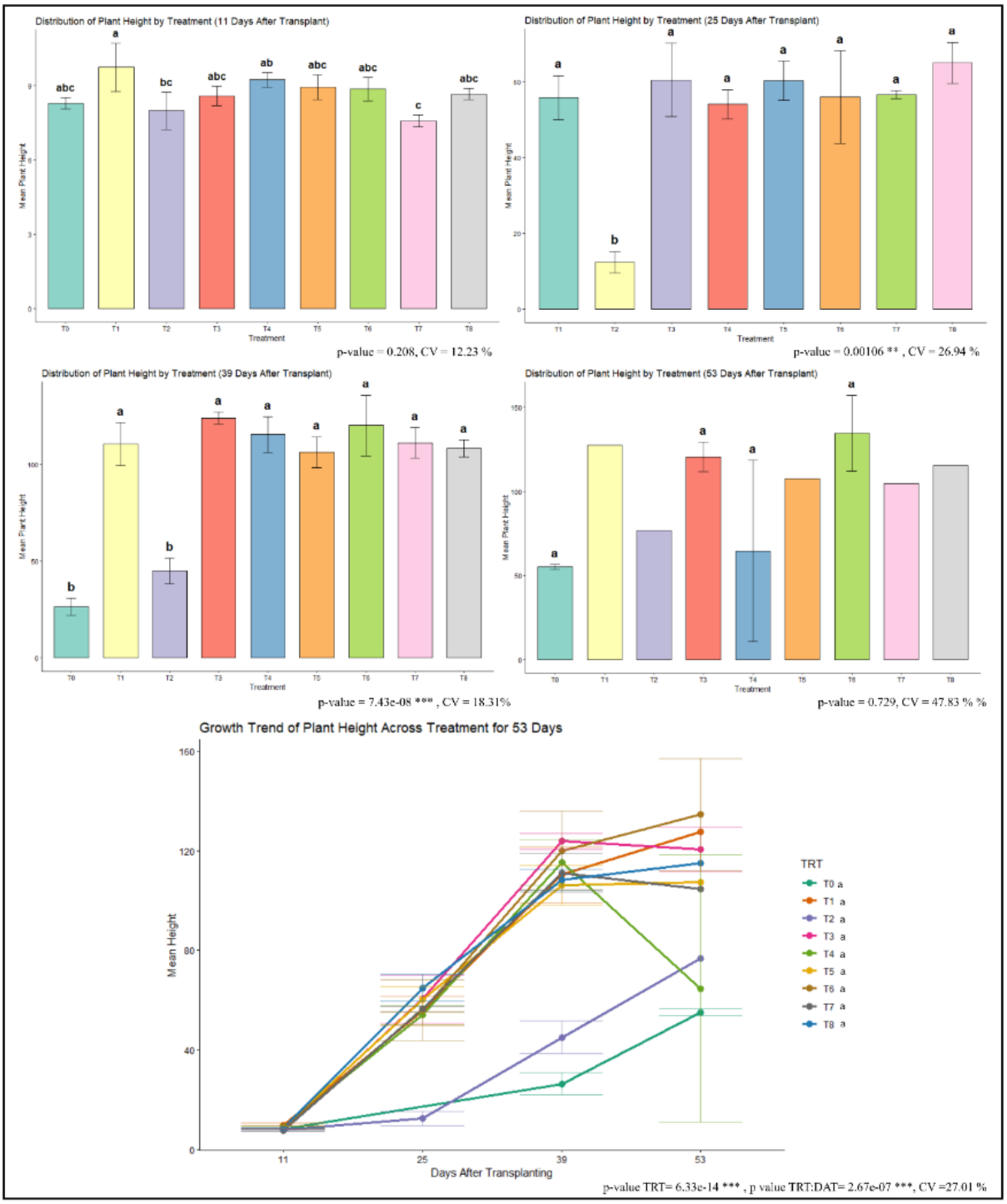



**Figure 5**. Plant height of cucumber plants at 11, 25, 39, and 53 days after transplant

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

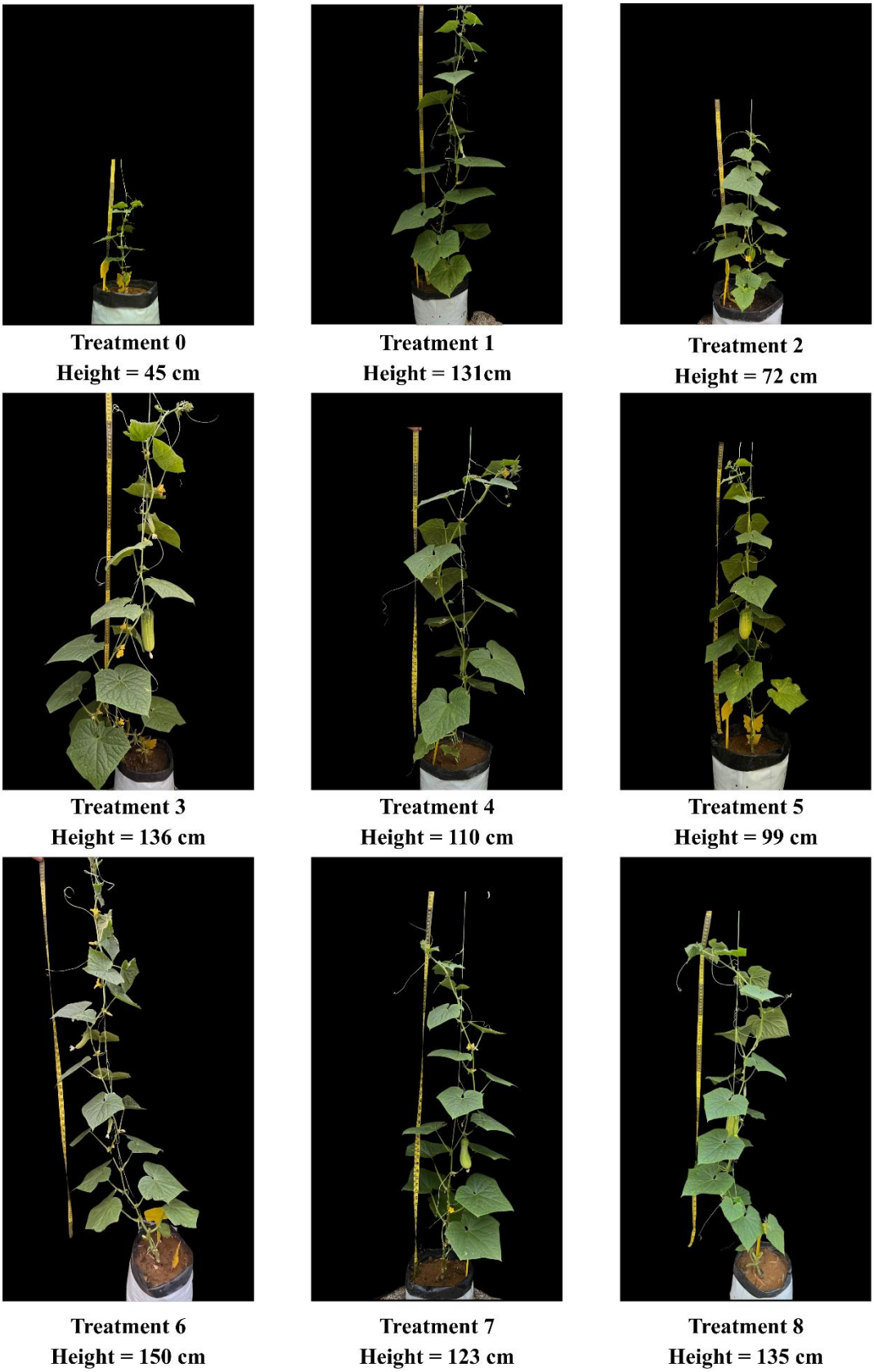



**Figure 6**. Comparison of plant height across different treatments

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

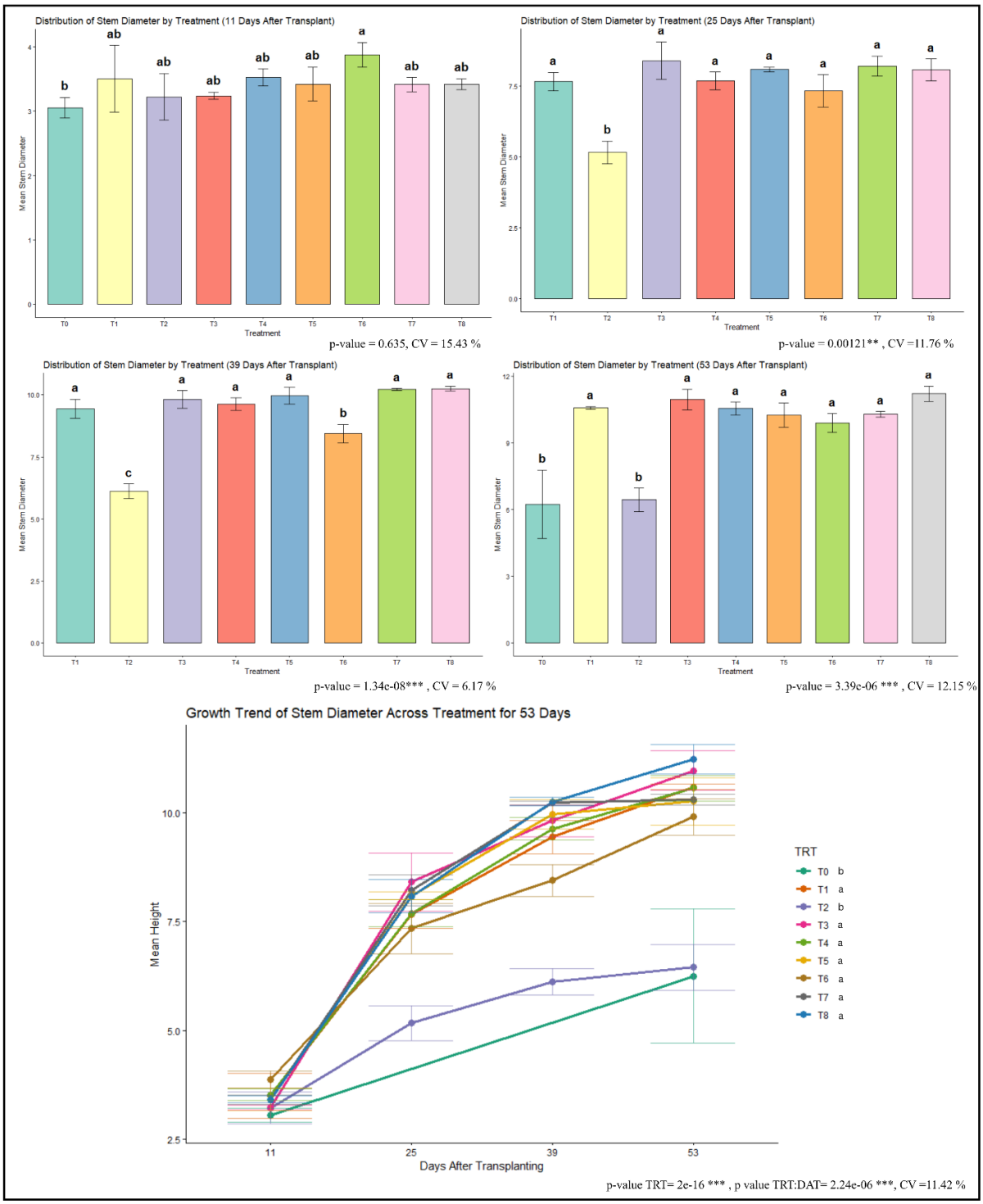



**Figure 7**. Stem diameter of cucumber plants at 11, 25, 39, and 53 days after transplant

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

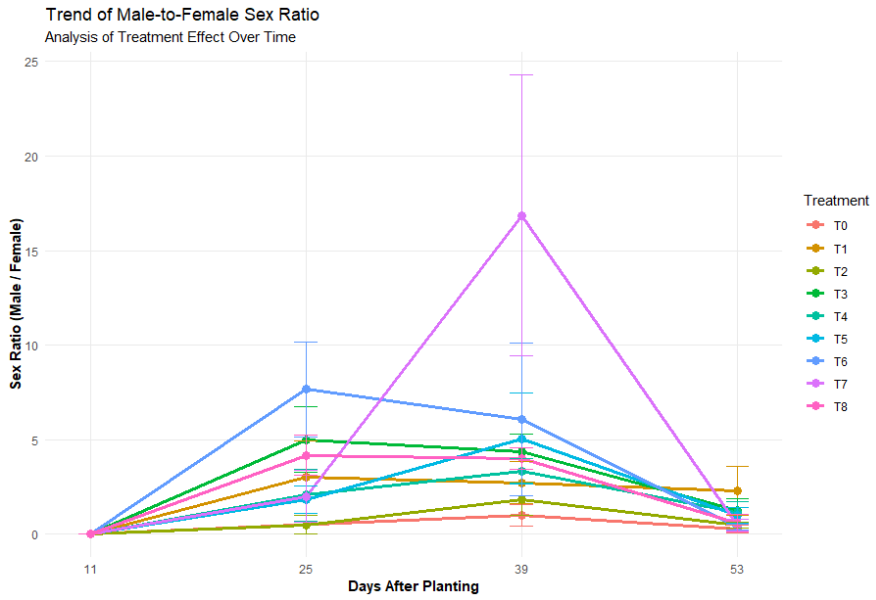



**Figure 8**. Ratio of male and female flowers across the 53 days after transplant

**Table 3**: Root length by treatments

| Treatment POME (ml) + NPK (g) | Root length (cm) |
|---|---|
| **T0** (0 + 0) | 36.52 ± 3.99de |
| **T1** (0 + 6) | 35.27 ± 8.23e |
| **T2** (300 + 0) | 62.73 ± 21.29abcd |
| **T3** (100 + 3) | 60.3 ± 2.87abcde |
| **T4** (100 + 6) | 70.2 ± 6.06ab |
| **T5** (200 + 3) | 65.97 ± 6.48abc |
| **T6** (200 + 6) | 50.62 ± 2.59bcde |
| **T7** (300 + 3) | 80.03 ± 11.13a |
| **T8** (300 + 6) | 39.83 ± 5.65cde |

Notes: Means followed by different letters indicate significant differences among treatments at $p < 0.05$.

## Physiological responses

Chlorophyll content was significantly influenced by treatment at 25 DAT (**Figure 9**), with T1 and T8 recording the highest values, while T2 and T7 showed the lowest. Similar trends were observed at 39 DAT with additional of T7 on the highest group, indicating sustained effects of nutrient availability on chlorophyll synthesis. However, by 53 DAT, no significant differences were detected among treatments. The initial increase in chlorophyll content under higher nutrient availability can be linked to the role of nitrogen, magnesium, and iron in chlorophyll formation (Kalaji *et al*., 2018). The gradual decline across treatments toward the final stage likely reflects nutrient remobilization from leaves to developing fruits, a common physiological response during reproductive growth. Significant differences in photosynthetic rate were observed among treatments (**Table 4**). Treatments T0, T1, T3, T4, and T5 recorded higher photosynthetic rates, whereas T2 and T7 exhibited significantly lower values. The enhanced photosynthetic performance under balanced fertilization may be associated with improved nutrient availability, particularly nitrogen, which is essential for chlorophyll synthesis and enzymatic activity involved in carbon fixation (Zhang *et al*., 2020). No significant differences were observed in transpiration rate or stomatal conductance among treatments (**Table 4**). This suggests that the different POME–NPK combinations did not markedly influence stomatal behaviour. The lack of treatment effects on these parameters indicates that stomatal regulation was primarily governed by environmental conditions rather than nutrient treatments, consistent with previous findings (Jing *et al*., 2026).

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

Vapour pressure deficit (VPD) did not differ significantly among treatments (**Table 4**), with values remaining relatively uniform across all plots. This reflects the fact that VPD is largely controlled by ambient atmospheric conditions rather than plant nutritional status. These findings are consistent with studies showing that VPD is an environmental parameter that influences plant water relations independently of fertilization treatments (Ding *et al*., 2022).

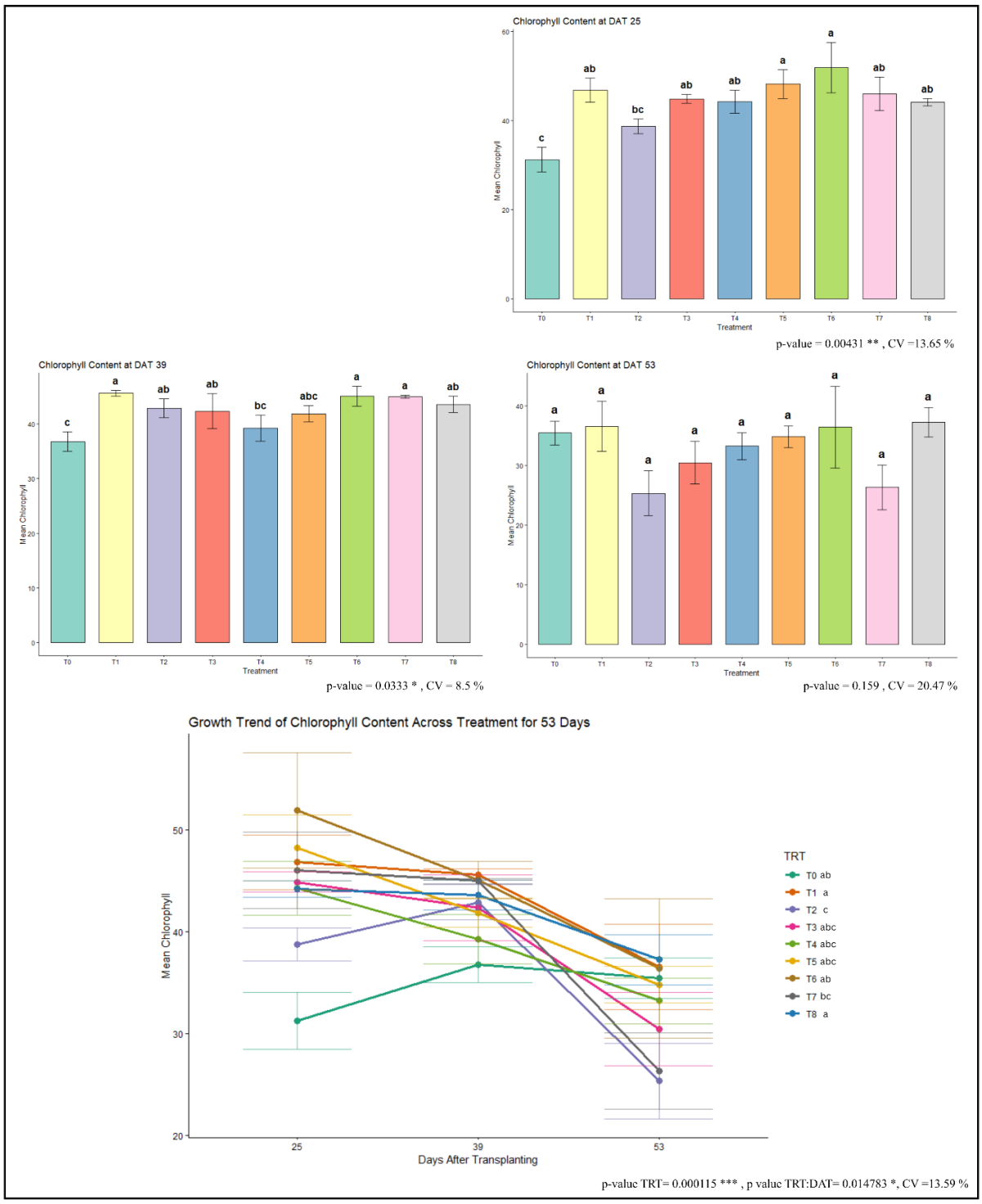



**Figure 9**. Chlorophyll content of cucumber plants at 25, 39, and 53 days after transplant

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

**Table 4.** Physiological responses by treatment

| Treatment | Photosynthesis (µmol $m^{-2}$ $s^{-1}$) | Transpiration (mmol $m^{-2}$ $s^{-1}$) | VPD (kPa) |
|---|---|---|---|
| **T0** | 32.26 ± 2.6 ab | 11.61 ± 2.31 ab | 1.42 ± 0.02 b |
| **T1** | 32.9 ± 6.32 a | 11.79 ± 3.48 ab | 1.42 ± 0.02 b |
| **T2** | 19.93 ± 4.8 cd | 16.78 ± 4.34 a | 1.39 ± 0.01 b |
| **T3** | 26.03 ± 4.31 abc | 9.04 ± 3.15 ab | 1.43 ± 0.04 ab |
| **T4** | 32.5 ± 4.59 ab | 7.61 ± 1.56 b | 1.45 ± 0 ab |
| **T5** | 27.94 ± 2.27 abc | 7.06 ± 1.92 b | 1.44 ± 0.02 ab |
| **T6** | 20.74 ± bcd | 6.26 ± 3.56 b | 1.42 ± 0.07 b |
| **T7** | 10.8 ± 1.97 d | 8.91 ± 2.9 ab | 1.44 ± 0.02 ab |
| **T8** | 12.54 ± 0.66 d | 4.19 ± 0.93 b | 1.51 ± 0.02 a |

Notes: Means followed by different letters indicate significant differences among treatments at $p < 0.05$.

## Plant yield and fruit quality

Total fruit production varied among treatments (**Figure 10**). Treatments T4 and T8 recorded the highest fruit numbers (10 fruits per plant), followed by T2 (8 fruits) and T5 (7 fruits). Treatments T1, T3, T6, and T7 produced intermediate yields (6 fruits), while the control (T0) recorded the lowest production (3 fruits). Overall, all fertilized treatments increased fruit number compared to the control, indicating a positive response to nutrient application. The superior performance of T4 and T8 suggests that higher NPK combined with POME enhances reproductive development, likely through improved flowering and fruit set. Adequate nutrient supply, particularly nitrogen, phosphorus, and potassium, is known to promote reproductive processes and increase fruit number in cucumbers (Karagatiya *et al*., 2025).

Fruit yield parameters (weight, length) were significantly affected by treatment (**Table 5**), with a significant Treatment × Harvest interaction observed, indicating that yield performance varied across harvesting periods. Treatments T1, T3, T4, T5, T6, and T8 formed the highest statistical group for yield while T0 and T2 produced the lowest yield group components. Variability in fruit weight among treatments was relatively high, as reflected by the high residual variance, suggesting non-uniformity in fruit development within treatments. The superior yield observed in integrated POME–NPK treatments can be explained by the source–sink relationship in plants. Enhanced vegetative growth and photosynthetic capacity (source) support the development of fruits (sink) through improved assimilate production and allocation. Treatments with higher photosynthetic rates and improved root development were therefore able to sustain greater fruit growth and yield. Similar findings were reported by (Ma *et al*., 2011), who demonstrated that increased source strength significantly enhances fruit set and fruit weight. Conversely, the poor performance of T0 and T2 can be attributed to nutrient limitations, particularly nitrogen and potassium, which are essential for chlorophyll synthesis, photosynthesis, and assimilate transport. Nutrient deficiency reduces photosynthetic efficiency and limits carbohydrate availability for fruit development, resulting in lower yield (Huang *et al*., 2021; Ma *et al*., 2011).




**Figure 10**. Cucumber yield by treatment

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

**Table 5.** Yield performance of *Cucumis sativus* L.

| Treatment POME (ml) + NPK (g) | Fruit weight (g) | Fruit Length (cm) | Fruit Diameter (mm) |
|---|---|---|---|
| **T0** (0 + 0) | 41.34 ± 16.58c | 6.87 ± 0.52c | 32.92 ± 3.69c |
| **T1** (0 + 6) | 163.05 ± 10.06ab | 14.17 ± 0.49ab | 40.86 ± 0.92abc |
| **T2** (300 + 0) | 124.48 ± 124.48bc | 9.43 ± 0.09bc | 44.08 ± 0.88ab |
| **T3** (100 + 3) | 225.32 ± 45.85ab | 15.57 ± 1.31ab | 44.01 ± 3.81ab |
| **T4** (100 + 6) | 193.85 ± 26.53ab | 13.43 ± 1.02abc | 45.63 ± 2.74ab |
| **T5** (200 + 3) | 251.60 ± 56.42a | 15.00 ± 1.5ab | 47.49 ± 4.8a |
| **T6** (200 + 6) | 244.00 ± 56.23a | 15.60 ± 1.18ab | 46.78 ± 3.54ab |
| **T7** (300 + 3) | 134.92 ± 26.96bc | 12.73 ± 1.28abc | 37.72 ± 2.79bc |
| **T8** (300 + 6) | 153.69 ± 41.57abc | 18.86 ± 5.99a | 39.71 ± 3.43abc |
| F-test significance | * | * | ns |
| Coefficient variance | 36.67 % | 28.46 % | 13.17 % |

Notes: Means followed by different letters indicate significant differences among treatments at $p < 0.05$.

## Postharvest performance

Sensory quality varied significantly among treatments and across storage time (**Figure 11**). At Day 1, all attributes (flavor, texture, odor, freshness, and greenness) showed significant differences ($p < 0.01$). Treatments T1, T7, and T6 consistently ranked among the highest for flavor and texture, while T7 and T1 also recorded superior freshness. In contrast, T8 showed the lowest scores for several attributes at this stage. By Day 3, differences in odor were no longer significant ($p > 0.05$), whereas other attributes remained significantly affected by treatment. Most fertilized treatments formed a statistically similar group for flavor and freshness, indicating a convergence in sensory quality during intermediate storage. However, T2 consistently ranked among the lowest-performing treatments. At Day 6, treatment differences re-emerged for several attributes. T4 and T8 recorded higher flavor scores, while T4, T3, and T7 maintained superior texture. Freshness and greenness were best preserved in treatments T4 and T7, indicating improved postharvest stability under these combinations. Overall, T4 and T7 demonstrated the most consistent sensory performance throughout storage, frequently appearing in the highest statistical groupings. The improved sensory quality under integrated POME–NPK treatments may be attributed to enhanced chlorophyll stability, turgor maintenance, and cell wall integrity, as reported in previous studies (Urrutia-Jalabert *et al*., 2020).

Fruit firmness was significantly influenced by treatment and storage duration (**Figure 12**). This suggests that although firmness declined over time, the relative ranking among treatments remained generally consistent. At Day 3, treatments T5 and T8 exhibited the highest firmness and were not significantly different from T3 and T6, forming the upper statistical group. In contrast, T0 and T2 recorded significantly lower firmness, indicating weaker structural integrity shortly after harvest. By Day 9, firmness decreased across all treatments. However, T6 remained significantly higher than all other treatments, demonstrating superior firmness retention. Most other treatments clustered within similar statistical groups, while T0 continued to show the lowest firmness. The enhanced firmness observed in selected treatments may be attributed to improved nutrient availability, particularly potassium and nitrogen, which play essential roles in maintaining cell wall strength and turgor pressure. Additionally, the gradual nutrient release from POME could contribute to sustained structural stability during storage. These findings are in agreement with (Bai *et al*., 2021) who reported that balanced nutrient supply enhances postharvest firmness and delays softening.

Weight loss increased progressively during storage and was significantly influenced by treatment (**Figure 13**). At Day 3, the control (T0) exhibited the highest weight loss (15.57%), indicating poor moisture retention. In contrast, T4, T5, and T6 recorded the lowest losses (<3%), demonstrating improved water retention under fertilized conditions. By Day 6,

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

weight loss increased across all treatments, with T0 remaining the highest (17.10%). Among fertilized treatments, T1, T4, and T8 maintained the lowest weight loss (approximately 3–4%), indicating superior shelf-life performance. In contrast, T7 and T2 showed relatively higher losses among the treated groups. The reduced weight loss observed in fertilized treatments may be attributed to improved cell membrane stability and water retention capacity, particularly due to the roles of potassium and calcium in maintaining tissue integrity. These nutrients enhance the structural strength of fruit tissues, thereby reducing moisture loss during storage (Bai *et al*., 2021). Additionally, the epidermal layer plays a critical role in limiting postharvest water loss, and its development is influenced by plant nutritional status (Pan, 2023).

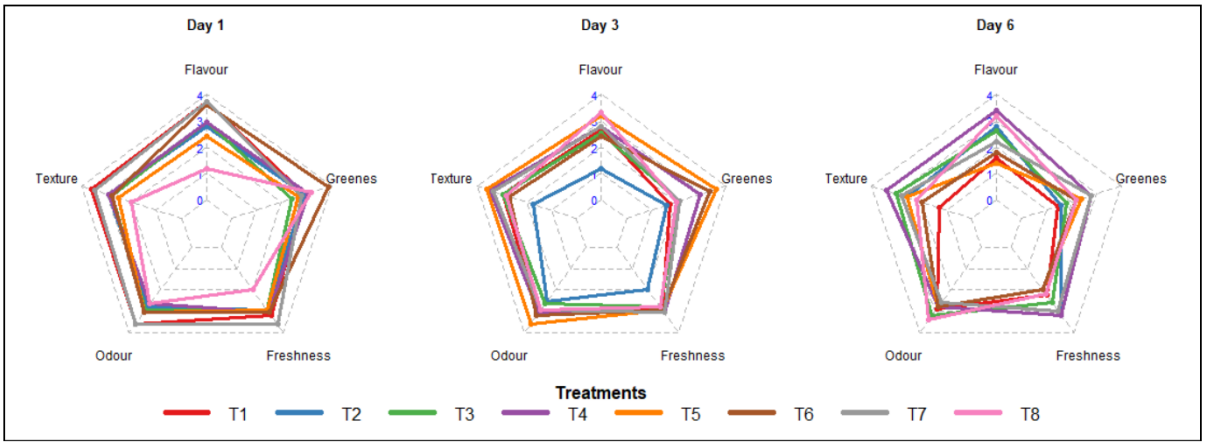



**Figure 11**. Sensory Evaluation of *Cucumis sativus* L. (Day 1, 3, and 6)

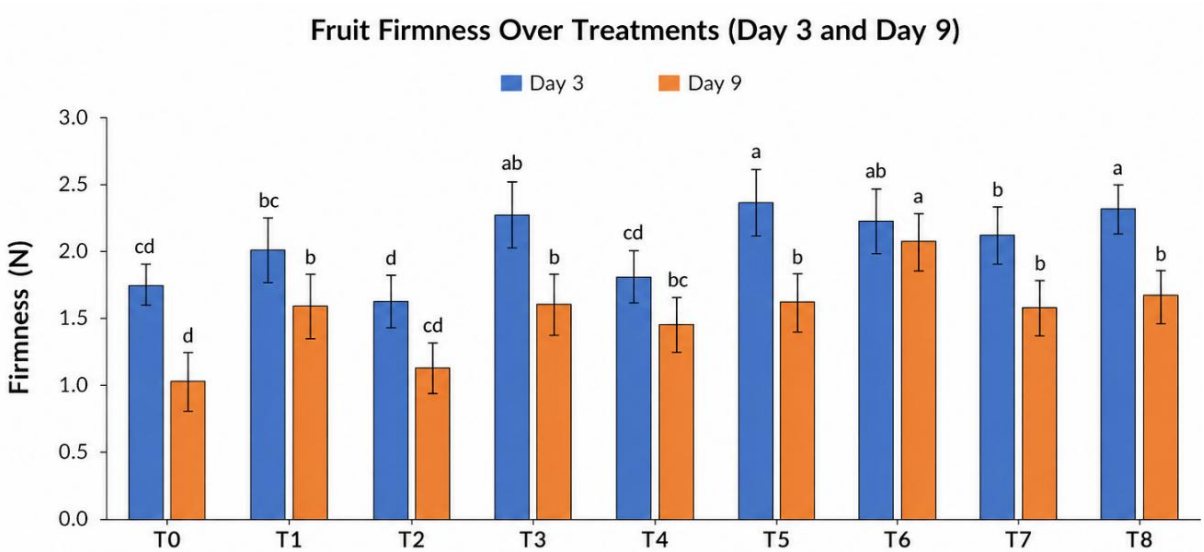



**Figure 12**. Fruit firmness by treatments

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

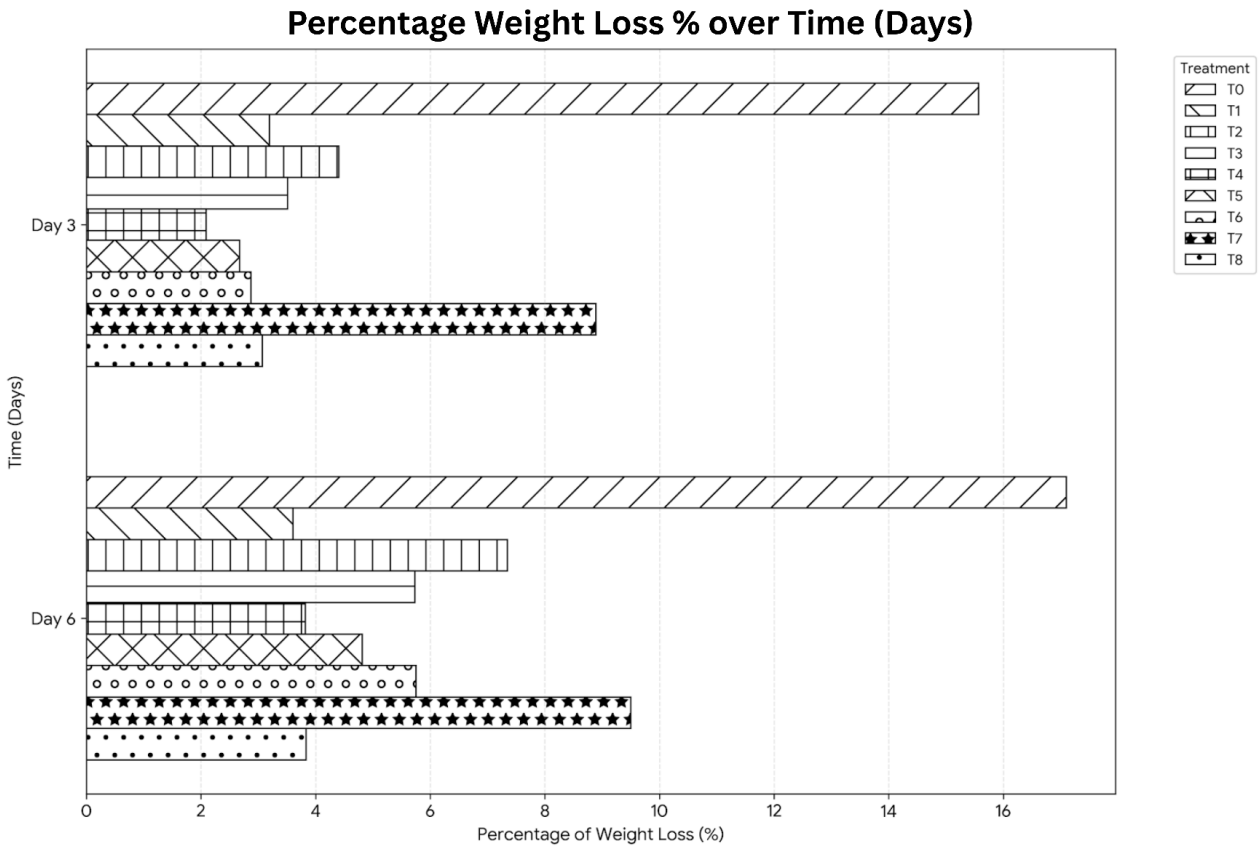



**Figure 13**. Percentage of weight loss over time

**Soil chemical properties**

Soil chemical properties were evaluated to assess residual nutrient levels following the application of different POME and NPK combinations (**Table 6**). No significant differences were observed for total nitrogen ($p = 1.00$), available phosphorus ($p = 0.459$), calcium ($p = 0.362$), and cation exchange capacity (CEC) ($p = 1.00$), indicating that these parameters were not substantially affected by the treatments within the duration of the study. In contrast, potassium (K) and magnesium (Mg) were significantly influenced by fertilizer application. Potassium levels differed significantly ($p = 0.01$), with T8 recording the highest value ($0.19 \pm 0.05$) and forming a distinct statistical group, while all other treatments remained significantly lower. Similarly, magnesium content was significantly higher in T8 ($0.04 \pm 0.01$), followed by T5, whereas the control (T0) recorded the lowest values. Soil pH was highly affected by treatment ($p < 0.001$). The control (T0) maintained the highest pH ($4.91 \pm 0.04$), while T8 resulted in the lowest pH ($4.34 \pm 0.04$), indicating increased soil acidity under this treatment. Intermediate values were observed in treatments T2 and T3. The elevated levels of potassium and magnesium in T8 may be attributed to the higher nutrient input from combined POME and NPK applications, leading to residual accumulation in the soil. In contrast, the decrease in soil pH under T8 is likely associated with nitrification processes from ammonium-based fertilizers, which release hydrogen ions and contribute to soil acidification (Tkaczyk *et al*., 2020).

*Malaysian Journal of Soil Science 2026, Vol. 30: 270-288*
*Received:3/3/2026; Revised:6/9/2026; Accepted:4/11/2026; Online: 8/11/2026*

**Table 6.** Soil chemical properties analyse at the end of experiment

| Treatment | Total N | Avail. P | Exch. K | Exch.Ca | Exch. Mg | pH | CEC |
|---|---|---|---|---|---|---|---|
| **T0** | 217.79 ± 164.36 a | 3.12 ± 0.45 a | 0.03 ± 0.02 b | 0.07 ± 0.01 b | 0.01 ± 0.00 c | 4.91 ± 0.04 a | 1.65 ± 0.39 a |
| **T1** | 338.66 ± 197.94 a | 3.81 ± 0.75 a | 0.08 ± 0.01 b | 0.11 ± 0.02 ab | 0.02 ± 0.00 bc | 4.47 ± 0.10 de | 2.95 ± 1.75 a |
| **T2** | 377.35 ± 216.44 a | 5.07 ± 1.23 a | 0.07 ± 0.01 b | 0.10 ± 0.02 ab | 0.02 ± 0.00 bc | 4.88 ± 0.03 ab | 3.23 ± 1.99 a |
| **T3** | 319.11 ± 184.50 a | 2.76 ± 0.46 a | 0.04 ± 0.00 b | 0.12 ± 0.01 a | 0.02 ± 0.00 bc | 4.76 ± 0.05 ab | 2.94 ± 2.00 a |
| **T4** | 327.50 ± 176.14 a | 3.44 ± 0.41 a | 0.10 ± 0.04 b | 0.10 ± 0.01 ab | 0.02 ± 0.00 bc | 4.43 ± 0.04 de | 2.97 ± 1.94 a |
| **T5** | 346.35 ± 204.18 a | 3.34 ± 0.12 a | 0.06 ± 0.01 b | 0.09 ± 0.01 ab | 0.03 ± 0.00 b | 4.54 ± 0.03 cd | 2.94 ± 1.86 a |
| **T6** | 310.85 ± 168.32 a | 3.66 ± 0.33 a | 0.10 ± 0.03 b | 0.08 ± 0.01 b | 0.02 ± 0.00 bc | 4.58 ± 0.11 cd | 3.14 ± 2.30 a |
| **T7** | 319.80 ± 175.34 a | 4.00 ± 0.72 a | 0.06 ± 0.01 b | 0.09 ± 0.02 ab | 0.02 ± 0.00 bc | 4.69 ± 0.04 bc | 3.12 ± 1.89 a |
| **T8** | 234.88 ± 193.61 a | 5.03 ± 1.54 a | 0.19 ± 0.05 a | 0.10 ± 0.01 ab | 0.04 ± 0.01 a | 4.34 ± 0.04 e | 3.40 ± 1.86 a |
| F-test significance | ns | ns | ** | ns | * | *** | ns |
| Coefficient variance | 128.85% | 40.45% | 38.85% | 28.32% | 34.36% | 2.69% | 135.03% |

Unit: Total N (mg $kg^{-1}$), Avail. P (mg $kg^{-1}$), Exch. K (cmolc $kg^{-1}$), Exch. Ca (cmolc $kg^{-1}$), Exch. Mg (cmolc $kg^{-1}$), EC (ms/cm)

## CONCLUSION

The combined application of treated palm oil mill effluent (POME) and NPK fertilizer influenced cucumber growth, yield, postharvest quality, and soil chemical properties. Combined applications enhanced vegetative growth parameters, including plant height, leaf number, stem diameter, chlorophyll content, and root development. Notably, treatments supplemented with POME and reduced NPK rates achieved growth performance comparable to the full-rate NPK treatment, highlighting the potential of treated POME as a partial substitute for inorganic fertilizers. Integrated POME–NPK applications also maintained cucumber yield performance equivalent to conventional fertilization, suggesting that balanced nutrient availability improved source–sink relationships and supported efficient crop productivity. In addition, postharvest assessments demonstrated that the combined treatments improved fruit firmness, greenness, and freshness during storage, thereby enhancing fruit quality and marketability. Soil chemical analysis revealed that higher NPK application rates increased residual potassium and magnesium concentrations, which may contribute to nutrient accumulation and alterations in soil acidity associated with nitrification processes. These findings emphasize the importance of precise fertilizer management to avoid nutrient imbalances and potential soil degradation. Among the evaluated treatments, the combination of 3 g NPK and treated POME demonstrated favourable agronomic responses, suggesting its potential as an integrated nutrient management option for cucumber cultivation. Overall, this study demonstrates that integrating treated POME with reduced NPK rates represents a promising and sustainable nutrient management approach for cucumber production. This strategy offers the dual advantages of maintaining crop performance while reducing dependence on inorganic fertilizers and promoting the beneficial reuse of agro-industrial waste. Further studies should evaluate the long-term impacts on soil health, nutrient dynamics, and economic feasibility to support the wider adoption of integrated fertilization practices in sustainable agricultural systems.

## ACKNOWLEDGEMENTS

This research was funded by Universiti Putra Malaysia through GP-IPM (9820600). The authors also acknowledge all individuals and parties who contributed directly or indirectly to the successful completion of this study.

## REFERENCES

Abu Hassan, M. A., & Puteh, M. H. (2020). *Pre-Treatment-Of-Palm-Oil-Mill-Effluent-POME-A-Comparison-Study-Using-Chitosan-And-Alum+(1)*.

Agbor, D. T., Egbe, L. E., Tambe, A. A., Sama, D. K., Lekelefeh, B. C., Tabot, P. T., & Mfombep, P. M. (2025). Organic fertilization strategies for enhancing soil fertility and cucumber yield: a sustainable alternative to synthetic fertilizers. *Organic Agriculture*, *15*(1), 137–146. https://doi.org/10.1007/s13165-025-00488-7

Ahmad, M. J., Ismail, R., & Ghani, F. A. (2023). Review on socioeconomic and sustainability of oil palm plantations among rural communities in Malaysia. *IOP Conference Series: Earth and Environmental Science*, *1208*(1). https://doi.org/10.1088/1755-1315/1208/1/012054

Bai, Q., Shen, Y., & Huang, Y. (2021). Advances in Mineral Nutrition Transport and Signal Transduction in Rosaceae Fruit Quality and Postharvest Storage. In *Frontiers in Plant Science* (Vol. 12). Frontiers Media S.A. https://doi.org/10.3389/fpls.2021.620018

Cai, Q., Ji, C., Yan, Z., Jiang, X., & Fang, J. (2017). Anatomical responses of leaf and stem of Arabidopsis thaliana to nitrogen and phosphorus addition. *Journal of Plant Research*, *130*(6), 1035–1045. https://doi.org/10.1007/s10265-017-0960-2

Chivenge, P., Vanlauwe, B., Gentile, R., & Six, J. (2011). Comparison of organic versus mineral resource effects on short-term aggregate carbon and nitrogen dynamics in a sandy soil versus a fine textured soil. *Agriculture, Ecosystems and Environment*, *140*(3–4), 361–371. https://doi.org/10.1016/j.agee.2010.12.004

Ding, J., Jiao, X., Bai, P., Hu, Y., Zhang, J., & Li, J. (2022). Effect of vapor pressure deficit on the photosynthesis, growth, and nutrient absorption of tomato seedlings. *Scientia Horticulturae*, *293*. https://doi.org/10.1016/j.scienta.2021.110736

Gao, L., Yu, G., Hu, F., Li, Z., Li, W., & Peng, C. (2021). The patterns of male and female flowers in flowering stage may not be optimal resource allocation for fruit and seed growth. *Plants*, *10*(12). https://doi.org/10.3390/plants10122819

Huang, X., Muneer, M. A., Li, J., Hou, W., Ma, C., Jiao, J., Cai, Y., Chen, X., Wu, L., & Zheng, C. (2021). Integrated nutrient management significantly improves pomelo (Citrus grandis) root growth and nutrients uptake under acidic soil of Southern China. *Agronomy*, *11*(6). https://doi.org/10.3390/agronomy11061231

Jabatan Pertanian. (1997). Pakej Teknologi Timun. Jabatan Pertanian Semenanjung Malaysia.

Jílková, V., & Angst, G. (2022). Biochar and compost amendments to a coarse-textured temperate agricultural soil lead to nutrient leaching. *Applied Soil Ecology*, *173*. https://doi.org/10.1016/j.apsoil.2022.104393

Jing, Y., Zheng, Z., Xu, Z., Yang, S., & Feng, Z. (2026). Effects of Biochar–Fertilizer Combinations on Photosynthetic and Transpiration Functions of Paddy Rice Using Box–Cox Transformation. *Agronomy*, *16*(2), 160. https://doi.org/10.3390/agronomy16020160

Joneer, A., & Sam, L. M. (2022). Effect of humic acid on growth and yield of Tadong upland rice. *Science Engineering and Health Studies*, *16*. https://doi.org/10.14456/sehs.2022.50

Joshi, N., Kaur, R., Bibi, M., Fahad, S., & Nawaz, T. (2025). Soil amendments and their impact on plant nutrient availability. In *Sustainable Soil Chemistry and Plant Nutrition: Innovations and Applications* (pp. 313–330). Elsevier. https://doi.org/10.1016/B978-0-443-40584-6.00004-8

Kader, A.A. (2002) Postharvest Technology of Horticultural Crops. 3rd Edition, University of California, Agriculture and Natural Resources, Oakland, Publication 3311, 535 p., Kader, AA.

Kalaji, H. M., Bąba, W., Gediga, K., Goltsev, V., Samborska, I. A., Cetner, M. D., Dimitrova, S., Piszcz, U., Bielecki, K., Karmowska, K., Dankov, K., & Kompała-Bąba, A. (2018). Chlorophyll fluorescence as a tool for nutrient status identification in rapeseed plants. *Photosynthesis Research*, *136*(3), 329–343. https://doi.org/10.1007/s11120-017-0467-7

Liu, H., Yuan, B., Hu, X., Yin, C., & Tang, X. (2021). Cucumber production and the economic revenues under various nitrogen applications in an unheated solar greenhouse on the North China Plain. *Agronomy Journal*, *113*(4), 3444–3459. https://doi.org/10.1002/agj2.20773

Luo, H., Ge, L., Zhang, J., Ding, J., Chen, R., & Shi, Z. (2016). Enhancing acetone biosynthesis and acetone-butanol-ethanol fermentation performance by co-culturing Clostridium acetobutylicum/Saccharomyces cerevisiae integrated with exogenous acetate addition. *Bioresource Technology*, *200*, 111–120. https://doi.org/10.1016/j.biortech.2015.09.116

Ma, Y. T., Wubs, A. M., Mathieu, A., Heuvelink, E., Zhu, J. Y., Hu, B. G., Cournéde, P. H., & De Reffye, P. (2011). Simulation of fruit-set and trophic competition and optimization of yield advantages in six Capsicum

cultivars using functionalstructural plant modelling. *Annals of Botany*, *107*(5), 793–803. https://doi.org/10.1093/aob/mcq223

Marliah, A., Anhar, A., Hayati, E., & Nura. (2020). Combine organic and inorganic fertilizer increases yield of cucumber (*Cucumis sativus* L.). *Iop Conference Series Earth and Environmental Science*, *425*(1). https://doi.org/10.1088/1755-1315/425/1/012075

Mohammad, N., Alam, M. Z., Kabbashi, N. A., & Ahsan, A. (2012). Effective composting of oil palm industrial waste by filamentous fungi: A review. In *Resources, Conservation and Recycling* (Vol. 58, pp. 69–78). https://doi.org/10.1016/j.resconrec.2011.10.009

Onoja, E., Chandren, S., Abdul Razak, F. I., Mahat, N. A., & Wahab, R. A. (2019). Oil Palm (Elaeis guineensis) Biomass in Malaysia: The Present and Future Prospects. In *Waste and Biomass Valorization* (Vol. 10, Number 8, pp. 2099–2117). Springer Netherlands. https://doi.org/10.1007/s12649-018-0258-1

Karagatiya, F.P., R, Kanzari, D.P., Mavadiya, V.V., & Daki, R.N.. (2025). Effect of different level of N, P and K on growth, yield and soil status of Guava under meadow orchard system. *International Journal of Research in Agronomy*, *8*(10), 09–18. https://doi.org/10.33545/2618060x.2025.v8.i10a.3940

Pan, Y. (2023). Research Progress in the Effects of Epidermal Tissue on Postharvest Fruit Water Loss. In *Guangdong Agricultural Sciences* (Vol. 50, Number 10, pp. 1–10). Guangdong Academy of Agricultural Sciences. https://doi.org/10.16768/j.issn.1004-874X.2023.10.001

Rupani, P. F., Ibrahim, M. H., & Ismail, S. A. (2013). Vermicomposting biotechnology: recycling of palm oil mill wastes into valuable products. *International Journal of Recycling of Organic Waste in Agriculture*, *2*(1). https://doi.org/10.1186/2251-7715-2-10

Siahaan, M., Sakiah, Sutanto, A. S., Lawary, A., & Mahmuda, R. (2021). The study of soil biological and chemical properties on palm oil plant rhizosphere with and without palm oil mill effluent applications. *IOP Conference Series: Earth and Environmental Science*, *819*(1). https://doi.org/10.1088/1755-1315/819/1/012003

Sutardi, Ghulamahdi, M., Aziz, S. A., Aswidinnoor, H., & Anda, M. (2025). Smart fertilizer: Ameliorant-based NPK coating enhanced rice yield and quality in vertisol paddy soil. *Journal of the Saudi Society of Agricultural Sciences*, *24*(4). https://doi.org/10.1007/s44447-025-00027-6

Teow, Y. H., Takriff, M. S., Masdar, M. S., Mutalib, S. A., Abdul, P. M., Jahim, J. Md., Yaakob, Z., Harun, S., & Mohammed Yunus, M. F. (2022). Zero-Waste Technologies for the Sustainable Development of Oil Palm Mills. In *Sustainable Technologies for the Oil Palm Industry Latest Advances and Case Studies*. https://doi.org/10.1007/978-981-19-4847-3_10

Tkaczyk, P., Mocek-Płóciniak, A., Skowrońska, M., Bednarek, W., Kuśmierz, S., & Zawierucha, E. (2020). The mineral fertilizer-dependent chemical parameters of soil acidification under field conditions. *Sustainability (Switzerland)*, *12*(17). https://doi.org/10.3390/su12177165

Urrutia-Jalabert, R., Lara, A., Barichivich, J., Vergara, N., Rodriguez, C. G., & Piper, F. I. (2020). Low Growth Sensitivity and Fast Replenishment of Non-structural Carbohydrates in a Long-Lived Endangered Conifer After Drought. *Frontiers in Plant Science*, *11*. https://doi.org/10.3389/fpls.2020.00905

Wang, N., Feng, K. Y., Nan, H. Y., & Zhang, T. H. (2022). Effects of Combined Application of Organic Fertilizer and Chemical Fertilizer on Root Characteristics and Yield of Cotton under Different Water Conditions. *Scientia Agricultura Sinica*, *55*(11), 2187–2201. https://doi.org/10.3864/j.issn.0578-1752.2022.11.009

Wüstenhöfer, S. (2010). *Clarification on POME and EFB*.

Zahrah & Fathurrahman, S. (2017). Aplikasi limbah cair pabrik kelapa sawit dan npk organik pada tanaman timun suri (*Cucumis sativus* L.) Application of Palm Oil Mill Liquid Waste and Organic NPK in Cucumber Suri Plants (*Cucumis Sativus* L.). In *Jl. Kaharuddin Nasution* (Vol. 113).

Zhang, M., Sun, D., Niu, Z., Yan, J., Zhou, X., & Kang, X. (2020). Effects of combined organic/inorganic fertilizer application on growth, photosynthetic characteristics, yield and fruit quality of Actinidia chinesis cv 'Hongyang.' *Global Ecology and Conservation*, *22*. https://doi.org/10.1016/j.gecco.2020.e00997