

Agronomic Response of Peanut (*Arachis hypogaea* L.) to Controlled-Release, Conventional and Local Organic Fertilizer Applications

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Abstract

This study evaluated the agronomic response of peanut (*Arachis hypogaea* L.) to controlled-release, conventional, complete inorganic, and locally available organic fertilizer management regimes under the conditions of Barangay Baleguian, Jabonga, Agusan del Norte, Philippines. The study was anchored on the agronomic concept of nutrient supply–crop demand synchronization, supported by nutrient-use efficiency, nutrient mineralization, and soil–plant interactions. A Randomized Complete Block Design was employed using five treatments with five replications, comprising 25 peanut plants. Agronomic responses included plant height at 14, 28, and 42 days after transplanting, root length, number of pods, and fresh and dry biomass. Data were analyzed using the Statistical Tool for Agricultural Research. Among the treatments, T3, consisting of 20 g Osmocote 14-14-14, consistently produced the strongest measured agronomic performance, attaining the greatest plant height at 42 days after transplanting (63.00 cm), root length (40.80 cm), pod number (17.80 pods per plant), fresh leaf biomass (202 g), dry leaf biomass (46 g), fresh root biomass (45 g), and dry root biomass (15 g). Conventional fertilization generally produced intermediate responses, while local organic fertilization showed comparatively slower early growth but contributed to plant and root development. Because fertilizer quantities and application schedules differed among treatments, the observed responses represent the fertilizer regimes as applied and cannot be attributed solely to nutrient-release mechanisms. The study concludes that controlled-release fertilizer showed the strongest short-term agronomic response under the experimental conditions, while integrated nutrient management involving organic and mineral nutrient sources may help balance crop nutrition and soil-management objectives. Further research should assess long-term soil properties, microbial communities, nutrient-equivalent fertilizer rates, and field-scale performance. The study primarily supports SDG 2—Zero Hunger and SDG 12—Responsible Consumption and Production by contributing evidence toward productive crop nutrition and more efficient nutrient management. Its sustainability significance lies in supporting agronomic productivity, responsible fertilizer use, soil management, and the potential integration of locally available organic nutrient sources into more sustainable production systems.

Keywords: Agronomic Response; Fertilizer Management; Integrated Nutrient Management; Local Organic Fertilizer; Nutrient Management; Peanut; Pod Production; Sustainable Agriculture

1. Introduction

Peanut (*Arachis hypogaea* L.) is an economically and nutritionally important leguminous oilseed crop cultivated across tropical, subtropical, and warm temperate regions. Its importance extends beyond food and edible oil production because peanut contributes protein, lipids, micronutrients, livestock feed, crop residues, and biological nitrogen fixation to agricultural systems. Recent literature recognizes peanut as originating from South America, while genomic research continues to refine understanding of the evolutionary relationships that produced cultivated *A. hypogaea* (Çiftçi & Suna, 2022; Pan et al., 2023). In the Philippines, peanut production remains constrained by multiple interacting agronomic and socioeconomic factors. These include access to quality planting materials, pests and diseases, limited mechanization, inadequate technical training, and nutrient-management limitations (Balba et al., 2025). Nutrient management is particularly important because peanut productivity depends not merely on the amount of fertilizer supplied but on nutrient balance, availability, timing, root-zone conditions, soil biological processes, and synchronization of nutrient release with crop demand. These considerations make the comparative assessment of fertilizer management regimes relevant to both productivity and agricultural sustainability. Conventional soluble fertilizers can rapidly provide nutrients but are vulnerable to nutrient losses when application rates, timing, soil properties, rainfall, and crop uptake are poorly synchronized. Controlled-release fertilizers (CRFs), in contrast, are designed to regulate nutrient availability through coating or encapsulation technologies, potentially improving synchronization between nutrient release and crop uptake. Organic fertilizers may contribute nutrients while improving soil organic matter, physical condition, water retention, and microbial activity, although their nutrient release depends substantially on decomposition and mineralization. Recent research therefore increasingly treats nutrient management not as a simple choice between “chemical” and “organic” fertilizers, but as a problem of matching nutrient supply, crop demand, soil processes, economic feasibility, and environmental performance. Reviews of enhanced-efficiency fertilizers similarly emphasize that performance varies with fertilizer formulation, soil conditions, temperature, moisture, and crop characteristics (Kassem et al., 2024; Firmanda et al., 2024; Asadu et al., 2024). Against this background, the present study evaluates the agronomic response of peanut to controlled-release, conventional, and locally available organic fertilizer management regimes. The comparison is intended to generate localized evidence regarding plant growth, root development, biomass accumulation, pod formation, and other measured agronomic responses under the experimental conditions of Jabonga, Agusan del Norte.

Peanut is an important source of edible oil, protein, vitamins, minerals, and bioactive compounds, supporting food consumption, processing, livestock feeding, and agricultural livelihoods. Çiftçi and Suna (2022) described peanut as a nutrient-dense oilseed rich in lipids, proteins, phytosterols, and phenolic compounds, while its importance as a food and oil crop is also recognized by El-temsah et al. (2023) and Hamza et al. (2021). As a legume, peanut contributes to nutrient cycling through symbiotic nitrogen fixation (Abaquita & Ferrer, n.d.), which can reduce dependence on external nitrogen inputs (Sebayang et al., 2022). However, Paudel et al. (2023) showed that rhizosphere responses vary with cropping system, cultivar, microbial communities, and rhizobial interactions, indicating that biological benefits do not always translate directly into higher yield. Despite its nitrogen-fixing capacity, peanut requires balanced nutrient availability. Nitrogen supports vegetative growth and protein formation, phosphorus contributes to energy transfer, root development, nodulation, and flowering, while potassium supports water regulation, stress tolerance, nutrient translocation, and pod development (Halim et al., 2023; Verma et al., 2026). Phosphorus is particularly important for root establishment and nodulation (Chuong, 2023), while Liu et al. (2023) demonstrated that potassium application influences root characteristics, nodulation, nutrient accumulation, and yield. Similar responses to potassium have been reported by Ardian et al. (2023). Calcium is also essential because developing peanut pods obtain much of their calcium directly from the pegging zone, and deficiencies may result in poorly developed kernels or “pops” (Hamza et al., 2021). Its importance is especially evident in sandy soils (El-temsah et al., 2023; Hamza et al., 2021). The Philippine context further emphasizes the need for improved nutrient management. Peanut yields reported in the original manuscript remain below attainable production levels (Balba et al., 2025), although this gap results from several interacting constraints rather than fertilizer management alone. Balba et al. (2025) identified limited access to quality seed, pests and diseases, inadequate training and extension support, and limited mechanization among the challenges faced by Central Luzon peanut farmers. Their finding that 94.81% of respondents had received no formal peanut-production training highlights the need for locally relevant and research-based production recommendations.

A major theme in fertilizer research is improving nutrient-use efficiency by synchronizing nutrient supply with crop demand. Conventional fertilizers provide readily available nutrients and can promote rapid growth, but nutrients may be lost through leaching, volatilization, and runoff when supply exceeds plant uptake or environmental conditions favor losses (Jiang et al., 2024; Meng et al., 2024a; Verma et al., 2026). Such losses reduce fertilizer-use efficiency and may contribute to groundwater contamination, eutrophication, soil degradation, and increased production costs (Jiang et al., 2024; Meng et al., 2024a). Asadu et al. (2024) similarly noted that substantial nutrient losses may occur under inefficient fertilizer management. Controlled-release fertilizers (CRFs) address this problem by regulating nutrient dissolution and extending nutrient availability (Jiang et al., 2024). Their release patterns are influenced by soil temperature, moisture, pH, coating properties, and

fertilizer composition (Verma et al., 2026). Kassem et al. (2024) and Firmanda et al. (2024) further explain that polymer coatings can improve synchronization between nutrient release and crop demand. However, CRF performance also depends on fertilizer rate, soil conditions, crop duration, and environmental factors. Concerns regarding cost and the persistence of synthetic coatings have also encouraged the development of biodegradable alternatives (Cidreira et al., 2025; Haydar et al., 2024). Despite these limitations, slow-release fertilization has shown potential to improve peanut growth and nutrient utilization, particularly during reproductive stages requiring sustained nutrient availability (Meng et al., 2024a; Verma et al., 2026). A second theme concerns organic nutrient sources and soil biological functioning. Local organic fertilizers, including manure, vermicompost, crop residues, fish-derived fertilizers, and fermented plant or seaweed materials, can supply nutrients and organic matter (Chuong, 2023). Organic matter may improve soil structure, water-holding capacity, porosity, microbial habitat, and nutrient retention (Sebayang et al., 2022), while organic amendments may also enhance nutrient cycling and biological nitrogen fixation (El-sherbeny et al., 2023; Halim et al., 2023). Paudel et al. (2023) found greater rhizosphere bacterial diversity under organic peanut production, although increased microbial diversity did not necessarily result in higher yield. Studies have likewise reported positive peanut responses to cattle manure and earthworm humus (Huerta Maciel et al., 2024), fermented seaweed extracts (Bangi & Sheirene M. Marajuli, 2024), and poultry manure combined with *Rhizobium* (Chuong, 2023). However, organic fertilizers often have variable nutrient concentrations and depend on microbial decomposition and mineralization before nutrients become readily available (Bangi & Sheirene M. Marajuli, 2024; El-sherbeny et al., 2023; Lang et al., 2021a). A third theme is integrated nutrient management, which combines mineral and organic nutrient sources to meet immediate crop requirements while supporting longer-term soil fertility. This approach is reflected in peanut fertilization research (“Combined Application of Chromolaena Odorata (L.) R.M. King & H. Rob Liquidorganic Fertilizer and Phosphate Fertilizer Enhances Peanut (Arachis hypogaeaL.) Yield and Forage Quality,” 2026). Sudirja et al. (2023) found that combining liquid organic fertilizer with mineral NPK improved nutrient uptake and pod production, while Sunitha et al. (2023) reported positive responses to integrated nutrient management in groundnut. Paramasivan et al. (2025) likewise showed that combining mineral fertilization, *Rhizobium*, humic acid, and poultry manure improved productivity, nutrient uptake, and economic returns. Collectively, these findings support integrated nutrient management as an important approach for balancing crop productivity and soil fertility.

At the local level, the study was conducted in Barangay Baleguian, Jabonga, Agusan del Norte. This context is important because fertilizer response is influenced by soil properties, climatic conditions, crop management, fertilizer availability, and locally accessible nutrient sources. Consequently, results under Jabonga conditions may provide useful preliminary evidence for subsequent field validation in the area. The localized nature of the experiment is particularly valuable where farmers must choose among commercially available mineral fertilizers, relatively expensive controlled-release products, and locally accessible organic materials. At the national level, Philippine peanut production occurs largely within smallholder agricultural systems in which access to inputs, technical information, labor, mechanization, and markets can influence productivity. The Central Luzon assessment of Balba et al. (2025) documented constraints involving quality seed, pest and disease management, training, extension support, and mechanization. The 94.81% lack of formal peanut-production training reported among their respondents illustrates a substantial knowledge and extension gap, although that percentage refers specifically to the farmers included in the Central Luzon study and should not be generalized automatically to all Philippine peanut farmers (Balba et al., 2025). At the global level, peanut productivity similarly depends on interactions among genotype, fertility management, crop protection, planting practices, and resource accessibility. Seidu et al. (2024), in field experiments in Ghana, demonstrated that fertilization interacted with cultivar, planting date, pest management, and other production decisions, showing that fertilizer response cannot be separated completely from the broader production system. Their findings also highlight the practical importance of input availability and affordability among smallholder producers. This local-to-global perspective strengthens the rationale for the present study. Fertilizer technologies developed or tested in other environments cannot simply be assumed to produce identical outcomes in northeastern Mindanao. Local evaluation is therefore necessary, while recognizing that results from a small container-based experiment should serve as preliminary evidence rather than as universal fertilizer recommendations.

The study is best grounded not in a social-science theory but in the agronomic concept of nutrient supply–crop demand synchronization, supported by the principles of nutrient-use efficiency, nutrient mineralization, and soil–plant interactions. Under this conceptual basis, fertilizer management affects the rate, timing, concentration, and location of nutrients available in the root zone. These characteristics subsequently affect nutrient uptake, root development, microbial activity, vegetative growth, assimilate production, and reproductive development. Conventional soluble fertilizers generally create rapid nutrient availability. Controlled-release fertilizers alter nutrient-release kinetics through coating mechanisms, whereas organic fertilizers depend more extensively on decomposition, mineralization, and microbial transformations before nutrients become plant-available. Kassem et al. (2024) and Firmanda et al. (2024) provide contemporary mechanistic support for this interpretation of controlled-release systems. For peanut specifically, root development and nodulation influence nutrient acquisition, while adequate phosphorus, potassium, calcium, and other nutrients support flowering, pegging, pod

development, and biomass accumulation. The interaction among root-zone nutrient availability, biological nitrogen fixation, soil microbial processes, and fertilizer release therefore provides the conceptual pathway linking the experimental treatments to measured plant responses (El-sherbeny et al., 2023). Nutrient-management effects on peanut are also highly dependent on crop and soil conditions (Meng et al., 2024a). Importantly, nutrient-use efficiency is an explanatory concept in the present study rather than a directly measured variable. The experiment did not determine tissue nutrient uptake, nutrient recovery efficiency, fertilizer losses, or nutrient balance. Likewise, because the treatments used different quantities and formulations of fertilizer, observed differences should be interpreted as responses to the fertilizer regimes as actually applied, not exclusively as evidence of the intrinsic superiority of one nutrient-release mechanism.

Recent literature shows that the performance of conventional, organic, controlled-release, and integrated fertilizer systems depends on soil conditions, crop genotype, nutrient rate, management practices, and the environment. Organic systems may improve rhizosphere microbial diversity but produce variable yield responses (Paudel et al., 2023), while organic manures can increase peanut productivity when applied at suitable rates (Huerta Maciel et al., 2024). Integrated mineral-organic approaches may also outperform single-source nutrient management under certain conditions (Sudirja et al., 2023; Paramasivan et al., 2025). In the Philippines, however, localized comparative evidence remains limited, particularly under conditions similar to Jabonga, Agusan del Norte. Existing studies often focus on individual nutrient sources or specific fertilizer combinations, creating a need for local comparisons of contrasting fertilizer regimes (Balba et al., 2025; Bangi & Sheirene M. Marajuli, 2024). The present study addresses this gap by comparing controlled-release, conventional, complete inorganic, local organic, and unfertilized treatments under the same experimental conditions. It focuses on plant height, root development, biomass accumulation, and pod production without assuming the superiority of any fertilizer type. Future studies should use nutrient-equivalent fertilizer rates, characterize organic amendments, measure mature pod and seed yield, assess soil properties before and after treatment, quantify nutrient uptake and nutrient-use efficiency, and include economic analysis. Field-scale and multi-location validation would further determine whether the observed responses are applicable under actual farm conditions.

The study has its strongest alignment with SDG 2 – Zero Hunger and SDG 12 – Responsible Consumption and Production. SDG 2 is relevant because improved nutrient management can contribute to more productive and resilient food-production systems. Determining how peanut responds to different fertilizer regimes can help identify strategies for improving crop performance while using nutrient inputs more effectively. SDG 12 is directly relevant to fertilizer-use efficiency and resource management. Controlled-release, conventional, and organic fertilizers represent different approaches to nutrient delivery, each carrying implications for resource use, nutrient losses, soil management, production cost, and waste utilization. The use of locally available organic materials may also support nutrient recycling when such materials are properly processed and applied. The research has secondary relevance to SDG 13 – Climate Action and SDG 15 – Life on Land because inefficient fertilizer use can contribute to nutrient losses, greenhouse-gas emissions, water contamination, and soil degradation, while improved soil organic matter and nutrient-use efficiency may support soil health. Enhanced-efficiency fertilizer research explicitly addresses some of these environmental concerns (Asadu et al., 2024; Cidreira et al., 2025). However, the present experiment did not measure greenhouse-gas emissions, nutrient leaching, soil biodiversity, carbon sequestration, or life-cycle environmental impacts. Its contribution to SDGs 13 and 15 should therefore be described as potential or indirect rather than empirically demonstrated.

The significance of the study extends across agronomic, environmental, technological, socioeconomic, and soil-management dimensions. Agronomically, it contributes evidence concerning how contrasting fertilizer-management regimes influence the vegetative, belowground, biomass, and reproductive responses of peanut. Environmentally, it raises the issue of improving nutrient-use efficiency and reducing avoidable nutrient losses. From a soil-management perspective, it compares nutrient-delivery approaches ranging from highly soluble mineral inputs to controlled-release formulations and organic materials that depend on biological mineralization. The study also has a technological dimension because controlled-release fertilizers represent an engineered nutrient-delivery technology. Recent developments increasingly focus on biodegradable, bio-based, and smart coating materials designed to improve fertilizer performance while reducing environmental persistence (Firminda et al., 2024; Cidreira et al., 2025). Such developments demonstrate that fertilizer innovation should evaluate not only crop response but also coating materials, degradability, nutrient-release characteristics, and environmental compatibility. From a socioeconomic perspective, the study addresses a practical decision faced by farmers: whether potentially higher-cost commercial nutrient technologies provide sufficient agronomic benefit relative to conventional and locally available alternatives. Seidu et al. (2024) emphasize that adoption of agricultural inputs depends partly on affordability and availability, while Philippine research likewise identifies resource and training limitations among peanut producers (Balba et al., 2025). Nevertheless, agronomic superiority should not automatically be equated with overall sustainability. A fertilizer system that produces stronger plant growth may still differ in cost, labor requirement, residual environmental effects, soil-health consequences, accessibility, and long-term productivity. Accordingly, this study provides an agronomic foundation for sustainability assessment but does not itself constitute a complete economic or environmental sustainability analysis. Future studies

incorporating cost-benefit analysis, soil-quality indicators, nutrient losses, farmer accessibility, and field-scale performance would provide a more comprehensive assessment.

2. Material and methods

2.1 Research Design

The study used a Randomized Complete Block Design (RCBD) consisting of five fertilizer and management treatments with five replications, for a total of 25 peanut plants. The treatments consisted of an untreated control, 3.28 g of complete fertilizer 14-14-14, 20 g of Osmocote 14-14-14 as controlled-release fertilizer, conventional fertilizer practices, and local organic fertilizer practices. The experimental arrangement used a spacing of 25 cm $\times$ 20 cm and was based on the layout described by Minh et al. 2021.

2.2 Locale of the Study

The experiment was conducted in Barangay Baleguian, Jabonga, Agusan del Norte, Philippines, from March 10 to May 31, 2026. Soil used in the experiment was obtained from garden soil in the locality and submitted to the Soil Laboratory in Barangay Taguibo, Butuan City, for analysis of nutrient availability.

2.3 Respondents of the Study

The study did not involve human respondents because it was an agricultural experiment. The experimental subjects were peanut plants exposed to different fertilizer and management treatments. Certified peanut seeds purchased from the market were used as planting materials. One seed was planted per polyethylene pot measuring 7 $\times$ 7 $\times$ 7 inches at a depth of approximately 3 cm.

2.4 Sample and Sampling Procedure

A total of 25 peanut plants served as the experimental units. These were distributed among five treatments with five replications under the Randomized Complete Block Design. The plants were maintained at a spacing of 25 cm $\times$ 20 cm to provide uniform growing conditions among the experimental units. Because the study was experimental, conventional respondent-sampling procedures were not used; instead, the plants were assigned according to the experimental treatment structure.

2.5 Research Instrument

Data were obtained using standard agricultural measuring instruments and field-recording materials. A ruler and measuring tape were used to determine plant height and root length, while a weighing scale was used to determine fresh biomass. A record notebook and field tags were used for documentation and identification of experimental units. Dry biomass was determined after plant materials were oven-dried at 70°C for 24 hours. The agronomic variables measured were plant height, root length, number of pods, and fresh and dry biomass. Plant height was measured at 14, 28, and 42 days after transplanting (DAT) from the base of the plant to the tip of the shoot. Root length and number of pods were determined at harvest. Fresh biomass was weighed immediately, whereas dry biomass was measured after oven drying.

2.6 Data Gathering Procedure

Certified peanut seeds were planted individually in polyethylene pots. Prior to the experiment, soil samples were collected and submitted for laboratory analysis. The controlled-release fertilizer used was Osmocote 14-14-14, while complete fertilizer 14-14-14 and locally available organic materials were used for the other fertilizer regimes. For the complete fertilizer treatment, 3.28 g of complete fertilizer 14-14-14 was applied per hill. The conventional practice involved side-dressing 3.28 g of complete fertilizer 14-14-14 during transplanting and applying the same fertilizer again at 28 DAT. The controlled-release treatment received 20 g of Osmocote 14-14-14 through side-dress application during planting. The local organic treatment used locally available materials such as animal manure, vermiculture, and farm wastes. All treatments received uniform crop management throughout the experiment. Plants were irrigated early in the morning and late in the afternoon, while hand weeding and pest monitoring were conducted to maintain comparable growing conditions. Plant height was recorded at 14, 28, and 42 DAT. At harvest, root length and pod number were recorded, and plant materials were weighed for fresh biomass before being oven-dried at 70°C for 24 hours to determine dry biomass.

2.7 Data Analysis Techniques

The data collected from the different fertilizer and management treatments were analyzed using the Statistical Tool for Agricultural Research (STAR). Statistical analysis was performed to determine whether significant differences existed among the treatments for the measured agronomic variables.

3. Results and Discussion

3.1 Agronomic Responses of Peanut to Fertilizer Treatments

3.1.1 Plant Height

Plant height differed among fertilizer treatments throughout the observation period. At 14 DAT, T3, which received 20 g Osmocote 14-14-14, recorded the greatest mean plant height at 9.60 cm, followed closely by T4 at 9.36 cm. T2 reached 7.48 cm, while T5 and T1 recorded 5.70 cm and 5.02 cm, respectively. At 28 DAT, T3 remained tallest at 23.80 cm, followed by T4 at 20.20 cm, T5 at 19.00 cm, T2 at 16.60 cm, and the control at 11.40 cm. The same pattern was generally maintained at 42 DAT, with T3 attaining 63.00 cm, followed by T4 at 57.20 cm, T2 at 54.60 cm, T5 at 43.80 cm, and T1 at 31.80 cm. The treatment effect on plant height was statistically significant at the recorded observation periods. The superior plant height observed under T3 and T4 indicates that greater and more readily available nutrient supply supported vegetative development during the experimental period. Controlled-release fertilizers are designed to regulate nutrient dissolution over time and potentially maintain nutrient availability across successive growth stages (Meng et al., 2024a). Kassem et al. (2024) similarly explained that polymer-coated fertilizers regulate nutrient release by controlling the movement of water and dissolved nutrients through the coating, potentially improving synchronization between fertilizer availability and plant demand. The initially slower response of T5 is also consistent with organic nutrient sources, whose nutrient availability depends substantially on decomposition and microbial transformation. El-sherbeny et al. (2023) demonstrated the importance of biological and organic nutrient management in peanut grown in sandy soil, while Paudel et al. (2023) observed clear differences between organic and inorganic peanut production systems in both plant performance and rhizosphere microbial communities. The improvement of T5 from 5.70 cm at 14 DAT to 19.00 cm at 28 DAT may indicate that nutrients from organic materials became progressively available as decomposition proceeded. Organic nutrient sources can contribute to peanut growth, although their effectiveness varies with material, application method, soil environment, and crop demand. Ardian et al. (2023) found improved peanut growth and yield following liquid organic fertilizer application, while Yilmaz (2023) demonstrated that vermicompost treatments could enhance peanut yield attributes under suitable application regimes.

3.1.2 Root Development

Root development varied considerably among the fertilizer regimes. Based on the consolidated treatment means in the appendix, T3 produced the longest roots at 40.80 cm, followed by T4 at 36.20 cm and T2 at 31.60 cm. T5 recorded 16.80 cm, while the control produced the shortest roots at 9.80 cm. These results indicate that the fertilizer treatments generally enhanced root development relative to the unfertilized control, with T3 showing the greatest numerical response. Root growth is highly responsive to nutrient availability because root elongation, branching, and nutrient-acquisition capacity depend on adequate mineral supply. Meng et al. (2024a) reported that slow-release fertilization can improve the root environment and nutrient-use efficiency of peanut. Liu et al. (2023) likewise demonstrated that appropriate potassium fertilization significantly increased peanut total root length, root surface area, and root volume and improved nutrient accumulation and yield. Their findings reinforce the importance of balanced nutrient availability in supporting peanut root architecture. Organic treatments may influence root development through mechanisms different from those of readily soluble or controlled-release mineral fertilizers. Organic matter can affect soil physical properties and biological activity, while microbial communities in the rhizosphere influence nutrient transformations and nutrient availability. Paudel et al. (2023) reported higher microbial diversity under organic peanut management than under conventional inorganic management, demonstrating that fertilizer systems can substantially alter peanut rhizosphere ecology. Similarly, the use of organic and mineral nutrient sources in combination has been associated with improved nutrient uptake in peanut (Sudirja et al., 2023). The greater root length recorded under T3 should nevertheless be interpreted within the experimental design. T3 received 20 g of Osmocote 14-14-14, whereas T2 received 3.28 g of complete fertilizer 14-14-14, and T4 followed a different application schedule. Consequently, differences in root development cannot be attributed solely to controlled-release technology; fertilizer quantity, nutrient availability, and application timing may also have contributed to the observed response.

3.1.3 Pod Production

Pod production differed markedly among treatments. T3 recorded the highest average number of pods at 17.80 pods per plant, followed by T4 with 11.40 pods and T2 with 7.60 pods. T5 produced 4.60 pods per plant, while the unfertilized control recorded only 2.60 pods per plant. Thus, all fertilizer regimes numerically increased pod production relative to the control, but the magnitude of the response varied substantially among treatments. The analysis presented in the manuscript indicated a significant treatment effect on pod number. Short-Term-Research The high pod production under T3 is consistent with literature showing that sustained nutrient availability can support reproductive development during fruiting and pod filling (Meng et al., 2024a). Balanced nutrition is particularly important because peanut pod production depends on sufficient nutrient uptake during both vegetative establishment and reproductive growth. Trinh et al. (2023) reported that balanced fertilization involving N, P, K, sulfur, lime, and organic manure increased peanut productivity under sandy-soil conditions in Central Vietnam. Their findings demonstrate that peanut response is determined by the adequacy and balance of the nutrient supply rather than by a single nutrient alone. The intermediate pod production under T4 and T2 suggests that conventional mineral fertilizers provided sufficient nutrients to improve reproductive performance over the control but did not produce the same response observed under T3. Conventional soluble fertilizers can rapidly supply nutrients but may provide a shorter period of availability depending on fertilizer form, soil characteristics, rainfall, and crop

uptake. Controlled-release formulations are specifically designed to prolong nutrient availability and reduce rapid nutrient release (Jiang et al., 2024; Kassem et al., 2024). However, because fertilizer rates were not nutrient-equivalent among treatments in the present experiment, the higher pod count under T3 should be interpreted as a response to the complete treatment regime rather than as definitive evidence that controlled-release formulation alone caused the increase. The lower pod count under T5 does not necessarily indicate that organic fertilization is agronomically ineffective. Organic fertilizer response varies according to source, nutrient concentration, degree of decomposition, application rate, timing, soil microbial activity, and cultivar. Paudel et al. (2023) found that organically managed peanut plots generally produced lower yields than inorganic systems in their experiment, although responses varied strongly among cultivars. Conversely, Yilmaz (2023) demonstrated that appropriately managed vermicompost applications increased peanut pod number and pod yield compared with the untreated control. Sudirja et al. (2023) further found that combining liquid organic fertilizer with NPK improved nutrient uptake and peanut pod yield. These findings suggest that organic nutrient management may perform more effectively when its formulation, application rate, and timing are optimized.

3.1.4 Fresh and Dry Biomass

Fresh and dry biomass showed clear numerical differences among fertilizer treatments. T3 produced the highest fresh leaf biomass at 202 g and dry leaf biomass at 46 g. T4 followed with 186 g fresh leaf biomass and 40 g dry leaf biomass. The control consistently recorded comparatively low biomass. Root biomass followed a similar pattern, with T3 producing 45 g fresh root biomass and 15 g dry root biomass, while T4 recorded 35 g fresh root biomass and 10 g dry root biomass. T5 produced 26 g of fresh root biomass, which was greater than the 18 g recorded under T2, although its dry root biomass remained relatively low at 4 g. The larger biomass observed under T3 is consistent with the principle that sustained nutrient availability can maintain vegetative growth and assimilate accumulation. Slow- and controlled-release fertilizers are designed to prolong nutrient supply and reduce rapid fluctuations in nutrient concentration, potentially allowing continued nutrient uptake across plant developmental stages (Meng et al., 2024a; Kassem et al., 2024). El-sherbeny et al. (2023) similarly demonstrated that nutrient-management strategies involving biological fertilizers and plant residues influenced peanut growth and productivity in sandy soil. The relatively greater fresh root biomass of T5 compared with T2 may reflect the different effects of organic materials on the root-zone environment. Organic amendments can influence soil structure, biological activity, nutrient cycling, and root-microbe interactions (Halim et al., 2023). Paudel et al. (2023) demonstrated that organic and conventional peanut production systems supported distinctly different rhizosphere microbial communities, with organic management generally maintaining greater bacterial diversity. However, higher microbial diversity did not necessarily translate directly into greater crop yield, reinforcing the need to distinguish soil biological benefits from short-term productivity responses. Overall, the biomass results indicate that T3 produced the greatest vegetative and root biomass under the conditions of the experiment. However, because no separate biomass ANOVA is presented in the manuscript, these differences should be described as numerical treatment differences unless the corresponding statistical analysis can be retrieved and verified. Likewise, the results support a conclusion about biomass accumulation and pod production, but not about final seed yield per hectare because field-scale mature seed yield was not measured.

4. Conclusion & Recommendations

The study concludes that the fertilizer management regimes produced different agronomic responses in peanut, with T3 (20 g Osmocote 14-14-14) consistently recording the highest plant height, root development, biomass accumulation, and number of pods under the experimental conditions. Conventional fertilization produced intermediate responses, while local organic fertilization showed slower nutrient availability but contributed to plant growth and root development. Overall, the controlled-release fertilizer treatment produced the strongest measured agronomic performance, while conventional and organic nutrient sources remained relevant because of their accessibility and potential contribution to soil management.

Based on the findings, controlled-release fertilizer may be considered by farmers with sufficient resources for improving pod production and biomass, while integrated nutrient management combining locally available organic materials with conventional or slow-release mineral fertilizers may be considered to balance crop nutrient requirements and soil health. For farmers relying on organic inputs, the manuscript recommends fermented seaweed extract at 5% concentration applied weekly. Further research should examine the long-term residual effects of the fertilizer treatments on soil chemical properties, including pH and organic matter, as well as changes in microbial community structure.

5. Compliance with ethical standards

The authors declare that no conflicts of interest exist in relation to this study. The research involved peanut (*Arachis hypogaea* L.) plants and did not include human participants or experimental animals; therefore, requirements concerning informed consent, participant confidentiality, voluntary participation, and human-subject ethical clearance were not applicable. The experiment was conducted using established agricultural

research procedures, with uniform crop management and controlled application of the prescribed fertilizer treatments. Soil sampling, plant measurements, biomass determination, and other experimental activities were undertaken solely for research purposes and in accordance with appropriate academic and agricultural research practices. The authors further affirm that the study was conducted responsibly, with due consideration for proper handling of fertilizers, plant materials, soil samples, and research data.

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