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## Response of Different Oil Palm Varieties Under Nutrient Management Strategies at Post-nursery Stage

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### ABSTRACT

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important crops for global palm oil production. This study was conducted to evaluate the effects of integrated nutrient management (INM) practices on growth, physiological traits, and nutrient contents and uptake at the post-nursery stage. The study was carried out over a period of eight (8) months. All data were analyzed using Statistix 8.1 software. A two-factor factorial ANOVA was used to test effects of treatment, variety, and treatment × variety interaction. The experiment comprised six nutrient management treatments using combinations of inorganic fertilizers (NPKMg) and poultry manure (PM) applied to three oil palm varieties, namely Deli × Lime, Deli × Lime #C, and Deli × Lime #S. The results showed that integrated nutrient management significantly affected all growth, physiological, and nutrient uptake parameters studied. Among the treatments, the application of 75% NPKMg + 25% poultry manure produced superior performance in terms of plant height (86.8 cm), number of leaves (11.3 plant<sup>-1</sup>), stem diameter (14.2 cm), number of fronds per palm (6.6), and chlorophyll content (63.8) compared with the recommended dose of NPKMg alone or sole poultry manure application. Similarly, leaf area (134.2 cm<sup>2</sup>) and total dry matter accumulation (101.7 g plant<sup>-1</sup>) were highest under the 75% NPKMg + 25% PM treatment. Among the tested varieties, Deli × Lime performed significantly better than the other varieties in most growth and physiological attributes. Leaf N and K concentrations as well as N and K uptake were highest under 75% NPKMg + 25% PM. Leaf P was highest under 25% NPKMg + 75% PM, while leaf Mg increased with higher PM proportion and peaked at 100% PM, reflecting the higher Mg content of organic manure and its gradual release pattern. It is concluded that the integration of 25% poultry manure with 75% inorganic fertilizer represents the most effective nutrient management practice for improving the growth and nutrient uptake of the oil palm variety Deli × Lime at the post-nursery stage. Field validation of the 75% NPKMg + 25% PM dose on mature Deli × Lime palms under coastal Sindh saline conditions is needed to assess long-term yield, soil health, and economic viability.

**KEYWORDS:** *Elaeis guineensis*; Integrated nutrient management; Poultry manure; Macronutrients; Seedling development

### INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.), a tropical tree crop, is primarily grown for its industrial production of vegetable oil. Southeast Asia is the primary production region, and Malaysia is currently the top producer and exporter of palm oil (Murphy *et al.*, 2021). Because of its high oil yield and adaptability, oil palm is a vital crop in the world's agricultural landscape. It is mostly grown in tropical climates, with major production occurring in Latin America, Africa, and Southeast Asia. Pakistan has started to increase oil palm cultivation, especially in the coastal areas of Sindh and Baluchistan, after realizing the plant's economic potential. A number of factors, such as soil type, agronomic practices, and climate, have a major impact on oil palm production and yield. High yield has often been associated with sustainable farming practices and proper management of nutrients.

Research and development in Pakistan aim at improving the production of oil palm through improved cultivation practices and effective management of resources. This will entail the application of organic and inorganic fertilizers to meet the nutritional requirements of the crop (Ahmed *et al.*, 2022). Recent studies conducted during 2024–2026 by Khan, M.A., *et al.* 2026, Rahman, S. & Ali, T. 2025, Memon, N.S., *et al.* 2024 further emphasized the importance of integrated nutrient management for sustainable oil palm production under changing climatic conditions.

Important macronutrients that the growth and development of oil palm require include nitrogen (N), phosphorus (P) and potassium (K). Several physiological processes that are attended by these nutrients comprise photosynthesis, energy transfer and growth of roots (Hussain *et al.*, 2021). Macronutrient

can be used to have an impact on growth and the number of fruit bunches and oil produced. The optimum productivity and trip cropping in Pakistan are advised based on rational utilization of the mentioned macronutrients (Khan *et al.*, 2021).

Chicken manure (poultry) is an excellent source of organic matter/ nutrient that can be productively applied in crop production in order to enhance crop yield and soil fertility. It provides the macro-nutrients which are balanced and improves the physical characteristics of soil that is utilized in growing oil palm (Zafar. *et al.*, 2021).

Studies show that the oil palm plants grow better when manure which is poultry is used. This consequently leads to an increased production of the oil, and the oil is of a better quality. Poultry manure is the alternative to oil palm farming that is under tests as a sustainable and viable alternative to chemical fertilizers in Pakistan (Rehman *et al.*, 2022). In particular, oil palms require macro components of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) to maintain high quality biomass production and effective lipid syntheses (Tarmizi and Tayeb, 2006). In fact, oil palm cannot remain in strong vitality unless the use of fertilizers is wisely employed (Darras *et al.*, 2019). Any organic amendments combined with the inorganic fertilizers are often assumed to be the best combination that helps in creating a conducive rhizosphere that helps sum up total plant development. Animal manure is a rich organic byproduct, that supplies large quantities of organic matter, which has a number of unique benefits. It gives a source of essential microbial communities and in this way improves soil fertility. Moreover, it is

#### **Factor A- Fertilizer and poultry manure treatments=06**

T<sub>1</sub> = Control (no fertilizer or manure)

T<sub>2</sub> = Recommended NPK Mg (100% chemical fertilizer) T<sub>3</sub> = 75% NPK Mg + 25% Poultry Manure (PM)

T<sub>4</sub> = 50% NPK Mg + 50% Poultry Manure (PM) T<sub>5</sub> = 25% NPK Mg + 75% Poultry Manure (PM) T<sub>6</sub> = 100% Poultry Manure (PM)

#### **Factor B- Oil Palm Varieties=03**

V<sub>1</sub> = Deli × LaMe (D × L)

V<sub>2</sub> = Deli × LaMe (D × L) #C V<sub>3</sub> = Deli × LaMe (D × L) #S

**Magnesium was supplied as MgSO<sub>4</sub>·7H<sub>2</sub>O:** The recommended dose was 8 g MgSO<sub>4</sub>·7H<sub>2</sub>O plant<sup>-1</sup> for 100% NPKMg treatment, reduced proportionally in integrated treatments: 6 g for 75%, 4 g for 50%, 2 g for 25% NPKMg.

#### **Seedling establishment and pot preparation:**

Healthy four month old pre-nursery seedlings of the three oil palm varieties were transplanted into polyethylene bags (18.5 × 14.5 inches), each filled with 20 kg of sieved, fertile surface soil (0–15 cm depth) collected from the Latif Experimental Farm, SAU Tandojam.

**Nutrient application schedule:** Fertilizer and poultry manure applications were made according to the treatment plan. Nitrogen, phosphorus, potassium and magnesium were supplied through NPK 15:15:15, while magnesium sulfate was used as Mg source. The

very instrumental in countering over drainage of the sandy soils through reducing porosity as well as enhancing exchange of gases together with the stability of the soils of argillaceous (clay) soils (Purba *et al.*, 2018). Manure is also an excellent source of macro and micronutrients and can greatly increase the overall edaphic quality and productive potential due to its extensive physical advantages (Muhereza *et al.*, 2020).

When the oil palm seedlings are past the nursery stage, it is evident that there were not all the types of seedlings (or cultivars) that responded equally to the different regimes of nourishment. It is highly crucial to understand these two different reactions in case we desire to realize optimal growth and ensure sustainable and long-term yields.

This is the very reason why this study explores the effect of various nutrient management regime in these Vario-cultivated oil palm varieties at that critical juncture of post-nursery stage. Our main objective is to examine the impact of post-nursery integration of macro nutrient and poultry manure rates on the growth characteristics of oil palm varieties and to compare the performance of different oil palm varieties under fertilizer and manure treatments

## **MATERIALS AND METHODS**

**Experimental site design and duration:** The experiment was conducted in the greenhouse of the Department of Soil Science, Sindh Agriculture University, Tandojam. The study was carried out over a period of eight (8) months. The study was arranged in Completely Randomized Design (CRD) in a factorial arrangement with four replications.

25%, 50%, 75%, and 100% levels refer to substitution of the recommended NPKMg dose with poultry manure on a nutrient-equivalent basis. PM nutrient content was 2.8% N, 2.3% P, 2.1% K, 0.8% Mg. For T<sub>3</sub>, 25% of total NPKMg requirement was supplied by PM and 75% by inorganic fertilizer. Different nutrients had different concentrations in PM vs fertilizer, but total NPKMg supply per treatment was kept equivalent across treatments.

**Poultry manure (PM):** Well-decomposed poultry manure was brought from Khatian town. As per treatment doze PM was mixed with soil in the pots. The fertilizer treatments were applied monthly doses following the plan provided in Table 3 (Fertilizer was incorporated into the soil around each seedling base and lightly mixed with soil to avoid volatilization losses

**Table 1.** Fertilizer and poultry manure treatments and application schedule (g plant<sup>-1</sup>)

| Treatment      | Nutrient combination   | Months at Post nursery |                 |                 |                                     |                                     |
|----------------|------------------------|------------------------|-----------------|-----------------|-------------------------------------|-------------------------------------|
|                |                        | 1 <sup>st</sup>        | 2 <sup>nd</sup> | 3 <sup>rd</sup> | 4 <sup>th</sup> and 5 <sup>th</sup> | 6 <sup>th</sup> and 7 <sup>th</sup> |
| T <sub>1</sub> | Control                | —                      | —               | —               | —                                   | —                                   |
| T <sub>2</sub> | 100% Recommended NPKMg | 10+5                   | 14+5            | 21+5            | 21+5                                | 28+8                                |
| T <sub>3</sub> | 75% NPKMg + 25% PM     | 7.5+3.75               | 10.5+3.75       | 15.75+3.75      | 15.75+3.75                          | 21+6                                |
| T <sub>4</sub> | 50% NPKMg + 50% PM     | 5+2.5                  | 7+2.5           | 10.5+2.5        | 10.5+2.5                            | 14+4                                |
| T <sub>5</sub> | 25% NPKMg + 75% PM     | 2.5+0.25               | 3.5+0.25        | 5.25+0.25       | 5.25+0.25                           | 7+2                                 |
| T <sub>6</sub> | 100% PM                | 0                      | 0               | 0               | 0                                   | 0                                   |

Values represent NPKMg + poultry manure (g plant<sup>-1</sup>).

**Growth conditions and cultural practices:** All seedlings were grown under uniform greenhouse conditions. Watering was done as needed to maintain adequate soil moisture, and manual weeding was performed periodically to prevent competition. No pest or disease incidence was observed during the study period.

**Data collection:** Data on morphological,

physiological, and chemical parameters collected at the end of the experiment Plant height (cm) total number of leaves per palm, Stem diameter (cm) Number of fronds per palm, Frond length (cm). Physiological observations recorded for leaf area (cm), Chlorophyll content (SPAD), and total dry matter (g pot<sup>-1</sup>).

**Table 2:** Physio-chemical properties of soil used in the pot experiment

| Properties                           | Average Value |
|--------------------------------------|---------------|
| Soil Texture                         | Sandy loam    |
| pH                                   | 7.7           |
| EC (dS m <sup>-1</sup> )             | 1.3           |
| Organic matter (%)                   | 0.85          |
| Nitrogen (%)                         | 0.08          |
| Phosphorus (mg kg <sup>-1</sup> )    | 7.0           |
| Potassium (mg kg <sup>-1</sup> )     | 108           |
| Magnesium (cmol(+)kg <sup>-1</sup> ) | 0.40          |

**Poultry manure analysis:** Samples of poultry manure were air-dried, ground, and analyzed for total N, P, K, and Mg contents using standard methods before application. The poultry manure used in the experiment exhibited an approximately neutral pH of 6.9 and an organic carbon content of 19%. Chemical analysis of its nutrient profile revealed macro-nutrient concentrations of 2.8% Nitrogen, 2.3% Phosphorus, 2.1% Potassium, and 0.8% Magnesium.

**Plant analysis:** The plant nutrient uptake and concentration was assessed for N (Bremner, 1960), P (Jackson, 1958) and K (Soltanpour and Schwab, 1977) and Mg by wet digestion method. Plant samples were oven-dried at 70°C, ground, and digested in H<sub>2</sub>SO<sub>4</sub>-H<sub>2</sub>O<sub>2</sub>. N was determined by Kjeldahl method, P by vanadomolybdophosphoric yellow color method using spectrophotometer at 420 nm, K by flame photometer, and Mg by atomic absorption spectrophotometer after wet digestion.

**Data Analysis:** All data were analyzed using Statistix 8.1 software. Analysis of Variance (ANOVA) was used to find the effects of treatments, varieties, and their interactions. Mean separation was done by Least Significant Difference (LSD) at 5% probability level (p ≤ 0.05) to locate the statistically significant differences between the treatments.

## RESULTS

**Agronomic traits of oil palm varieties as affected by INM strategies:** The ANOVA revealed that integrated nutrient management (INM) techniques significantly (p < 0.05) affected the whole set of growth parameters of oil palm seedlings at the post-nursery stage. There were also significant differences in varietal traits, and the interaction of treatment × variety (T × V) reached a significant level for all traits but frond length.

Plant height has been very much improved by the combined use of organic and inorganic nutrients (Table 4.1). The tallest average plant height (86.8 cm) was measured in the seedlings with 75% NPK Mg + 25% poultry manure, and it was significantly higher than the plant height of the seedlings under the recommended NPK Mg (82.9 cm). On the other hand, only the application of poultry manure (100% PM) led to the production of the shortest plants (30.5 cm), whereas the control treatment (61.4 cm) was also less effective than the integrated fertilization.

The total number of leaves also followed similar patterns (Table 3). Apparently, the leaves of seedlings treated with 75% NPK Mg + 25% PM were the most numerous (11.3), and this value was significantly higher than that for the leaves of the seedlings under recommended NPK Mg (9.2) and 50% NPK Mg + 50% PM (9.2) treatments. The lowest leaf numbers have been achieved in control (6.1) and 100% PM (6.3).

Additionally, the stem diameter (Table 3) was also very receptive to INM. The most voluminous stem diameters (14.2 cm) were achieved under the 75% NPK Mg + 25% PM condition, and the next best was the recommended NPK Mg (13.6 cm). On the other hand, the leaves of the seedlings in the control (8.7 cm) and 100% PM (7.5 cm) were significantly thinner, suggesting that the positive combined effect of nutrient can be seen in stem girth development.

The number of fronds per palm (Table 3) was also influenced positively in a similar way. With 75% NPK Mg + 25% PM, the maximum number of fronds (6.6) was achieved, while 50% NPK Mg + 50% PM (5.9) ranked the second. The control (3.7) and 100% PM (3.4) were statistically the lowest and thus leave no doubt that proper nutrient inputs facilitate leaf expansion and frond development.

Regarding frond length (Table 3), the longest fronds (86.8 cm) were from the seedlings that received 75% NPK Mg + 25% PM, and their length was statistically equal to that of the fronds from seedlings under the recommended NPK Mg (84.9 cm). In contrast, the shortest fronds were those of seedlings in

the control (59.0 cm) and the 100% PM (62.4 cm) treatments. Unlike other traits, the  $T \times V$  interaction did not show significant effects on frond length, indicating that varietal differences in response to treatments were similar for this trait.

Significant varietal differences ( $p < 0.05$ ) in performance were also observed for all traits. Consistently, among the three different varieties, Deli x lame outperformed both Deli x lame #C and Deli x lame #S. It achieved higher plant height (64.1 cm), more leaves (8.87), greater stem diameter (10.58 cm), more fronds (5.41), and longer fronds (72.3 cm) than the other varieties, which kept statistically close to each other but were lower in performance.

The significant interaction of treatment  $\times$  variety (except for frond length) also pointed out that the extent of the effect differed between the varieties. On most parameters, the combination of Deli x lame  $\times$  75% NPK Mg + 25% PM was a consistent source of the most robust seedlings, while Deli x lame #s and Deli x lame #c under 100% PM or control conditions exhibited the weakest growth.

**Table 3.** Growth parameters of oil palm varieties as affected by INM strategies

| Treatment          | Plant height (cm)      | Leaves palm <sup>-1</sup> | Stem diameter (cm)     | Fronds palm <sup>-1</sup> | Frond length (cm)      |
|--------------------|------------------------|---------------------------|------------------------|---------------------------|------------------------|
| Control            | 61.433 D               | 6.080 D                   | 8.667 F                | 3.670 E                   | 59.000 F               |
| Recommended NPKMg  | 82.867 B               | 9.222 B                   | 13.600 B               | 5.500 C                   | 84.934 B               |
| 75% NPKMg + 25% PM | 86.800 A               | 11.333 A                  | 14.200 A               | 6.570 A                   | 86.836 A               |
| 50% NPKMg + 50% PM | 71.567 C               | 9.222 B                   | 9.200 D                | 5.930 B                   | 69.467 C               |
| 25% NPKMg + 75% PM | 42.667 E               | 7.444 C                   | 9.433 C                | 5.170 D                   | 64.100 D               |
| 100% PM            | 30.467 F               | 6.288 D                   | 7.533 E                | 3.430 F                   | 62.367 E               |
| <b>Varities</b>    |                        |                           |                        |                           |                        |
| Deli x Lame        | 64.072 A               | 8.873 A                   | 10.580 A               | 5.410 A                   | 72.251 A               |
| Deli x Lame #C     | 62.633 B               | 8.167 B                   | 10.500 B               | 4.920 B                   | 70.818 B               |
| Deli x Lame #S     | 61.183 C               | 7.755 C                   | 10.230 C               | 4.800 C                   | 70.283 B               |
| Treatments (T)     | SE 0.0200 / LSD 0.0406 | SE 0.0200 / LSD 0.0406    | SE 0.0200 / LSD 0.0406 | SE 0.0200 / LSD 0.0406    | SE 0.0200 / LSD 0.0406 |
| Varities (V)       | SE 0.0489 / LSD 0.0993 | 0.2761 / 0.5612           | 0.0992 / 0.2013        | 0.1517 / 0.3082           | 0.5625 / 1.143         |
| T $\times$ V       | SE 0.0282 / LSD 0.0574 | 0.1594 / 0.3240           | 0.1641 / 0.3328        | 0.0876 / 0.1780           | NS                     |

Values followed by different letters within columns differ significantly at  $P \leq 0.05$  using LSD test. SE = Standard Error; LSD = Least Significant Difference; NS = Non-significant.

**Physiological traits of oil palm varieties as affected by INM strategies:** Chlorophyll content of the leaves based on SPAD values was strongly affected by INM strategies ( $p < 0.05$ ) with the varietal differences being significant as well (Table 4). The maximum chlorophyll content (63.8) was found in the 75% NPK Mg + 25% PM treatment, which did not show any significant difference from the NPK Mg (60.6) level. On the other hand, the control (30.4) and poultry manure only (28.8) treatments resulted in the lowest SPAD values for the leaves. The dominance of the integrated fertilization system indicates an adequate

supply of both macro- and microelements, which are the building blocks of chlorophyll. As for the varieties, Deli x lame had a higher SPAD value (44.9) than Deli x lame #C (42.8) and Deli x lame #S (40.8), and the  $T \times V$  interaction was not significant, thus suggesting a similar response of the varieties to the nutrient regimes.

Leaf area was also significantly affected by INM treatments and varietal differences, as well as treatment  $\times$  variety interaction ( $p < 0.05$ ) (Table 4). The leaf area of the plants (134.2 cm<sup>2</sup>) grown under 75% NPK Mg + 25% PM was the greatest and that of the seedlings under the recommended NPK Mg (124.3

cm<sup>2</sup>) came the next. The leaf area of the plants in 25% NPK Mg + 75% PM (93.9 cm<sup>2</sup>) and sole PM (95.7 cm<sup>2</sup>) was the smallest, which suggested that the high-level replacement of inorganic nutrients with poultry manure had a negative effect on leaf expansion. On the varietal side, Deli x lame (116.5 cm<sup>2</sup>) had a larger leaf area than Deli x lame #c (113.1 cm<sup>2</sup>) and Deli x lame #s (103.8 cm<sup>2</sup>). The significant T × V interaction also revealed that when Deli x lame was combined with 75% NPK Mg + 25% PM, the maximum leaf area was obtained across the treatments, whereas the leaf area of Deli x lame #S under solo PM was at its lowest.

Total dry matter (TDM) accumulation followed a similar trend (Table 4). The greatest TDM production (107.2 g/plant) was observed in seedlings supplied with recommended NPK Mg, which was followed closely by 75% NPK Mg + 25% PM (101.7 g/plant). Control and sole PM treatments were equally and significantly lower (81.4 and 81.9 g/plant,

respectively), and thus, there was an insufficient nutrient level to support biomass accumulation. Among the varieties, Deli x lame had gained the most TDM (94.8 g plant<sup>-1</sup>), and Deli x lame #S (88.6 g plant<sup>-1</sup>) had the least. The high T × V interaction value showed that Deli x lame, with NPK Mg as recommended, resulted in the greatest dry matter production, whereas Deli x lame #S showed the lowest with NPK Mg as recommended sole PM.

Sole poultry manure performed equal to or slightly below control for chlorophyll, leaf area, and TDM. This is because PM releases nutrients slowly and initial N, P availability was lower than control seedlings that used native soil nutrients. High C:N ratio of PM can also cause temporary N immobilization during early decomposition, limiting early seedling growth. Thus PM alone is good for long-term soil health but inadequate for rapid post-nursery growth without mineral fertilizer

**Table 4.** Physiological parameters of oil palm varieties as affected by INM strategies

| Treatment          | Chlorophyll content    | Leaf area (cm <sup>2</sup> ) | Total dry matter (g plant <sup>-1</sup> ) |
|--------------------|------------------------|------------------------------|-------------------------------------------|
| Control            | 30.356 E               | 102.57 D                     | 81.43 D                                   |
| Recommended NPKMg  | 60.600 B               | 124.30 B                     | 107.17 B                                  |
| 75% NPKMg + 25% PM | 63.767 A               | 134.23 A                     | 101.70 A                                  |
| 50% NPKMg + 50% PM | 38.317 C               | 116.13 C                     | 92.83 C                                   |
| 25% NPKMg + 75% PM | 35.093 D               | 93.87 F                      | 84.44 E                                   |
| 100% PM            | 28.834 E               | 95.67 E                      | 81.90 E                                   |
| <b>Varieties</b>   |                        |                              |                                           |
| Deli × Lame        | 44.900 A               | 116.47 A                     | 94.783 A                                  |
| Deli × Lame #C     | 42.783 B               | 113.12 B                     | 91.389 B                                  |
| Deli × Lame #S     | 40.800 C               | 103.80 C                     | 88.567 C                                  |
| Treatments (T)     | SE 1.0311 / LSD 2.0954 | SE 1.1628 / LSD 2.3631       | SE 0.7700 / LSD 1.5648                    |
| Varieties (V)      | 0.7291 / 1.4817        | 0.8222 / 1.6710              | 0.5445 / 1.1065                           |
| T × V              | NS                     | 2.0140 / 4.0930              | 1.3337 / 2.7104                           |

Values followed by different letters within columns differ significantly at  $P \leq 0.05$  using LSD test. SE = Standard Error; LSD = Least Significant Difference; NS = Non-significant.

#### Leaf N, P, K and Mg (%) content of oil palm varieties as affected by INM strategies

**Leaf Nitrogen (N %):** Control seedlings maintained the lowest N values (<1.0%), confirming nutrient deficiency under no fertilization. Application of the recommended NPK Mg dose raised leaf N significantly (~2.0%), while further substitution of mineral fertilizer with poultry manure (25–50%) enhanced N uptake, with maximum concentrations (~2.2–2.4%) under 50% NPK Mg + 50% PM. Alone pure poultry manure also enhanced N compared to control although not as much as integrated regimes. This means that concomitant nutrient sources guaranteed greater coordination of nutrient liberation and uptake. The differences in the varietal means were high as Deli x lame tended to be higher, compared with Deli x lame #C and Deli x lame #S, and there was a strong interaction between the treatment and the variety which indicated that the varietal responses were sensitive to the nutrient regime (Table 5).

**Leaf Phosphorus (%):** Also, Leaf P was improved by INM, which was approximately 0.06 in control and turned out to be approximately 0.18 in 25% NPK Mg

+ 75% PM. Higher PM share (i.e., integrated) gave higher levels of P uptake than control (i.e. using mineral fertilizer), hence showing the relevance of organic matter in promoting P availability in the soil. The concentration of P in the leaves of the vegetation plants was much different in the sense that the highest concentration pool was in Deli x lame followed by the concentration of P in Deli x lame #C, and in Deli x lame #S. There was a great influence on the effects of the interaction which portrays that the benefits of poultry manure substitution in Deli x lame were enhanced significantly (Table 5).

**Leaf Potassium (%):** Leaf K content of oil palm varieties increased significantly with INM, and increased by approximately 0.55 to 1.38 percent under 75% NPK Mg + 25% PM (Tables 5). The balanced organic inorganic applications (75:25 and 50:50) provided the best results, therefore, it was superior to the solitary mineral fertilizer. Variety means varied a bit (Deli x lame > Deli x lame #C > Deli x lame #S), but the interaction of treatment variety was not significant, indicating that all varieties responded similarly to INM in terms of K uptake.

**Leaf Magnesium (Mg %):** Contrary to other

nutrients, Mg was at highest levels below 100 per cent poultry manure (0.66 -0.74 per cent), whereby it increased with proportion of PM increased. Control seedlings showed the lowest Mg (0.20%). This reflects the richness of organic sources in Mg and their gradual

release pattern. Significant varietal differences were observed, with Deli x lame accumulating higher Mg compared to the other varieties, though treatment × variety interaction was not significant (Table 5).

**Table 5.** Leaf nutrient contents of oil palm varieties as affected by INM strategies

| Treatment          | Leaf N (%)             | Leaf P (%)    | Leaf K (%)      | Leaf Mg (%)   |
|--------------------|------------------------|---------------|-----------------|---------------|
| Control            | 0.9533 E               | 0.0578 E      | 0.5533 E        | 0.2000 F      |
| Recommended NPKMg  | 1.9933 C               | 0.0911 D      | 0.9111 D        | 0.3133 E      |
| 75% NPKMg + 25% PM | 2.1333 A               | 0.1267 C      | 1.2911 A        | 0.3600 D      |
| 50% NPKMg + 50% PM | 2.1633 A               | 0.1400 B      | 1.1567 B        | 0.4100 C      |
| 25% NPKMg + 75% PM | 2.0600 B               | 0.1567 A      | 1.0278 C        | 0.5967 B      |
| 100% PM            | 1.9167 D               | 0.1300 C      | 0.9044 D        | 0.7000 A      |
| <b>Varieties</b>   |                        |               |                 |               |
| Deli × Lame        | 1.7717 A               | 0.1306 A      | 1.0256 A        | 0.4633 A      |
| Deli × Lame #C     | 1.8217 B               | 0.1183 B      | 0.9683 B        | 0.4306 B      |
| Deli × Lame #S     | 2.0167 C               | 0.1022 C      | 0.9283 C        | 0.3967 C      |
| Treatments (T)     | SE 0.0319 / LSD 0.0647 | 1.828 / 3.714 | 0.0174 / 0.0353 | 0.0125/0.0255 |
| Varieties (V)      | SE 0.0225/ LSD 0.0458  | 4.477 / 9.098 | 0.0123 / 0.0249 | 0.0089/0.0180 |
| T × V              | SE 0.0552/ LSD 0.1121  | 2.585 / 5.253 | 0.0301 / 0.0611 | 0.0217/0.0441 |

Values followed by different letters within columns differ significantly at  $P \leq 0.05$  using LSD test. SE = Standard Error; LSD = Least Significant Difference.

**NPK and Mg uptake of oil palm varieties as affected by INM strategies:** The uptake of major nutrients (N, P, K) and secondary nutrient (Mg) was significantly ( $P \leq 0.05$ ) influenced by integrated nutrient management (INM) treatments. Varietal differences were also significant, whereas treatment × variety interactions remained statistically non-significant across all parameters (Tables 6).

**Nitrogen Uptake ( $\text{g plant}^{-1}$ ):** Nitrogen uptake was lowest in the control ( $0.98\text{--}1.10 \text{ g plant}^{-1}$ ), while application of recommended NPK Mg raised uptake to  $1.70\text{--}1.80 \text{ g plant}^{-1}$  (Table 4.20). A substantial improvement was observed with 75% NPK Mg + 25% poultry manure ( $2.50\text{--}2.70 \text{ g plant}^{-1}$ ), which significantly ( $P \leq 0.05$ ) outperformed all other treatments. In contrast, 100% poultry manure resulted in the poorest uptake ( $0.40\text{--}0.50 \text{ g plant}^{-1}$ ), even lower than the control. Across varieties, Deli x lame accumulated the highest N ( $1.62 \text{ g plant}^{-1}$ ), followed by Deli x lame #C ( $1.53 \text{ g plant}^{-1}$ ) and Deli x lame #S ( $1.46 \text{ g plant}^{-1}$ ).

**Phosphorus Uptake ( $\text{g plant}^{-1}$ ):** Control seedlings recorded the lowest P uptake ( $0.39\text{--}0.47 \text{ g plant}^{-1}$ ), whereas the maximum ( $2.18\text{--}2.00 \text{ g plant}^{-1}$ ) was found in the 75% NPK Mg + 25% PM treatment, which was significantly ( $P \leq 0.05$ ) higher than all other regimes (Table 6). Recommended NPK Mg also improved uptake ( $\sim 1.44\text{--}1.55 \text{ g plant}^{-1}$ ), while sole

poultry manure was at par with the control, both yielding the lowest P values. Varietal means revealed higher uptake in Deli x lame ( $1.05 \text{ g plant}^{-1}$ ) compared to Deli x lame #C ( $0.96 \text{ g plant}^{-1}$ ) and Deli x lame #S ( $0.90 \text{ g plant}^{-1}$ ).

**Potassium Uptake ( $\text{g plant}^{-1}$ ):** Potassium uptake followed a trend similar to N and P. The control recorded  $\sim 0.67\text{--}0.72 \text{ g plant}^{-1}$ , while recommended NPK Mg increased uptake to  $\sim 1.11\text{--}1.26 \text{ g plant}^{-1}$  (Table 6). The highest uptake ( $1.34\text{--}1.48 \text{ g plant}^{-1}$ ) was achieved under 75% NPK Mg + 25% PM, significantly ( $P \leq 0.05$ ) surpassing all other treatments. On the other hand, 100% poultry manure produced the lowest K uptake ( $0.41\text{--}0.51 \text{ g plant}^{-1}$ ). Varietal effects showed Deli x lame consistently outperforming the other two, with mean values of  $0.90 \text{ g plant}^{-1}$  against 0.85 and  $0.79 \text{ g plant}^{-1}$  in Deli x lame #C and Deli x lame #S, respectively.

**Magnesium Uptake ( $\text{g plant}^{-1}$ ):** For Mg, uptake ranged from  $0.15\text{--}0.21 \text{ g plant}^{-1}$  in 100% poultry manure to  $0.55\text{--}0.61 \text{ g plant}^{-1}$  in 75% NPK Mg + 25% PM, which was significantly superior ( $P \leq 0.05$ ). Recommended NPK Mg also ensured relatively higher Mg uptake ( $0.50\text{--}0.55 \text{ g plant}^{-1}$ ). Conversely, sole organic input (100% PM) failed to maintain adequate Mg uptake, performing even lower than control. Varietal means again revealed higher Mg uptake in Deli x lame ( $0.39 \text{ g plant}^{-1}$ ), followed by Deli x lame #C ( $0.36 \text{ g plant}^{-1}$ ) and Deli x lame #S ( $0.34 \text{ g plant}^{-1}$ ) (Table 6).

**Table 6.** Nutrient uptake of oil palm varieties as affected by INM strategies

| Treatment          | N uptake (g plant <sup>-1</sup> ) | P uptake (g plant <sup>-1</sup> ) | K uptake (g plant <sup>-1</sup> ) | Mg uptake (g plant <sup>-1</sup> ) |
|--------------------|-----------------------------------|-----------------------------------|-----------------------------------|------------------------------------|
| Control            | 1.0278 E                          | 0.4267 E                          | 0.6978 C                          | 0.2833 D                           |
| Recommended NPKMg  | 1.7544 C                          | 1.4978 B                          | 1.1900 B                          | 0.5233 B                           |
| 75% NPKMg + 25% PM | 2.6056 A                          | 2.0233 A                          | 1.4100 A                          | 0.5833 A                           |
| 50% NPKMg + 50% PM | 1.8900 B                          | 0.8567 C                          | 0.7200 C                          | 0.3300 C                           |
| 25% NPKMg + 75% PM | 1.4767 D                          | 0.5744 D                          | 0.6000 D                          | 0.2600 E                           |
| 100% PM            | 0.4511 F                          | 0.4511 E                          | 0.4667 E                          | 0.1800 F                           |
| <b>Varieties</b>   |                                   |                                   |                                   |                                    |
| Deli × Lame        | 1.6183 A                          | 1.0511 A                          | 0.8967 A                          | 0.3850 A                           |
| Deli × Lame #C     | 1.5267 B                          | 0.9589 B                          | 0.8522 B                          | 0.3583 B                           |
| Deli × Lame #S     | 1.4578 B                          | 0.9050 B                          | 0.7933 C                          | 0.3367 C                           |
| Treatments (T)     | SE 0.0492 / LSD 0.1001            | 0.0435 / 0.0883                   | 0.0246 / 0.0500                   | 7.419 / 0.0151                     |
| Varieties (V)      | SE 0.0348 / LSD 0.0708            | 0.0307 / 0.0625                   | 0.0174 / 0.0354                   | 0.0182 / 0.0369                    |
| T × V              | NS                                | NS                                | NS                                | NS                                 |

Values followed by different letters within columns differ significantly at  $P \leq 0.05$  using LSD test. SE = Standard Error; LSD = Least Significant Difference; NS = Non-significant.

## DISCUSSION

### Agronomic and physiological traits of oil palm varieties:

The findings of this study clearly establish that integrated nutrient management (INM), particularly the application of 75% NPK Mg combined with 25% poultry manure, significantly improved the growth performance of oil palm seedlings at the post-nursery stage. This treatment consistently produced the tallest plants, highest number of leaves, greatest stem diameter, most fronds, and longest fronds, outperforming both the sole mineral fertilizer (recommended NPK Mg) and sole organic manure (100% poultry manure) applications. The excellent outcome of this integrated treatment shows that the partial replacement of chemical fertilizers by organic input results in the most balanced and prolonged nutrient supply which, in turn, leads to the rapid vegetative growth. Several reviewed studies have also confirmed such effects. As an example, Fuady *et al.* (2019) discovered that the co-use of organic and inorganic fertilizers had a considerable positive impact on the increase of oil palm plant height and stem circumference in the juvenile stage in Indonesia. Memon *et al.* (2024), in Pakistan, similarly observed that the synergizing of farmyard manure with the diminished level of NPK expedited growth characteristics like height, leaf number, stem girth, and frond length, thus, backing the current results. Integrated nutrient regimes also elicited positive changes in the stem diameter as experiments carried out by Fuady *et al.* (2019) and Yusof *et al.* (2022) in Malaysia had shown, the latter affirmed that improved nutrient uptake and better soil structure, resulting from the combination of organic and inorganic fertilizers, were the main reasons for the thicker stem growth. The current study showed the implementation of integrated

fertilization regimes caused a significant increase in the number of fronds per seedling, which is, therefore, in agreement with the findings of Memon *et al.* (2024), who observed more frond development in post-nursery oil palm seedlings treated with FYM plus NPK.

Frond length similarly followed the pattern where the longest fronds were recorded in the treatment of 75% NPK Mg + 25% poultry manure seedlings. This finding aligns with the research of Satriawan *et al.* (2019) who reported that leaf length and area in oil palm changed mostly with nutrient sufficiency rather than genotype fertilizer interactions. Moreover, the consistently low performance of the single poultry manure (100% PM) treatment across all traits strengthens the idea that organic fertilizers are good for soil health and long-term fertility, however, they might not provide enough nutrients that are readily available, especially nitrogen and phosphorus, for optimal early seedling growth.

The three varieties tested, Deli x lame, Deli x lame #C and Deli x lame #S, showed that Deli x lame was superior to the other two varieties in all growth traits. It may indicate this variety to have a higher nutrient uptake efficiency or be more physiologically responsive to balanced nutrient supply. These results emphasize the importance of genotype-specific fertilizer strategies that were already indicated by Memon *et al.* (2024) and, additionally, they are in line with wide-ranging research from Nigeria, Malaysia, and Indonesia, which recommend integrated fertilization as a way of optimizing early oil palm development (Yusof *et al.*, 2022).

The remarkable changes in chlorophyll content, leaf area, and total dry matter (TDM) due to integrated nutrient management (INM), especially the 75% NPK Mg + 25% poultry manure treatment, is a clear-cut

example of how the balanced nutrient supply can help oil palm seedlings to grow faster thanks to the enhanced physiological processes and biomass accumulation. The results are in line with what Adeniyani *et al.* (2020) found when they said that the use of organic and inorganic fertilizers together is what really leads to the increase of chlorophyll content in oil palm because of the synergistic effect of nutrient availability and micronutrient uptake, which are both very important for chlorophyll biosynthesis. In the same way, Khairulmazmi *et al.* (2021) found that the highest SPAD values in oil palm seedlings were recorded when biofertilizer and NPK were applied together than when only organic sources were used. Adekayode and Olayinka (2019), stated that the leaf area in oil palm and maize was increased when poultry manure was partially integrated with NPK fertilizers because of the better provision of nitrogen and phosphorus. Also, the results support Memon *et al.* (2024) findings in Pakistan. The total dry matter (TDM) accumulation was very much like this. The current finding goes in line with what Fuady *et al.* (2019) found, when they said that INM is the main driver of young oil palms dry matter accumulation due to better nutrient uptake and supply. While the full chemical fertilizer reached a bit higher TDM than the integrated treatment, the latter still offers advantages in terms of sustainability and long-term soil fertility.

**Leaf nutrient content of oil palm varieties:** Significant changes in the oil palm seedling leaf macronutrient concentrations under integrated nutrient management (INM) treatments notably emphasize the role of balanced fertilization in raising nutrient uptake efficiency. This present research has demonstrated that the leaf N content have been substantially elevated, in the control leaves less than 1.0% N content was detected, while under recommended NPK Mg and integrated treatments the levels changed to about 2.0–2.4% and 50% NPK Mg + 50% poultry manure have shown the highest N values. By this, the process of INM facilitating nutrient release in synchronization with crop demand therefore N availability and N assimilation are enhanced, is strongly supported by this improvement, a concept, which was already mentioned by Fuady *et al.* (2019) and Mohd Fahmi Keni *et al.* (2021) in their papers on oil palm fertilization. The organic portion of the mixture can enhance microbial activity and soil organic nitrogen pools that mineralize slowly to meet plant demand (Ayeni *et al.*, 2016). Deli x lame was consistently higher in N uptake and the significant treatment × variety interaction suggests that efficiency of different genotypes in utilizing available nitrogen under varied nutrient regimes may vary. Leaf P content also changed significantly after the substitution of RDN with poultry manure, from around 0.06% in the control to about 0.18% in 25% NPK Mg + 75% PM. The findings confirm that organic matter attracts more P into the soil by involving the microbial process in solubilization that uses fixed phosphorus

and also less P is fixed since the antimicrobial action reduces it very largely, especially in the tropical soils as Adeniyani *et al.* (2020) reported. Similar to this, leaf K concentrations were greatly ameliorated under INM in 75% NPK Mg + 25% PM. The findings provide evidence for the role played by chicken manure in supplying K to the soil and thereby improving the cation exchange capacity, which K retention and K uptake are enhanced by, as has been demonstrated in the studies by Adekayode and Olayinka (2019) and Memon *et al.* (2024) carried out earlier. In spite of the fact that potassium uptake differed among the genotypes, the fact that there is no significant treatment × variety interaction indicates that potassium response was almost at the same level for all genotypes, which in turn, strengthens the general effectiveness of INM in meeting K requirements in oil palm seedlings. Magnesium content was the only one that exhibited quite different behavior, with the maximum values being found under the single poultry manure application, thus indicating that PM is a good source of Mg and that it releases it slowly, hence coating better Mg accumulation over time. The finding corresponds with that of Ojeniyi and Adeniyani (2018), who concluded that magnesium content in the leaves of perennials increased when organic matter was added. Control plants were severely deficient in Mg (0.20%), thus pointing out the necessity for external supplementation. Deli x lame bettered Mg uptake once again but the lack of significant interaction effects implies that different varieties responded similarly to Mg availability under different fertilization treatments.

**Nutrient uptake of oil palm varieties:** The findings of the current research reveal that integrated nutrient management (INM), especially the mixture of 75% NPK Mg + 25% poultry manure, brought about a significant increase in the uptake of nitrogen, phosphorus, potassium, and magnesium by oil palm seedlings as compared to a sole organic or inorganic application. In fact, nitrogen uptake was at its highest in this treatment (2.50–2.70 g plant<sup>-1</sup>), which is in line with the results of Mohd Fahmi Keni *et al.* (2021) and Fuady *et al.* (2019), who attributed the increase of N uptake to nutrient synchronization and microbial activity under INM. Along the same line, phosphorus uptake (2.00–2.18 g plant<sup>-1</sup>) attained its maximum value in the same condition, agreeing with Adeniyani *et al.* (2020) who observed that P availability was enhanced as a result of organic inputs improving soil chemistry. Potassium uptake also exhibited a similar pattern, in conformity with Adekayode and Olayinka (2019) who pinpointed INM as a major factor in K use efficiency through improved soil structure and cation exchange capacity. Even though poultry manure is recognized as a source of Mg, magnesium uptake was the highest (0.55–0.61 g plant<sup>-1</sup>) in the integrated system, probably because of the enhanced immediate availability from mineral sources, thus, confirming Ojeniyi and Adeniyani's (2018) findings. Different

from other genotypes, Delixlame appeared to be the most responsive in terms of nutrient uptake as it recorded the highest values for all the macronutrients, thus, indicating superior nutrient use efficiency, a characteristic that was also pointed out by Yusof *et al.* (2022) and Ajayi *et al.* (2022) in genetically vigorous oil palm genotypes. In conclusion, the moderate replacement of mineral fertilizers with 25% poultry manures not only led to the optimization of nutrient uptake but also conformed with the principles of sustainable nutrient management as outlined by Khairulmazmi *et al.* (2021) and Memon *et al.* (2024), who advocated for balanced fertilization as a means to increase productivity and at the same time conserve soil health.

## CONCLUSION

The research revealed that integrated nutrient management (INM) fed the oil palm seedlings the most, in particular the nutrient uptake (N, P, K, and Mg) which was significantly increased by the mixture of 75% NPK Mg with 25% poultry manure. Besides that, seedling growth and their physiological performance of the oil palm varieties were also improved. Of the three varieties tested, Deli x lame had the highest nutrient uptake and growth, thus it showed the greatest nutrient use efficiency. The use of poultry manures alone or the complete omission of fertilization led to poor nutrient uptake and reduced growth. These results are a demonstration that proper nutrient management through the use of both organic and inorganic sources leads to the optimal supply, uptake, and vigor of oil palm seedlings. For the most effective nutrient uptake and seedling growth, oil palm seedlings in nurseries should be fertilized with 75% of the recommended NPK Mg fertilizer mixed with 25% poultry manure. Under INM conditions, sustain nutrient uptake and growth by using the Deli x lame variety that has been proven to be the best. The findings of this study provide the first localized evidence for optimizing oil palm nursery nutrition under coastal Sindh conditions and may serve as a baseline for future field-scale validation in saline environments.

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## AUTHOR’S CONTRIBUTION

A.W. G: Conceived the research idea, designed and conducted the experiment, analyzed and interpreted the data, and led the writing of the manuscript. H. G, assisted in conducting the

experiment, application of treatments, collection and recording of data, and contributed to manuscript preparation. M. S. S, contributed to experiment planning, supervised the experimental work, and provided guidance during manuscript preparation and revision. H. B, assisted with soil and plant analyses, provided technical input on nutrient management, and contributed to writing and reviewing the manuscript. T. F. A., Provided technical support in varietal evaluation, contributed to the experimental design, and assisted with data collection and interpretation.

## CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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