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# NITROGEN UPTAKE MODEL OF OIL PALM IN MAIN NURSERY

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## ABSTRACT

*Optimising the use of nitrogen (N) fertiliser in the main nursery will save costs, optimise seedling growth, and minimise N leaching. Appropriate N fertiliser recommendations can be approached by modelling growth and nitrogen uptake. This study aimed to obtain a model of nitrogen uptake from oil palm seedlings in the main nurseries. The trial was conducted at the Leuwikopo Experimental Farm, IPB University, from May 2021-January 2022. The experiment consisted of five levels of N replicated five times. Treatments N0, N1, N2, N3 and N4 consisted of 0%, 50%, 100%, 150% and 200% standard fertiliser, respectively. The developed growth and N uptake model can only be used to predict oil palm growth and nutrient uptake in the main nurseries. The model was built from the dry matter partition coefficient, nutrient partition coefficient, and the actual amount of nutrient requirement. The model validation results during the main nursery showed that the model developed generally corresponded to the observed values for dry weight and nutrient uptake in the field. The developed model can predict oil palm seedlings' dry weight and nutrient uptake in the main nurseries under various conditions of deficiency or excess of N fertiliser level and climate conditions.*

**Keywords:** dry weight, growth, optimisation, nutrient demand, precision.

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## INTRODUCTION

Indonesia is the largest palm oil producer and exporter in the world. In 2022, the area of oil palm plantations has increased to 15.38 million hectares (DJP, 2023). The expansion of the planting area should increase productivity. Oil palm productivity is generally affected by land issues, seedling quality and agronomic practices such as fertilising activity. Nurseries are one of the stages of cultivation that can be optimised to support oil palm productivity. Indeed, Tao *et al.* (2017) reported that the bunch index increased by 12% under best management and fertiliser application practices compared to standard plantation practices. In addition, plants from good seeds will grow and develop faster and, in the end, produce earlier and provide higher yields (Sudradjat *et al.*, 2014). Good seedling care in nurseries through the right dose of fertiliser application is one of the efforts to achieve optimal seedling growth (Santi and Goenadi, 2016).

Optimal and balanced fertiliser application will maximise the growth of oil palm seedlings. However, currently, Indonesia only uses the same fertiliser recommendations for oil palm seedlings in all nurseries. According to Broschat (2009), oil palm fertiliser application should be based on the type of soil and climate at the place of planting (specific location). In addition, location-specific fertiliser dosage recommendations can also overcome low

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fertiliser efficiency (Chen *et al.*, 2014b). However, it is difficult to implement site-specific fertiliser application recommendations because Indonesia has various weather and soil types. Creating a nutrient uptake model is an approach to getting site-specific fertiliser recommendations. A model is a simple representation of a system and simulation for building mathematical models and studying plants that refer to the system. The model helped estimate the best growth and nutrient uptake for regions with different soil and weather nutrient conditions.

In oil palm, plants at the juvenile stage have a particular need for N (Rowe *et al.*, 2005). Nitrogen (N), which mainly enters the plant as a soluble nitrate ion, is a building block for tissue growth and essential components, including chlorophyll and nucleic acids (Ikhajiagbe *et al.*, 2022). N modeling is important because N is a mobile macronutrient, easily lost in the fields. Efficient N fertiliser application would reduce costs, optimise seedling growth, and minimise N leaching (Prado *et al.*, 2006). It is thus essential to obtain an accurate understanding of N dynamics and losses in plantations in order to optimise the management of N and the use N fertilisers.

Numerous models on oil palm have been established. In Nye and Tinker's model, nutrient uptake was discussed based on root morphology and soil reactions (Roose *et al.*, 2001). However, this model is challenging to apply because the input requirements are large and difficult to obtain. Growth modelling and other production predictions, such as PALSIM, have not considered water and nutrient limitations (Hoffmann *et al.*, 2014). Thus far, oil palm modelling has only focused on predicting bunches and dry matter production in the field (>1 yr). Thus, modelling for nurseries has yet to be reported. This study was established to obtain a model of nitrogen uptake from oil palm seedlings in the main nursery, which can predict growth and N uptake in various soil and weather conditions.

## MATERIALS AND METHODS

Modelling research was carried out in four stages: Model concept assessment, model concept development, model simulation and verification, and model validation. The assessment and preparation of the model concept were carried out using a literature study. Model simulation and verification were carried out with the Stella 9.02 application. Model validation was carried out by paired T-test between the absorption of the N model and the results of experiments in the field.

The literature study was conducted to review the model concept and obtain existing models' input coefficients. The coefficients obtained from the literature study are:

- Extinction coefficient = 0.72 (Squire, 1984).
- The respiration coefficient of oil palm (g $CH_2O$ $kg^{-1}$ dry weight $day^{-1}$) of oil palm for roots, petiole, and leaves were 15.04, 9.35 and 38.28, respectively (Henson, 1992).
- The basic temperature of oil palm growth is 15°C (Hartley, 1988).

Field trials were conducted to obtain coefficients for model input that did not yet exist and to obtain growth and N uptake data for model validation. The field trial was conducted at Leuwikopo Experimental Farm, IPB University, from May 2021-January 2022. Uniform 3 month old oil palm seedlings (Damimas variety) were selected and transplanted in 40 x 50 cm polybags. The experiment was carried out in a randomised block design of five levels N replicated five times. The treatments of N0, N1, N2, N3, and N4 consisted of 0%, 50%, 100%, 150% and 200% standard fertiliser, respectively. The total N fertiliser dose of 100% using the standard fertiliser application for oil palm seedlings of the Damimas variety in the main nursery. Each seedling in the experiment was fertilised with a 100% dose of phosphorus (P), potassium (K) and magnesium (Mg) of the standard dose for the Damimas variety. Fertiliser application was done every two weeks with a predetermined dose. The total N, P, K and Mg fertiliser application standards for each seedling were 28 g N, 28 g P, 33 g K, and 14 g Mg. Each experimental plot consisted of six seedlings.

Oil palm seedlings from pre-nursery (3 months old) were selected to obtain uniform seedlings with average growth. The planting medium for the main nursery was topsoil (pH ($H_2O$) of 5.9, 4% C, 0.29% N (Kjeldahl), 0.47% total P, 0.20% total K and 0.23% total Mg). The media was filled in 40 x 50 cm black polybags. Polybags containing seedlings were arranged according to treatment blocks with a spacing of 90 x 90 x 90 cm. Watering was done every morning and evening. Fertiliser application was carried out according to the treatment dose every two weeks. Fertiliser application was done by spreading the fertiliser on the soil surface at ± 5 cm from the seedlings, and different types of fertilisers were placed on different sides of the plant. Measurement of actual nutrient uptake by the seedlings in the nursery was carried out by adding up the product of the dry weight of each organ (DWx) with its N content (Nx) [Equation (1)]:

$$\text{Total N uptake} = \begin{array}{c} (DW_{root} \times N_{root}) + \\ (DW_{petiole} \times N_{petiole}) + \\ (DW_{leaf} \times N_{leaf}) \end{array} \qquad (1)$$

Variables of the dry weight of plant organs (roots, petiole, and leaves), leaf area index (LAI), radiation use efficiency ($\varepsilon$) [Equation (3)], and partition coefficient of dry weight and N partition [Equation (12)] were measured at 3, 6, 9 and 12 months after planting. LAI was derived by calculating the leaf area and the leaf dry weight [Equation (4)]. The plant dry weight was calculated destructively by weighing the plant organs that had been dried for 48 hr at 80°C. N content was measured at the Laboratory of Soil Research Centre, Bogor.

The N uptake model consists of the growth model and the N uptake submodel. The growth simulation model (Handoko, 1992) is based on plant growth response to N and its interactions. Actual biomass estimation is calculated by:

$$Ba = wdf \times Bp = wdf \times \varepsilon \times Q_{int} \tag{2}$$

where, Bp is the potential biomass production (kg $ha^{-1}$ $day^{-1}$); wdf is the water deficit factor (actual transpiration/maximum transpiration). Actual transpiration is calculated based on potential evapotranspiration (ETp) by the Penman method, which is considered as maximum evapotranspiration (ETm) (Handoko, 1994); $\varepsilon$ is the radiation use efficiency (kg $MJ^{-1}$). $\varepsilon$ is calculated based on the ratio of the dry weight of plants produced over a certain period ($\Delta DW$) to the amount of solar radiation energy intercepted ($Q_{int}$) by plants. $Q_{int}$ ($MJ^{-1}$ $ha^{-1}$ $day^{-1}$) is the difference between the amount of radiation that comes above the canopy (Qs) and the radiation below the plant canopy (Ql).

$$\varepsilon = \frac{\Delta DW}{Q_{int}},\ Q_{int} = Qs\text{-}Ql = (1\text{-}e^{-k\,LAI})\,Qs \tag{3}$$

where, k is the extinction coefficient = 0.72 (Squire, 1984), and LAI is the leaf area index. LAI changes are calculated by:

$$dILD = SLA \times dWL \tag{4}$$

SLA is the specific leaf area (ha $kg^{-1}$); dWL is the difference in leaf mass change (kg $ha^{-1}$ $day^{-1}$).

Net biomass production is the actual biomass estimation reduced by maintenance respiration. The maintenance respiration coefficients (g $CH_2O$ $kg^{-1}$ dry weight $day^{-1}$) of oil palm for roots, petiole, and leaves were 15.04, 9.35 and 38.28 (Henson, 1992).

The availability of N in the soil is estimated by the actual rate of soil nitrification ($d_{NO_3}$) minus the estimated N leaching. Calculation of the rate of soil nitrification and N-leaching followed that of Handoko (1992):

$$d_{NO_3} = Q_{10} {}^{*}\, d_{NO_3p} {}^{*}FKat \tag{5}$$

$$FKat = -0.039 + (1.02{}^{*}SWC/FC) \tag{6}$$

$$Q_{10} = 2^{(T-20)/10} \tag{7}$$

where, $d_{NO_3p}$ is the potential rate of soil nitrification; T is the daily temperature (°C); SWC is the soil water content (mm); FC is the field capacity (mm). Nitrogen leaching from soil ($L_{NO_3}$) was calculated based on the amount of percolation water:

$$L_{NO_3} = \frac{(\text{Percolation}{}^{*}[NO_3\ \text{contentration}]}{\text{soil water content+Percolation}} \tag{8}$$

$$\text{Nitrogen soil availability} = d_{NO_3}{}^{*}wdf\text{-}L_{NO_3} \tag{9}$$

N uptake by plants takes into consideration the available soil N-content and N-demand of the plant. N requirements during plant growth are determined by the actual N concentration in plant organs and the maximum organ concentration (Handoko, 1992):

$$\begin{aligned} N_{demand} &= dW{}^{*}[N_{max}] && \text{if } [N_{act}] < [N_{max}]; \\ N_{demand} &= 0 && \text{if } [N_{act}] \geq [N_{max}] \end{aligned} \tag{10}$$

$$N_{actual} = N_{plant}{}^{*}W_{plant}/100 \tag{11}$$

where, dW is the plant biomass increment; $N_{act}$ is the actual N concentration (%); $N_{max}$ is the maximum N concentration (%); $N_{plant}$ is the initial N plant concentration; $W_{plant}$ is the plant dry weight. The maximum N concentration was determined as the highest plant concentration during the observation period. N partition ($p_i$) is the ratio of the increase in nitrogen uptake of certain plant organs (roots, petiole, leaves) at a certain age ($dDW_i$) to the total increase in nitrogen uptake of plants at the same age ($dDW_{total}$).

$$pi = \frac{dDw_i}{dDWtotal} \tag{12}$$

When there is sufficient available N in the soil to cover the plant demand for N, root uptake is driven by the demand. The maximum N concentration of the daily growth of the plant determines the demand. However, the demand is also limited to staying within the maximum N concentration of the standing biomass that decreases with plant biomass and decreasing day length. The plant N demand is limited to the difference between the maximum plant N and its actual N content. The N uptake submodel is shown in *Figure 1*.

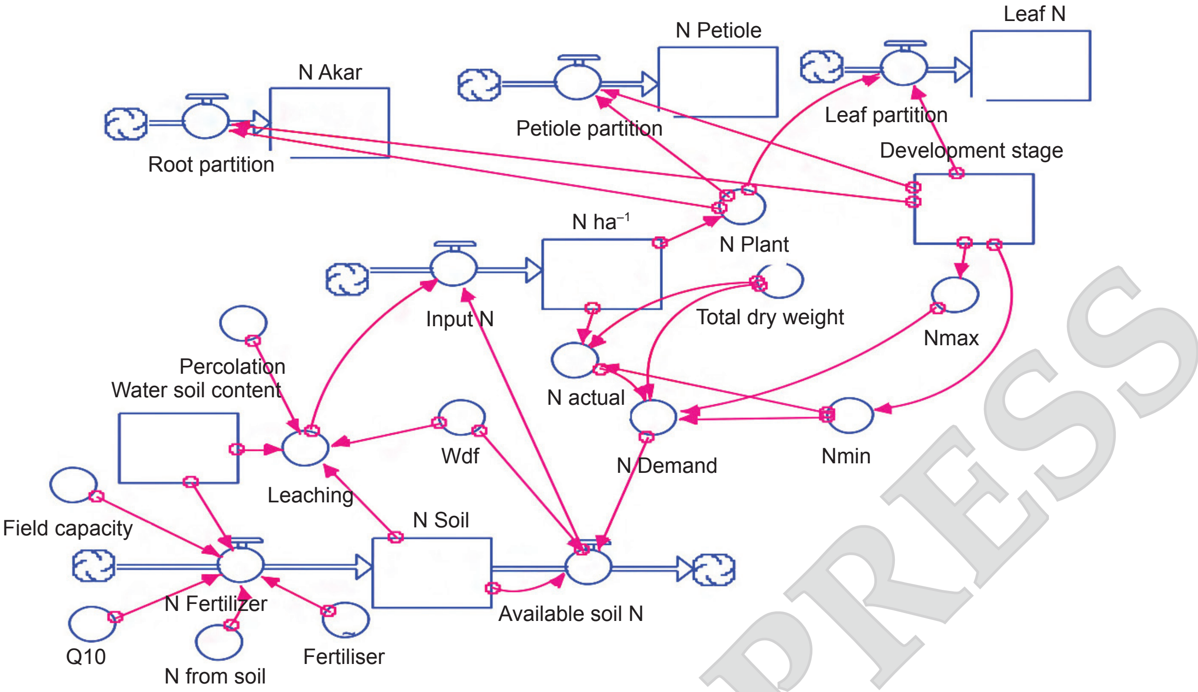

*Figure 1. Approximate schematic description of N dynamics of the N uptake model. Total biomass and soil mineral N are simulated with linked models programmed in Stella.*

## RESULTS

Initial soil conditions and daily weather are inputs in the growth model. Monthly weather conditions consist of total rainfall, average temperature, radiation intensity, light exposure length and relative humidity during the study, as seen in *Table 1*. The average rainfall during the study was 310 mm month$^{-1}$. The average daily temperature was 27.1°C. The average radiation intensity was 18.8 MJ m$^{-2}$. The average light exposure length was 7.4 hr day$^{-1}$. The average relative humidity was 83.1%.

### Leaf Area Index (LAI)

The results of LAI measurements on oil palm seedlings at various doses of N fertiliser are shown in *Table 2*.

TABLE 1. WEATHER ON TRIAL SITE IN MAY 2021-JANUARY 2022

| Month | Total rainfall (mm month$^{-1}$) | Temperature (°C) | Radiation intensity (MJ m$^{-2}$) | Light exposure length (hr day$^{-1}$) | Relative humidity (%) |
|---|---|---|---|---|---|
| May 2021 | 510.3 | 26.8 | 20.4 | 9.3 | 84.2 |
| June 2021 | 311.1 | 25.9 | 16.0 | 7.8 | 84.1 |
| July 2021 | 115.6 | 26.0 | 19.3 | 9.2 | 79.8 |
| August 2021 | 399.5 | 26.0 | 19.2 | 8.9 | 81.9 |
| September 2021 | 317.3 | 30.0 | 21.8 | 9.0 | 81.0 |
| October 2021 | 566.5 | 31.0 | 23.2 | 8.5 | 82.6 |
| November 2021 | 183.6 | 26.4 | 16.0 | 4.2 | 83.7 |
| December 2021 | 279.1 | 26.1 | 16.7 | 3.8 | 85.2 |
| January 2022 | 106.6 | 26.0 | 16.5 | 6.0 | 85.0 |

TABLE 2. LEAF AREA INDEX OF OIL PALM ON SEVERAL DOSAGES OF N FERTILISER APPLICATION

| **Treatment** | **Leaf area index (LAI)** | | |
|---|---|---|---|
| | **6 MAP** | **9 MAP** | **12 MAP** |
| N0 | 0.17 | 0.95 | 2.11 |
| N1 | 0.24 | 1.09 | 1.66 |
| N2 | 0.22 | 1.57 | 2.63 |
| N3 | 0.21 | 1.29 | 3.03 |
| N4 | 0.20 | 1.14 | 1.88 |

Note: MAP - month after planting.

### Radiation Use Efficiency (ε) (g MJ$^{-1}$)

*Table 3* presents data on oil palm's radiation use efficiency at various N fertiliser doses. Increasing the dose of N fertiliser causes an increase in the value of ε up to a dose limit of 100%. Higher fertiliser application in the N3 and N4 treatments caused a decrease in the value of ε.

TABLE 3. RADIATION USE EFFICIENCY OF OIL PALM ON SEVERAL DOSAGES OF N FERTILISER APPLICATION

| **Treatment** | **Radiation use efficiency (g MJ$^{-1}$)** | | |
|---|---|---|---|
| | **3-6 MAP** | **6-9 MAP** | **9-12 MAP** |
| N0 | 1.10 | 0.70 | 0.91 |
| N1 | 1.02 | 0.72 | 1.07 |
| N2 | 1.02 | 0.73 | 1.20 |
| N3 | 1.07 | 0.69 | 1.05 |
| N4 | 1.01 | 0.67 | 0.89 |

Note: MAP - month after planting.

### Partition of Dry Weight and Nitrogen

The dry-weight partition of oil palm is shown in *Table 4*. The dry weight of oil palm in the nursery phase was more partitioned into shoots. At 12 MAP, the N1, N2 and N3 treatments, the dry weight partition to roots was higher than N0 and N4. *Table 5* shows the N partitions on roots, petioles and leaves. Nutrient partitioning also indicated that more N produces a lengthy canopy (*Table 5*). N accumulation in roots increased during the main nursery. The highest N accumulation was found in leaves.

TABLE 4. DRY WEIGHT PARTITION OF OIL PALM ON SEVERAL DOSAGES OF N FERTILISER APPLICATION

| **Age (months)** | **Organ** | **Treatment** | | | | |
|---|---|---|---|---|---|---|
| | | **N0** | **N1** | **N2** | **N3** | **N4** |
| 3-6 | Roots | 0.28 | 0.26 | 0.28 | 0.29 | 0.27 |
| | Petiole | 0.30 | 0.30 | 0.30 | 0.29 | 0.29 |
| | Leaves | 0.43 | 0.45 | 0.43 | 0.43 | 0.45 |
| 6-9 | Roots | 0.34 | 0.27 | 0.26 | 0.22 | 0.26 |
| | Petiole | 0.28 | 0.33 | 0.35 | 0.32 | 0.31 |
| | Leaves | 0.38 | 0.40 | 0.39 | 0.45 | 0.43 |
| 9-12 | Roots | 0.15 | 0.33 | 0.36 | 0.37 | 0.24 |
| | Petiole | 0.42 | 0.34 | 0.31 | 0.19 | 0.32 |
| | Leaves | 0.43 | 0.34 | 0.33 | 0.43 | 0.44 |

TABLE 5. N PARTITION OF OIL PALM ON SEVERAL DOSAGES OF N FERTILISER APPLICATION

| **Age (months)** | **Organ** | **Treatment** | | | | |
|---|---|---|---|---|---|---|
| | | **N0** | **N1** | **N2** | **N3** | **N4** |
| 3-6 | Roots | 0.20 | 0.13 | 0.13 | 0.18 | 0.17 |
| | Petiole | 0.29 | 0.28 | 0.23 | 0.23 | 0.24 |
| | Leaves | 0.51 | 0.58 | 0.64 | 0.59 | 0.59 |
| 6-9 | Roots | 0.30 | 0.26 | 0.26 | 0.13 | 0.18 |
| | Petiole | 0.10 | 0.24 | 0.23 | 0.25 | 0.18 |
| | Leaves | 0.60 | 0.50 | 0.51 | 0.62 | 0.65 |
| 9-12 | Roots | 0.10 | 0.26 | 0.36 | 0.33 | 0.23 |
| | Petiole | 0.19 | 0.17 | 0.08 | 0.00 | 0.13 |
| | Leaves | 0.71 | 0.57 | 0.56 | 0.67 | 0.64 |

### Growth Model Validation

Dry weight simulation was carried out according to Equations (2-4). A comparison of the dry weight of each organ in the actual and model conditions can be seen in *Figure 2*. At 3 MAP, the dry weight of the roots was 0.84 g, the petiole was 0.91 g, and the leaves was 1.87 g. Dry matter accumulation was focused on above-ground biomass enlargement. At 9 MAP, root growth was increased to compensate for shoot growth. At 12 MAP, treatments N1, N2, and N3 showed a similar trend of dry matter accumulation among roots, petiole, and roots. On the other hand, N4 treatment tended to accumulate dry matter in the canopy (leaf and petiole). A comparison of actual and simulated growth data for each treatment is shown in *Figure 2*.

*Figure 2* shows an agreement between the simulation results of oil palm seedlings' dry weight at various N fertiliser application doses with the measurement results. The data from the simulation results are still included in the confidence interval (1-$\alpha$ = 0.95) of the measurement results. Paired T-test showed no difference between the actual dry weight in the field and the model simulation results (*Table 6*).

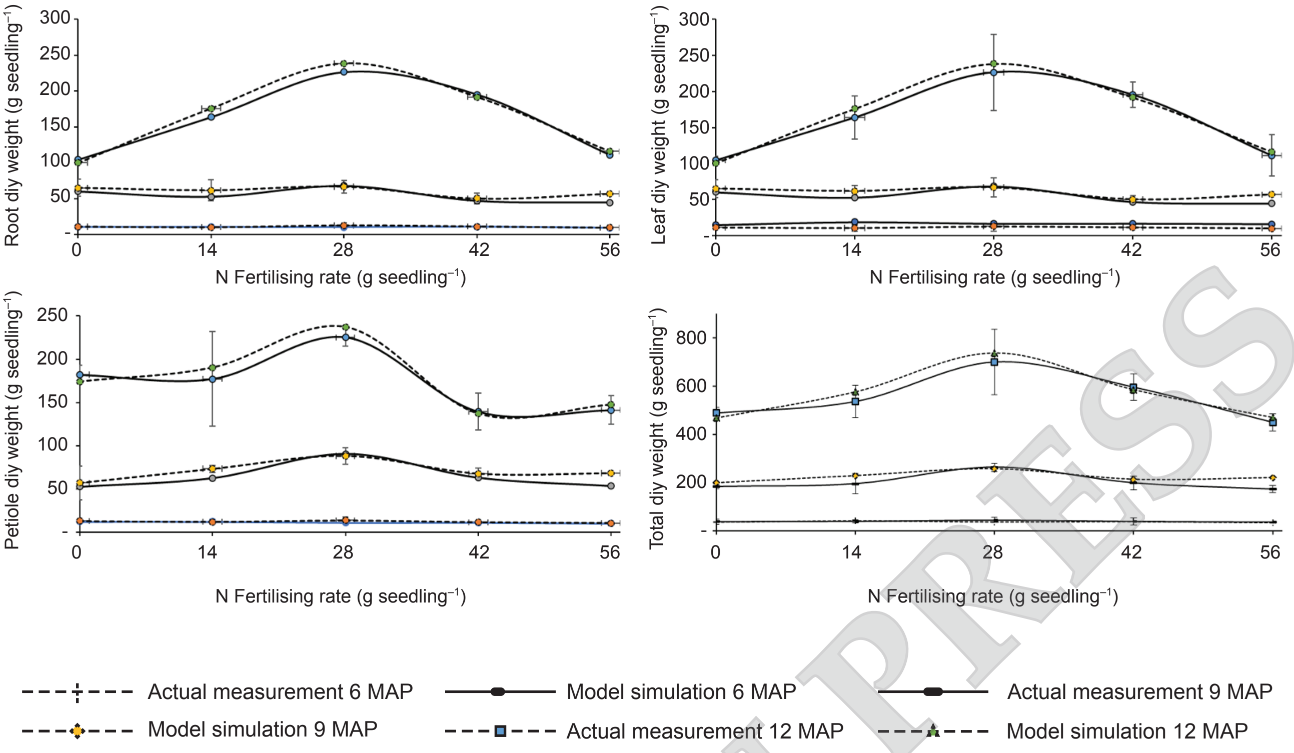

*Figure 2. Simulated (dotted line) and measured dry weight (solid line) of N0, N1, N2, N3 and N4.*

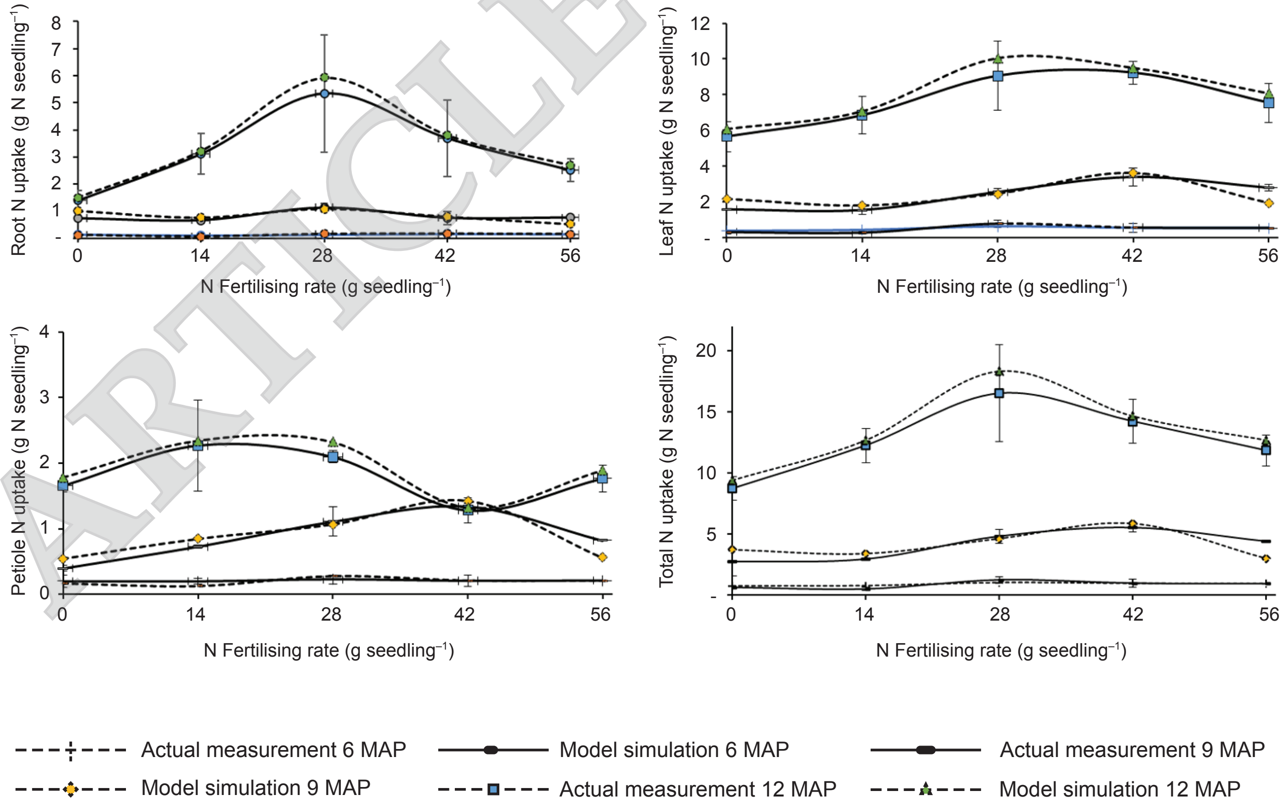

*Figure 3. Simulated (dotted line) and measured N uptake (solid line) of N0, N1, N2, N3 and N4.*

**Nitrogen Uptake Validation**

At the beginning of seedling growth in the main nursery (6 MAP), there was no difference in treatments (*Figure 3*). At 9 MAP, the highest N accumulation in N1 was in roots, while at N2, N3 and N4, the highest N accumulation was in leaves. At 12 MAP, the trend of N accumulation in roots and leaves was high in N2 and N3, while N1 and N4 tended to be lower. A comparison of simulation data and measured N absorption can be seen in *Figure 3*.

At 3-6 MAP, the accumulation of N nutrient partitions in each plant organ for all treatments tended to be the same (*Table 4*). The highest N accumulation was found in the leaves. At 6-9 MAP, the partitioning of N in the leaf in N3 and N4 is higher than that of N1 and N2. On the other hand, the partition N at the root of N1 and N2 is higher than that of N3 and N4. In 9-12 MAP, N1 and N4 had a similar trend of accumulation N, as well as N2 and N3.

*Figure 3* shows the agreement between the simulation results of the N uptake of oil palm seedlings at various doses of N fertiliser and the measurement results. The suitability is based on the data from the simulation results, which are still included in the confidence interval ($1-\alpha = 0.95$) of the measurement results. T-test result can be seen at *Table 6*.

TABLE 6. DRY WEIGHT AND N-UPTAKE T-TEST RESULT OF ACTUAL MEASUREMENT AND MODEL SIMULATION

| **Parameter** | **Treatment** | | | | |
|---|---|---|---|---|---|
| | **N0** | **N1** | **N2** | **N3** | **N4** |
| **Growth model** | | | | | |
| Dry weight 6 MAP | | | | | |
| t | 0.07 | 0.06 | -0.37 | 0.04 | 0.18 |
| $t_{0.05}$ | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| result | ns | ns | ns | ns | ns |
| Dry weight 9 MAP | | | | | |
| t | 0.65 | 0.32 | 0.15 | 0.21 | 1.34 |
| $t_{0.05}$ | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| result | ns | ns | ns | ns | ns |
| Dry weight 12 MAP | | | | | |
| t | 0.38 | -0.23 | -0.11 | 0.08 | -0.22 |
| $t_{0.05}$ | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| result | ns | ns | ns | ns | ns |
| **N uptake model** | | | | | |
| N uptake 6 MAP | | | | | |
| t | 0.05 | 0.92 | 0.36 | 0.02 | 0.02 |
| $t_{0.05}$ | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| result | ns | ns | ns | ns | ns |
| N uptake 9 MAP | | | | | |
| t | 3.43 | 0.33 | 0.22 | 0.17 | 1.61 |
| $t_{0.05}$ | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| result | * | ns | ns | ns | ns |
| N uptake 12 MAP | | | | | |
| t | 0.28 | 0.12 | 0.18 | 0.09 | 0.27 |
| $t_{0.05}$ | 2.31 | 2.31 | 2.31 | 2.31 | 2.31 |
| result | ns | ns | ns | ns | ns |

From *Figure 4*, increasing N fertiliser affected the N uptake to the optimum limit. At the same time, the higher application of N fertiliser increased the leaching of N in the soil.

## DISCUSSION

The LAI of the oil palm plantation can be described as the ratio of the total leaflet area of the plantation to the total ground area of that plantation. LAI describes a fundamental property of the oil palm canopy. It is an important index related to the growth and metabolism of the plant, as well as the accumulation of dry matter and yield (Awal *et al*., 2010). *Table 2* shows that increasing the dose of N will increase LAI to the optimum fertiliser application and then decrease at excessive fertiliser application doses. Increasing the LAI shows that N fertiliser application causes an increase in leaf area per unit area of planting area.

Increasing N fertiliser application increases the growth and biomass of oil palm seedlings to the 100% dose. The increase in plant dry weight caused increased plant shoot, which could be seen from the LAI. Moradi *et al.* (2014) showed that N fertiliser application positively increased palms trunk measurements and leaf area. The LAI determines the amount of intercepted of radiation ($Q_{int}$). The $Q_{int}$ value determines the amount of potential biomass production. The accumulation of dry matter reflects the ability of plants to bind energy from radiation through the process of photosynthesis, as well as interactions with other environmental factors (Fried and Hademenos, 2000). Furthermore, leaf N content is a solid factor influencing optimum canopy radiation use efficiency and photosynthesis rate (Sastrohartono *et al*., 2016).

Furthermore, the growth rate was slower with increased excessive N fertiliser application. Excess N fertiliser application causes disorders on the uptake of nutrients by plant roots and nutrient balance in plant tissues (Fairhurst and Hardter, 2003). Excessive application of N also causes the oil palm growth to be inhibited due to antagonistic interactions among several nutrients (Uexkull and Fairhurst, 1991). Excess N content in plant tissues also causes stunted growth and reduced crop production, making plants vulnerable to attack by pests (Goh and Hardter, 2003).

Higher N levels in plants with higher N fertiliser application cause plants to reduce N demand. This decreased demand in turn causes N uptake to decrease, even though N is available in the soil. Reduction in demand and biomass cause N uptake at higher N doses to be lower. Sugihara *et al.* (2012) reported that changes in inorganic N concentration would affect N assimilation by plants and the potential for nitrogen loss. Subsequent N demand may also help to explain differences in species' response to increases in soil N (Boardman, 1977).

The N partition in oil palm seedlings depends on the condition of N availability in the plant. Optimal N content causes N to be partitioned less in the petiole. Deficiency or excess of N in treatments N0, N1 and N4 treatments resulted in more partitioning of N in the petiole than in leaves. This condition caused N to be preferentially partitioned in the shoot of oil palm seedlings, probably due to an increase in the rate of amino acid translocation to the shoot than the roots (Mohidin *et al*., 2015). Regarding the proportion of biomass partitioning, the portion partitioned of the shoot consisting of leaves and stems accounted for the most significant proportion of dry matter partitioning, 81.1%-90.9%, while root accounted for only 9.1%-18.9%, (Mohidin

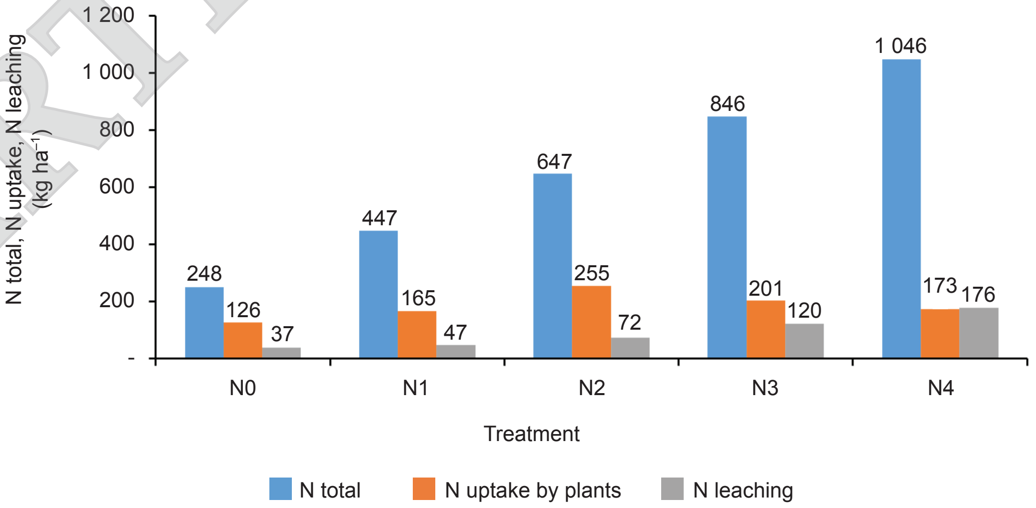

*Figure 4. Simulation N total, N uptake, and N leaching by model.*

*et al.*, 2015). However, the partition distribution of dry matter is influenced by various environmental factors such as air temperature, drought and nutrient deficiencies (Wardlaw, 1990). In plants that experience a deficiency of N and P, more dry matter will be partitioned in the roots than the shoots (Ericsson, 1994).

Increasing N fertiliser application was positively correlated with increased N leaching in the soil (*Figure 4*). The availability of N in soil and high rainfall are associated with the leaching of N. According to Tung *et al.* (2009), leaching losses are related to rainfall patterns, fertiliser treatment, and nutrient uptake by roots. Chen *et al.* (2014a) reported that nitrogen loss might occur if excessive nitrogen is available during the seedling stage. Estimates of total losses of N are highly variable, ranging from 21 to 139 kg N $ha^{-1}$ $yr^{-1}$ around an average of 77 kg N $ha^{-1}$ $yr^{-1}$ (Pardon *et al.*, 2016).

Model verification in this study was only carried out on plant dry weight and N uptake variables. The model can estimate the dry weight of oil palm seedlings, so with the model's input, the model, in principle, can be used as a tool to distinguish the level of N adequacy in oil palm seedlings. The advantages of the model constructed in this study are follows:

- The growth and nutrient uptake models were constructed specifically for the main oil palm nursery.
- The model can be used in conditions of lack/excess of water and nutrients (N, P, K and Mg).
- The nutrient uptake model is built based on nutrient partitioning so that the model can predict nutrient uptake in each seedling organ (leaves, petioles and roots).
- The demand for nutrients (N-demand) in the model is determined based on the actual needs of the seedlings.
- The constructed model requires simple data input (easy to apply).

## CONCLUSION

The developed growth and N uptake model can only be used to predict oil palm growth and nutrient uptake in main nurseries. The model requires relatively fewer input data (weather elements and soil fertility) than other models, so the model becomes more applicable than other models. The model was built from the dry matter partition coefficient, nutrient partition coefficient, and actual nutrient requirement amounts. The model validation results during the main nursery (9 months) showed that the model developed generally corresponded to the observed values for dry weight and nutrient uptake in the field. The developed model can predict oil palm seedlings' dry weight and nutrient uptake in main nurseries under various conditions of deficiency or excess of N fertiliser level.

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