Research article

Phosphorus Uptake Model of Oil Palm Seedlings in the Main Nursery

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Abstract

Keywords

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Oil palm is generally cultivated on tropical soils that have low levels of chemical fertility and various physical fertility. Environmental factors, genetics, and cultivation techniques generally influence oil palm productivity. This study aimed to obtain a model of oil palm growth and phosphorus (P) uptake in the main nursery. The oil palm growth model was carried out through literature studies and field trials. The trial was conducted at Leuwikopo Trial Farm (Bogor Agricultural Institute) IPB University from May 2021-January 2022. The experiment was designed using a non-factorial randomized block design with five replications. The experiment consisted of one treatment with five levels of P fertilization: P0 = no fertilizer; P1 = 50% standard fertilization; P2 = 100% standard fertilization; P3 = 150% standard fertilization; and P4 = 200% standard fertilization. The fertilizer dose of 100% using the standard fertilization for oil palm of the Damimas variety was 28 g P seedling^{-1}. This study concluded that the model of oil palm nutrient P uptake for the main nursery was able to simulate oil palm nutrient uptake as shown by actual measurements (observations in the field). The dry weight simulation results fell within the range of standard deviation values for average measurements in the field. The nutrient uptake simulation model is thus a valid tool for planning the optimal fertilization of oil palm seedlings in the main nursery.

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1. Introduction

Oil palm is generally cultivated on tropical soils that have low levels of chemical fertility and various physical fertility [1]. Environmental factors, genetics, and cultivation techniques generally influence oil palm productivity [2]. Fertilization is the main factor for overcoming marginal soil conditions, especially in soil fertility, and a balance of dosage and type of fertilizer is needed. Moreover, high dosage levels should be avoided.

Phosphorus (P) is a major growth-limiting nutrient, and unlike nitrogen, no large atmospheric source of P is biologically available [3]. According to Imogie *et al.* [4], a crucial aspect of improving and maintaining soil fertility is the application of deficient nutrients, of which phosphorus is one of the most important. Phosphorus is a structural component of nucleic acids, nucleotides, and coenzymes. The low availability of P is a limiting factor for plant growth [5]. Phosphorus deficiency causes reduced leaf expansion, leaf surface area, and number of leaves, all of which in turn cause lower biomass production. Phosphorus deficiency is due to inadequate P slowing down the processes of carbohydrate metabolism, including photosynthesis and respiration [6]. Phosphorus fertilization has been shown to increase the height of oil palm seedlings [7], stem circumference, and leaf area [8].

Efficient P fertilization is needed to reduce costs and fertilization residues. The recommended fertilizers should be applied so that the oil palms absorb them at maximum efficiency. This efficiency is best achieved by minimizing fertilizer losses in the plantation, which is even more important now because of the current economic woes. Careful optimization of fertilizer application should also minimize environmental problems. Nutrients can be lost by surface run-off, leaching through the soil profile, nutrient fixation, volatilization, and immobilization by ground cover in young oil palms. Understanding these nutrient loss mechanisms is essential to alleviating nutrient loss and improving fertilizer efficiency. One approach to efficient P fertilization is carried out by P nutrient uptake modeling.

Numerous models of oil palm nutrient uptake have been established. There was Nye and Tinker's model, which was concerned with nutrient uptake based on root morphology and soil reaction [9]. Another growth and production prediction model such as PALSIM, did not deal with water and nutrient limitations [10]. Thus far, oil palm modelling has only been focused on predicting bunches and dry matter production in the field (> 1 year), and modelling for nurseries has yet to be reported.

Nutrient modeling in the nursery can be used to predict location-specific oil palm nutrient requirements. Phosphorus modeling can provide information on the amount of P nutrient absorbed by plants based on climatic and soil conditions. Modeling of P nutrient uptake in the main nursery can be a basis for modeling nutrients in the field, so this basic information is needed. The nutrient model can predict the number of P requirements to obtain optimal oil palm growth. This study aimed to obtain a model of growth and nutrient P uptake of oil palm in the main nursery. The built model can also provide information on the recommended doses of oil palm seedlings on various planting areas.

2. Materials and Methods

2.1 Study area

The trial was conducted at Leuwikopo Experimental Farm, IPB University, from May 2021 to January 2022. The experiment was designed according to non-factorial randomized block design with five replications. The experiment consisted of one treatment with five levels of P fertilizing, consisting of P0 = no fertilizer; P1 = 50% standard fertilization; P2 = 100% standard fertilization; P3 = 150% standard fertilization; P4 = 200% standard fertilization. The total fertilizer dose of 100% using the standard fertilization for oil palm seeds of the Damimas variety in the main nursery (28 g P seedling^{-1}). Each seedling in the experiment was also fertilized with nitrogen (N), potassium (K), and magnesium (Mg) according to the standard dose for the Damimas variety, which was 24 g N, 41.9 g K, and 16.1 g Mg. Each fertilizer was applied every 2 weeks at the recommended dosage.

Uniform oil palm seedlings from pre-nursery (3 months old) were selected. The seedlings were of average growth. The planting medium for the main nursery was topsoil. The media was filled in (50x40) cm black polybags. Polybags containing seedlings were arranged according to treatment blocks with a spacing of 90 cm x 90 cm x 90 cm. Watering was done every morning and evening. Fertilization was carried out according to the treatment dose every 2 weeks. Fertilization was done by spreading the fertilizer on the soil surface at ± 5 cm from the seeds, and different types of fertilizer were placed on different sides of the plant. Pest and weed control were carried out chemically depending on the level of pest attack and the weed amount.

The variables of the dry weight of plant organs (roots, petiole, and leaves), leaf area index (LAI), light use efficiency (LUE), and partition coefficient were measured at 3, 6, 9, and 12 months after planting. The dry weight of the plant was calculated destructively by weighing the plant organs that had been dried for 72 h at 70ºC. Phosphorus content was measured at the Laboratory of Soil Research Centre, Bogor. The model consisted of four main modules that simulated plant biomass, plant development, water availability and P uptake. All main modules were simulated by using Stella 9.0.2. The phosphorus uptake model can be seen in Figure 1.

$$pi = \frac{dDWi}{dDWtotal} \tag{6}$$

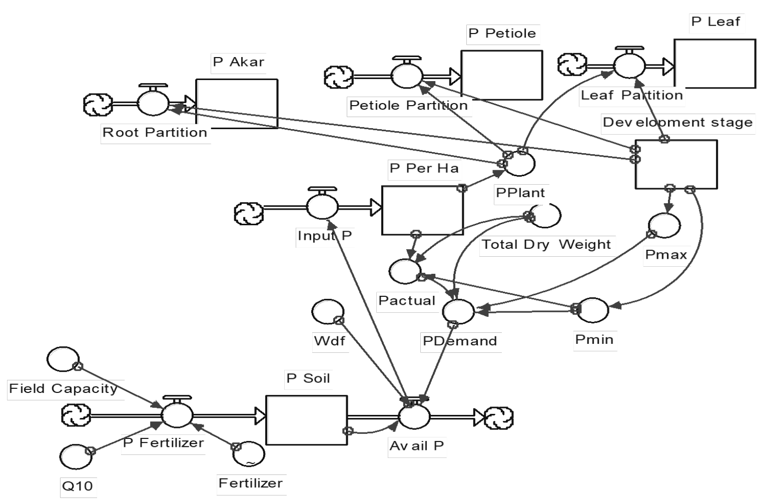

Figure 1. Approximate schematic description of P dynamics of the P uptake model. Total biomass and soil mineral P are simulated with linked models programmed in Stella.

2.2 Plant growth model

The growth model consisted of the plant development, growth, and water availability models. The growth simulation model [11] developed is based on plant growth response to P and its interactions. Potential biomass production is calculated using:

$$Bp = LUE \times Qint \tag{1}$$

Where Bp is the potential biomass production (kg ha^{-1} day^{-1}); LUE is the light use efficiency (kg MJ^{-1}). LUE is calculated based on the ratio of the dry weight of plants produced over a certain period (ΔDW) to the amount of solar radiation energy intercepted (Qint) by plants. Qint (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).

$$LUE = \frac{\Delta DW}{Qint}, \ Qint = Qs\text{-}Ql = (1\text{-}e^{-k\ LAI})\ Qs \tag{2}$$

where, k = extinction coefficient (0,72) (Squire 2018) and LAI = leaf area index.
Actual biomass production (Ba) is calculated by the formula:

$$Ba = wdf \times Bp \times fP; \quad wdf = Tm/Ta \tag{3}$$

Where Ba is the actual biomass production (kg ha^{-1} day^{-1}); wdf is the water availability factor; Ta is actual transpiration (mm); Tm is the maximum transpiration (mm); fP = Phosphorus availability factor. Actual transpiration is calculated based on potential evapotranspiration (ETp) by the Penman method. Penman method is used to determine maximum evapotranspiration (ETm) [12].

The development sub model is structured based on the thermal unit concept [13]. The base temperature for oil palm is 15°C [14]. Net biomass production is the actual biomass reduced by maintenance respiration. The oil palm's maintenance respiration coefficients (g CH_2O kg^{-1} dry weight day^{-1}) for roots, petiole, and leaves were 15.04, 9.35, and 38.28, respectively [15].

2.3 Phosphorus uptake model

P uptake model was built to predict the amount of P absorbed by plants. The calculation of P uptake by plants in the model considers the available P content in the soil and the plant's need of P. P requirements during plant growth are determined by the actual P concentration in plant organs and the maximum organ concentration [11]:

$$P_{demand} = dW*[Nmax] \qquad \text{if } [Pact] < [Pmax];$$

$$P_{demand} = 0 \qquad \text{if } [Pact] \geq [Pmax] \tag{4}$$

$$P_{actual} = P_{plant}*W_{plant}/100 \tag{5}$$

Where dW: Plant biomass increment; Pact: Actual P concentration (%); Pmax: Maximum P concentration (%); P_{plant} = Initial P plant concentration; W_{plant} = Plant dry weight. The maximum P concentration was determined as the highest plant organ concentration during the observation period.

Nutrient partition (p_i) is the ratio of the increase in P uptake of certain plant organs (roots, petiole, leaves) at a certain age (dDW_i) to the total increase in P uptake of plants at the same age (dDW_{total}).

$$pi = \frac{dDWi}{dDWtotal} \tag{6}$$

Principle of the P uptake model: When there is sufficient P in the soil to cover the plant's need. This need drives N uptake by roots. The maximum P concentration of the daily plant growth determines P demand. However, the demand is also limited to the maximum P concentration of standing biomass, which decreases with plant biomass and reduces day length. Crop P demand is limited to the difference between the plant's maximum P and actual P content.

3. Results and Discussion

The topsoil media used in this study had a 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. Initial soil conditions and daily weather were inputs in the growth model. Monthly weather conditions during the study consisted of total rainfall, average temperature, light intensity, light exposure length, and relative humidity can be seen in Table 1.

Table 1. Weather on trial site in May 2021-January 2022

Month	Total Rainfall (mm month^{-1})	Temperature (ºC)	Light Intensity (cal cm^{-2} min^{-1})	Light Exposure Length (%)	Relative Humidity (%)
May 2021	510.3	26.8	488.0	77.6	84.2
June 2021	311.1	25.9	383.1	65.3	84.1
July 2021	115.6	26.0	460.0	76.5	79.8
August 2021	399.5	26.0	459.7	74.0	81.9
September 2021	317.3	30.0	521.0	75.1	81.0
October 2021	566.5	31.0	553.5	70.9	82.6
November 2021	183.6	26.4	381.8	34.8	83.7
December 2021	279.1	26.1	399.8	31.6	85.2
January 2022	106.6	26.0	393.3	49.8	85.0

The average rainfall during the study was 310 mm month^{-1}. The average daily temperature was 27.1ºC. The average light intensity was 448.9 cal cm^{-2} min^{-1}. The average light exposure length was 61.7%. The average relative humidity was 83.1%.

3.1 Leaf area index and light use efficiency

P deficiency reduced leaf area index (LAI). Oil palm seedlings in the P0 treatment had the lowest LAI (0.827) (Table 2). Increasing P fertilization at P1, P2 and P3 increased the LAI of oil palm seedlings to optimum levels. Amanullah *et al*. [16] reported that P and zinc (Zn) were the most important factors influencing rice LAI. P deficiency affects the relative rates of leaf area expansion and plant growth during the early stages. Tissue phosphorus concentration and relative growth rate decrease simultaneously during growth [17]. Mohidin *et al*. [6] also stated that P deficiency reduced leaf expansion, leaf surface area, and the number of leaves, affecting the light use efficiency and the amount of biomass. The result of limiting P uptake is due to insufficient amount of P in assisting the photosynthesis and respiration processes.

P fertilization increased the light use efficiency of oil palm seedlings. The lowest LUE was found in treatment P0 (1.10 g MJ^{-1}). Light use efficiency value corresponds to the LAI value in the treatment with P fertilization (P1-P4) (Table 2). P fertilization increases LAI, thereby increasing the absorption of light and LAI. According to Gitelson and Gamon [18], the absorption of light by plants is affected by several factors: photosynthetically active radiation (PAR) irradiance, canopy structure, photosynthetic pigment content, LAI, leaf angle distribution, and PAR absorption. Furthermore, increasing crop light use efficiency (LUE) increases yield and produce quality [19].

Table 2. Leaf area index (LAI) and light use efficiency (LUE) of oil palm seedlings of various dosages of phosphorus fertilization

Treatment	Leaf Area Index (LAI)			Light Use Efficiency (g MJ^{-1})		
	6 Months	9 Months	12 Months	3-6 Months	6-9 Months	9-12 Months
P0	0.072	0.673	0.827	0.90	0.65	1.10
P1	0.109	0.514	3.059	0.90	0.68	1.51
P2	0.091	0.661	2.290	0.91	0.68	1.51
P3	0.094	0.679	3.628	0.89	0.70	1.43
P4	0.096	0.493	2.618	0.90	0.70	1.40
Average P	0.093	0.604	2.485	0.90	0.68	1.39

Increasing P fertilizing increased the proportion of biomass in all treatments which was dominated by biomass accumulation in the shoots (petioles and leaves) (Table 3). The proportion of biomass in the shoots contributed the most significant proportion of dry matter separation, which was about 81.1-90.9% while the roots accounted for 9.1-18.9% [6]. Several environmental factors such as air temperature, drought and nutrient deficiency influence the distribution of dry matter partitions [20]. In plants that experience a deficiency of N and P, the dry matter gets partitioned in the roots rather than the shoots [21].

Table 3. Dry weight partitioning of oil palm seedlings on various dosages of phosphorus fertilization

Plant Age (Months)	Organ	Treatment				
		P0	P1	P2	P3	P4
3-6	Root	0.24	0.25	0.25	0.24	0.24
	Petiole	0.29	0.29	0.31	0.30	0.30
	Leaf	0.46	0.46	0.44	0.46	0.45
6-9	Root	0.23	0.24	0.25	0.26	0.26
	Petiole	0.33	0.34	0.34	0.31	0.33
	Leaf	0.45	0.42	0.42	0.43	0.41
9-12	Root	0.28	0.35	0.27	0.23	0.45
	Petiole	0.34	0.32	0.45	0.37	0.25
	Leaf	0.37	0.33	0.29	0.40	0.31

Partitioning of dry matter of oil palm seedlings at various doses of P fertilization can be seen in Table 3. The percentage of dry matter partitioned in all treatments showed similar partitioning. Deficiency or excess of P does not affect the dry matter allocation in oil palm seedlings. The allocation was more affected by P, K, and Mg equilibrium. Although total dry matter production is the same in P, K, and Mg deficient plants, P-deficient plants partition a much greater proportion of dry matter into the roots [22].

3.2 Growth model simulation

The dry weight results of roots, petioles, leaves, and total oil palm seedlings at various doses of P fertilization can be seen in Table 4 and Figure 2. An increase in P fertilization increased the dry weight of oil palm seedlings. A sufficient level of P causes an increase in root dry weight and thus increases nutrient absorption and growth [6]. Pembengo *et al.* [23] also stated that an increase in P fertilization did not increase the LUE values of sugarcane but increased the dry weight of sugarcane stalks. Furthermore, increasing the amount of P fertilization in high quantities reduces seedlings' dry weight because increasing P availability in the soil can limit the absorption of other nutrients [24]. Nutrient balance must be applied to avoid antagonistic interactions that can upset or suppress the uptake of other nutrients and affect plant growth and development [6].

Tabel 4. Dry weight of organs and total seedlings on various dosages of P fertilization

Plant Age (Months)	Treatment	Organ and Total Seedling Dry Weight (g)							
		Root		Petiole		Leaf		Total	
		actual	model	actual	model	actual	model	actual	model
6	P0	8.0	7.1	9.7	8.6	15.7	13.9	33.4	29.6
	P1	12.4	12.7	14.5	14.8	22.9	23.5	49.7	51.1
	P2	11.0	11.7	13.3	14.1	19.5	20.7	43.7	46.5
	P3	10.3	9.8	13.0	12.3	20.0	19.0	43.2	41.0
	P4	10.8	9.9	13.3	12.2	20.4	18.8	44.5	40.9
9	P0	47.2	48.3	66.2	67.8	93.0	95.3	206.4	211.4
	P1	46.2	52.9	61.9	70.9	81.9	94.0	190.0	217.8
	P2	55.6	56.2	74.1	74.9	95.4	96.5	225.2	227.6
	P3	56.9	53.3	70.0	65.6	97.9	91.7	224.9	210.6
	P4	47.4	51.9	59.0	64.7	77.1	84.5	183.4	201.1
12	P0	122.1	130.7	147.3	157.8	160.7	172.1	430.1	460.6
	P1	304.2	283.0	304.9	283.6	332.3	309.1	941.4	875.7
	P2	233.9	234.1	375.7	376.0	282.9	283.2	892.5	893.3
	P3	231.0	206.6	348.1	311.3	394.9	353.1	974.1	870.9
	P4	337.4	333.5	224.4	221.8	291.4	288.0	853.2	843.3

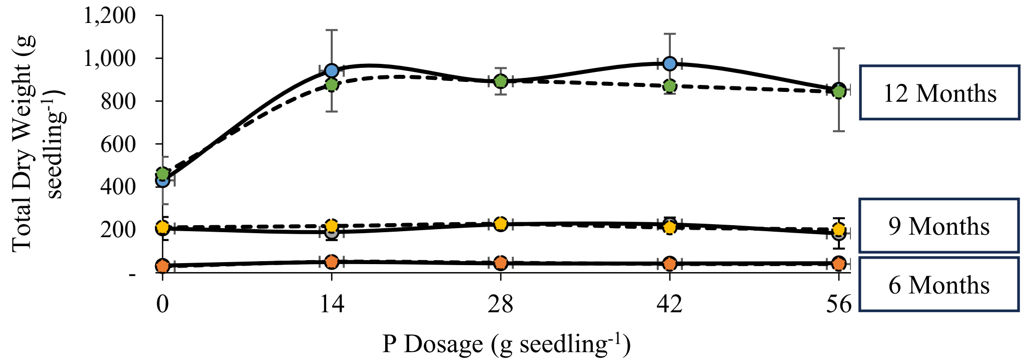

Figure 2. Simulated (---) and actual measurement (—) of total dry weight of oil palm seedling at 6. 9 and 12 months.

3.3 Phosphorus uptake simulation

P partitioning at various levels of P fertilization is shown in Table 5. At the end of the main nursery (12 months), the highest accumulation of P was found in the roots. Regarding P accumulation, Mohidin *et al*. [6] stated that element P was partitioned the most in the roots and this accumulation led to an increase in the shoot/root ratio. The uptake and availability of nutrients in the soil through fertilization affected seedling growth, biomass accumulation and partitioning of oil palm seedlings.

In Table 6 and Figure 2. it can be seen that an increase in P fertilization increases the P uptake of oil palm seedlings. Increasing the provision of P increases the availability of P. Tan et al. [25] showed that having more P fertilizer available to some plants resulted in higher phosphate uptake efficiency. Goh, and Chew [26] stated that P absorption increased by >300% compared to P uptake in standard fertilized oil palm when P fertilizer was given two times the standard dose. In addition, P levels in plants affect the amount of P that plants can absorb from fertilizers [27].

Tabel 5. Partition of P in oil palm seedlings at various dosages of phosphorus fertilization

Plant Age (months)	Organ	Treatment				
		P0	P1	P2	P3	P4
3-6	Root	0.25	0.23	0.27	0.23	0.18
	Petiole	0.39	0.40	0.34	0.38	0.42
	Leaf	0.37	0.37	0.40	0.38	0.40
6-9	Root	0.27	0.22	0.26	0.27	0.24
	Petiole	0.24	0.39	0.39	0.36	0.39
	Leaf	0.49	0.40	0.35	0.37	0.37
9-12	Root	0.48	0.52	0.37	0.40	0.60
	Petiole	0.16	0.14	0.22	0.14	0.06
	Leaf	0.36	0.34	0.40	0.46	0.34

Table 6. Organ and total phosphorus uptake of oil palm seedling at various dosages of phosphorus fertilization

Plant Age (Months)	Treatment	Organ and Total Seedling Dry Weight (g)							
		Root		Petiole		Leaf		Total	
		actual	model	actual	actual	actual	model	actual	model
6	P0	0.02	0.02	0.03	0.03	0.03	0.03	0.09	0.08
	P1	0.03	0.03	0.06	0.05	0.05	0.05	0.14	0.13
	P2	0.03	0.02	0.05	0.04	0.04	0.03	0.11	0.09
	P3	0.03	0.02	0.04	0.03	0.04	0.03	0.11	0.09
	P4	0.02	0.02	0.05	0.04	0.04	0.04	0.11	0.10
9	P0	0.13	0.13	0.13	0.13	0.22	0.23	0.48	0.49
	P1	0.11	0.05	0.20	0.10	0.20	0.10	0.51	0.25
	P2	0.16	0.08	0.22	0.12	0.21	0.11	0.59	0.31
	P3	0.17	0.08	0.24	0.11	0.24	0.11	0.65	0.29
	P4	0.13	0.15	0.22	0.25	0.22	0.24	0.57	0.63
12	P0	0.28	0.31	0.18	0.19	0.34	0.37	0.80	0.87
	P1	0.82	0.54	0.40	0.26	0.66	0.43	1.88	1.23
	P2	0.54	0.52	0.45	0.43	0.74	0.72	1.73	1.67
	P3	0.67	0.60	0.42	0.37	0.83	0.74	1.92	1.71
	P4	0.98	0.99	0.31	0.32	0.70	0.71	1.99	2.01

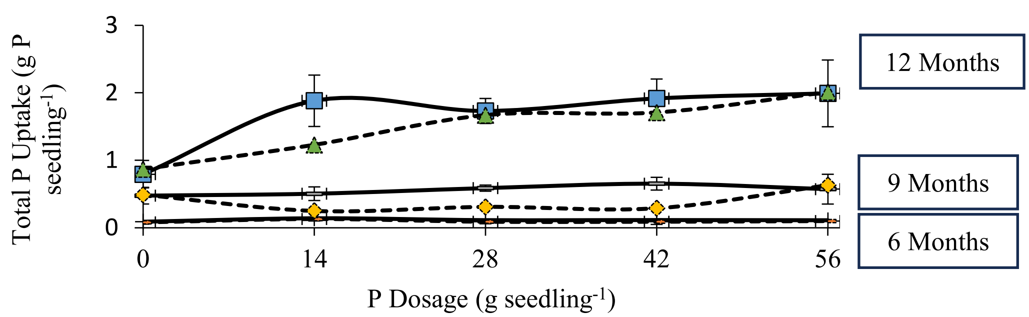

Figure 3. Simulated (---) and actual measurement (—) of total P uptake of oil palm seedling at 6, 9 and 12 months

3.4 Model validation

Based on the validation results, the model built could predict most of the oil palm dry weight and P nutrient uptake at various fertilizer doses. This validation was based on the t-test results between the average actual measurements in the field, most of which (26 out of 30 parameters) were not significantly different from the model simulation results (Table 7). According to Brisson *et al*. [28],

Table 7. Dry weight and N-uptake Paired T-Test results of actual measurement and model simulation

Parameter	Treatment				
	P0	P1	P2	P3	P4
Growth model					
Dry weight 6 MAP					
t	1,01	0,36	0,55	0,48	0,58
$t_{0.05}$	2,31	2,31	2,31	2,31	2,31
result	ns	ns	ns	ns	ns
Dry weight 9 MAP					
t	0,23	1,85	0,35	1,09	0,62
$t_{0.05}$	2,31	2,31	2,31	2,31	2,31
result	ns	ns	ns	ns	ns
Dry weight 12 MAP					
t	0,69	0,86	0,03	1,85	0,13
$t_{0.05}$	2,31	2,31	2,31	2,31	2,31
result	ns	ns	ns	ns	ns
Parameter	**Treatment**				
	P0	**P1**	**P2**	**P3**	**P4**
N uptake Model					
P-uptake 6 MAP					
t	1,01	1,10	2,01	2,05	0,75
$t_{0.05}$	2,31	2,31	2,31	2,31	2,31
result	ns	ns	ns	ns	ns
P-uptake 9 MAP					
t	0,28	6,32	15,34	9,63	0,65
$t_{0.05}$	2,31	2,31	2,31	2,31	2,31
result	ns	*	*	*	ns
P-uptake 12 MAP					
t	0,92	4,28	0,83	1,80	0,09
$t_{0.05}$	2,31	2,31	2,31	2,31	2,31
result	ns	*	ns	ns	ns

the plant simulation model can be considered valid within an error range of 15%. The growth and nutrient uptake model can then be used as a technical tool for decision-making in agronomy.

4. Conclusions

It can be concluded from this study that modeling of oil palm nutrient uptake of P in the main nursery was able to simulate oil palm nutrient uptake as measured in the field. The simulated dry weight simulation results were in the range of standard deviation values of the average measurements in the field. The nutrient uptake simulation model is a valid tool that can be used to plan the optimal fertilization of oil palm seedlings in the main nursery.

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