Determination of Nitrogen Fertilizer Requirement for Four-Year-Old Oil Palm

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ABSTRACT— ***Fertilization is one of the methods to increase the productivity of oil palm in Indonesia, especially in smallholder plantations. The aim of this research were to study the effect of nitrogen (N) fertilizer and to determine the optimum N fertilizer rate for a four-year-old oil palm (1st mature oil palm). This study was conducted at IPB-Cargill Teaching Farm of Oil Palm, Jonggol, Bogor, Indonesia from April 2016 to March 2017. This experiment used one factor of randomized complete block design that consisted of five treatment levels, three replications and five palm samples. The treatment levels were 0, 725, 1450, 2175 and 2900 g N palm^{-1} year^{-1}. Nitrogen fertilizer significantly affects the palm height, trunk girth, leaf area, leaf greenness, stomata density, leaf N content, bunch number, and productivity of fresh fruit bunches (FFB), but didn't affect the frond length and average bunch weight on 1st mature oil palm. The optimum N fertilizer rate was 1632 ± 207 g N palm^{-1} year^{-1} for four-year-old oil palm (1st mature oil palm). Application of N fertilizer with application rate of 1632 g N palm^{-1} year^{-1} could increase the productivity by 35% compared to control (4.9 ton FFB ha^{-1} year^{-1} higher than control).***

Keywords— Bunch number, leaf greenness, palm height, productivity, stomata density, trunk girth

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1. INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a plantation commodity that has an important role for the economy in Indonesia [1]. However, the productivity of *crude palm oil* (CPO) in smallholder plantations in 2015 is still very low (3.212 tons ha^{-1}) [2,3]. Fertilization with single inorganic fertilizer is one effort that can be done to increase the growth [4,5] and productivity of oil palm [6]. The loss of N nutrient is very high in the soil (4-17%) which can be caused by evaporation, runoff, losses through Al, Fe, and clay minerals absorption [7]. Provision of nutrients in the soil through fertilization must be balanced that is adjusted to the needs of the plant [8]. The oil palm is a perennial crop that bears fruit of the year so that the nutrient needs of nitrogen (N) are high enough during its lifetime [9]. Nitrogen plays an important role for oil palm in the physiological processes, growth, and yield [10]. Nitrogen is a major constituent of proteins, nucleic acids, phytohormones, coenzymes, secondary metabolites, and chlorophyll [11]. Nitrogen affects leaf production rate [12], leaf area, leaf greenness, net assimilation rate [13], leaf chlorophyll content [14], plant height, trunk girth, and stomata density [4].

Nitrogen is needed by plants in large quantities about 1-5% of total dry matter [11]. Lack of N can cause disruption to the physiological processes and barriers of oil palm growth so that the productivity is not maximal. In contrast, the excessive N application rate may cause oil palm growth to be inhibited due to antagonistic interactions between several nutrients [12], greenhouse gas (GHG) emissions, soil and water pollution [15,10], increase in production costs [9] and decrease in soil fertility [16]. The use of excessive inorganic fertilizers especially N is the largest contributor of GHG emissions in the input of oil palm cultivation [17,18]. Fertilization is one of the largest variable costs in the palm oil industry. The incurred cost for fertilization is 60% of the overall crop maintenance costs [19]. Increasing the efficiency of fertilization is very important to be done through the concept of nutrient balances and nutrient uptake associated with plant age, growth, and production [20]. Determination of optimum N rate is needed to know the optimal nutrient uptake efficiency for oil palm plantation and to maintain the environmental quality due to the residue of inorganic fertilizer application [21,22,23]. The objectives of this research are to study the effect of N application rates for morphology, physiology, and yield as well as to determine the optimum rate of N fertilizer for four-year-old oil palm (1st mature oil palm).

2. MATERIALS AND METHODS

This study was conducted from March 2016 to March 2017 at IPB-Cargill Teaching Farm, Jonggol, Bogor, West Java, Indonesia. Soil and leaves analysis was carried out in the Laboratory of Soil Science and Land Resources, while stomata density was observed in the Microtechnical Laboratory, Department of Agronomy and Horticulture, Bogor Agricultural University. This study used Tenera oil palm that aged four years old (1st mature oil palm), Dami Mas variety as plant materials and used urea fertilizer (46% N) as N source. The experiment used a randomized complete block design with one factor that consisted of five levels of treatment and three replications. The treatment levels were 0, 725, 1450, 2175 and 2900 g N palm^{-1} year^{-1}. The experiment consisted of 15 experimental units and each experimental unit consisted of five palm samples so that the total samples was 75 palms.

Soil analysis was conducted in March 2016 before the first fertilizer application. Soil sampling was done by composite method and taken with 30 cm depth by using soil drill (auger). Observations were done on morphological, physiological, and yield responses. The observation of morphological response was done to palm height, trunk girth, frond length, and leaf area. The palm height was measured from the base of the stem above the soil surface to the highest tip of the palm canopy using a haga altimeter. The trunk girth was measured about 25 cm from the soil surface using a caliper. The frond length was measured on frond 17. The leaf area was calculated by measuring the length of the leaflet, the width of the leaflet and the number of leaflets on frond 17.

Observation of physiological responses was done on the variables of stomata density, leaf greenness level, and leaf N content on frond 17. The stomata density was observed by applying clear nail polish on the lower surface of the leaf and then taken with clear tape. The stomata density was observed using a microscope with magnification 40 x 10. The leaf greenness level was measured using SPAD-502 plus chlorophyll meter. The leaf N content was observed by taking samples of three leaflets of the right and left on frond 17 and then was analyzed the nitrogen content. Observation of yield response was done on the number of fresh fruit bunch (FFB) and productivity. The number of FFB was observed by counting the FFB that have been matured. The productivity was calculated by weighing the FFB and converting it to units of hectares. Data were statistically analyzed at significant level $P < 0.05$ using analysis of variance (ANOVA). If the ANOVA showed significant effect, data analysis was continued by orthogonal polynomial test and regression analysis.

3. RESULTS AND DISCUSSIONS

3.1 *Soil and climate condition*

Based on the criteria [24], soil physical and chemical properties in the study site indicated that the soil texture is clay with composition 15.64% sand, 27.21% dust, and 57.15% clay, pH (H_2O) classified as acid (4.51), C-organic was considered moderate (2.40%). N-total was considered moderate (0.29%), P-available was considered low (6.94 ppm). Exchangeable bases such as Ca was considered moderate (6.23 cmol(+) kg^{-1}), Mg was considered moderate (1.54 cmol(+) kg^{-1}), K was considered low (0.28 cmol(+) kg^{-1}), Na was considered low (0.12 cmol(+) kg^{-1}). Cation exchange capacity (CEC) was considered high (26.93 cmol(+) kg^{-1}) and base saturation (BS) was considered low (30.34%). Exchangeable Al and H were 7.72 cmol(+) kg^{-1} and 1.08 cmol(+) kg^{-1}, respectively. Base saturation is closely related to pH in the soil [25]. The low of soil pH in the study site indicated that the high complex of acid cations such as Al^{3+} and H^+ was compared to base cations such as K^+, Ca^{2+}, Mg^{2+}, and Na^+ so that the base saturation was low. Soil conditions with high acid cations cause P-available to be low because P is bound by Al and Fe complex [26].

Climatic condition in the study site over 12 months period from April 2016 to March 2017 showed that rainfall was 3211 mm per year. The highest rainfall occurred in November 2016 with rainfall of 489 mm, while the lowest rainfall occurred in September 2016 with rainfall of 124 mm. Rainfall condition was evenly distributed over the year and rainy days was over 123 days. There was no dry month in the study site based on Schmidt-Ferguson climatic classification. The average temperature ranges from 26 ºC to 31 ºC per month with the highest temperature of 32 ºC and the lowest temperature of 26 ºC for a year. The average humidity was 79% per month with the highest humidity of 80% and the lowest humidity of 78%.

3.2 *Morphological responses*

Application of N fertilizer affected the palm height, trunk girth, and leaf area, but didn't affect frond length on 1st mature oil palm (Table 1). Application of N fertilizer quadratically affected the palm height at 39, 42, 45, and 48 months after planting (MAP). The highest response of palm height was found in the treatment of N fertilizer with application rate of 1450 g N palm^{-1} year^{-1}. Application of N fertilizer with application rate of 1450 g N palm^{-1} year^{-1} was able to increase palm height by 13.16% compared to control at 48 MAP. The excess application of N fertilizer could lead to a decrease in the palm height growth.

Application of N fertilizer quadratically affected the trunk girth at 39, 42, 45, and 48 MAP. The highest increase in trunk girth was in the treatment with application rate of 1450 g N $palm^{-1}$ $year^{-1}$. Application of N fertilizer with application rate of 1450 g N $palm^{-1}$ $year^{-1}$ was able to increase trunk girth by 6.67% compared to control at 48 MAP. The trunk is an active sink compared to other organs such as midrib and leaves [27] so that application of N fertilizer with optimum rate has significant effect on the growth of the trunk girth. This indicated that N element was still needed in sufficient quantities of the growth of the trunk eventhough the oil palm has entered the production period (mature oil palm).

Table 1: Morphological responses of 1st mature oil palm to N application rates

N application rates (g N $palm^{-1}$ $year^{-1}$)	Age of palm			
	39 MAP	42 MAP	45 MAP	48 MAP
	Palm height (m)			
0 (control)	7.02	7.23	7.41	7.52
726.25	7.45	7.75	8.09	8.45
1452.5	7.52	7.83	8.17	8.51
2178.75	7.36	7.68	7.99	8.23
2905	7.07	7.33	7.57	7.79
F-value ^	5.27*	5.49*	7.30**	8.28**
Response pattern ¢	Q**	Q**	Q**	Q**
	Trunk girth (cm)			
0 (control)	260.6	266.6	272.7	275.9
726.25	277.5	282.3	286.6	291.8
1452.5	279.3	283.4	291.6	294.3
2178.75	276.6	281.7	289.2	291.5
2905	275.6	280.9	284.1	288.2
F-value ^	7.39**	13.58**	9.05**	14.73**
Response pattern ¢	Q**	Q**	Q**	Q**
	Frond length (cm)			
0 (control)	482.4	515.8	552.8	584.5
726.25	497.4	532.4	565.7	595.2
1452.5	501.8	529.6	556.9	591.9
2178.75	500.9	527.3	563.1	592.5
2905	497.7	523.8	562.4	589.6
F-value ^	0.73^{ns}	1.25^{ns}	0.44^{ns}	0.28^{ns}
	Leaf area of frond 17 (m^2)			
0 (control)	4.84	5.21	5.39	5.55
726.25	5.03	5.53	5.84	6.07
1452.5	5.45	5.57	5.92	6.15
2178.75	5.42	5.56	5.78	5.94
2905	5.09	5.46	5.66	5.81
F-value ^	3.19^{ns}	1.69^{ns}	4.18*	6.16*
Response pattern ¢	-	-	Q**	Q**

Notes: ^ : ANOVA, ¢: orthogonal polynomial test; **: significant effect at level P<0.01, *: significant effect at level P<0.05, ns: not significant, Q: quadratic response pattern.

Application of N fertilizer didn't affect the frond length at 39, 42, 45, and 48 MAP. Application of N fertilizer quadratically affected the leaf area on 1st mature oil palm at 45 and 48 MAP, but didn't have significant effect at 39 and 42 MAP. Nitrogen plays an important role in the photosynthesis process. The wider leaf surface will increase the amount of light that can be captured by palm so that the photosynthesis rate will also increase [28]. A well photosynthesis process will increase the amount of assimilate formed so that the yield will also increase [29,10]. However, the more assimilates were transferred to the trunk and fruits so that the growth of trunk and fruits had a rapid response to N fertilizer compared to the leaf area. The response of leaf area to the treatment of the N application rate started to show significant effect when the plant entered the age of 45 and 48 MAP. The availability of N nutrient in the soil up to the optimum rates would give maximum response to the leaf area. A significant decrease in the leaf area on the highest N application rate indicated that the N rate exceeds the capacity of plant to absorb N element in the soil. The excessive N application rates will decrease the leaf area of oil palm [13].

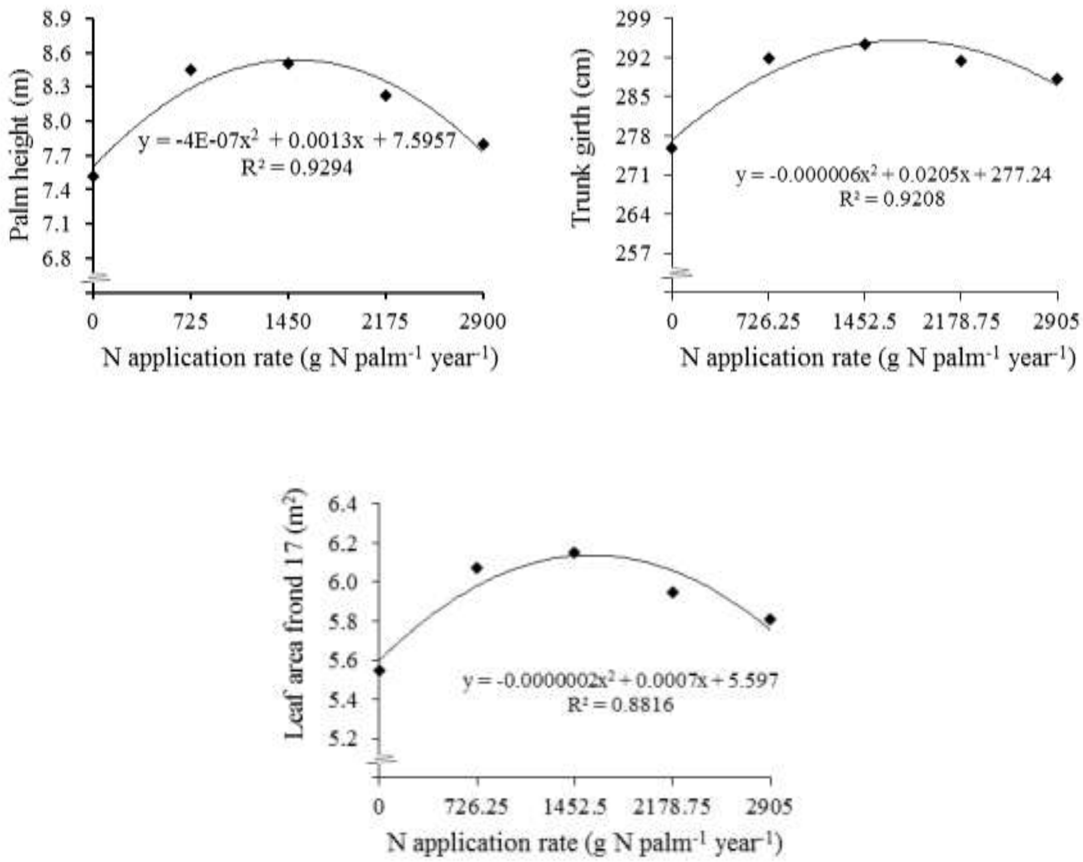


Figure 1: Regression equation and response curve of palm height (A), trunk girth (B), and leaf area of frond 17 (C) to N application rates at 48 MAP

3.3 Physiological responses

Application of N fertilizer affects the leaf greenness level, stomata density, and N content in the leaf tissue (Table 2). Application of N fertilizer quadratically affected the stomata density at 42 MAP and 48 MAP. Stomata density plays an important role in plant physiology processes such as photosynthesis and transpiration [30]. High stomata density will help increase plant activity for CO_2 and O_2 gas exchange [4]. In addition, high stomata density will also increase the rate of plant transpiration [31]. Increasing the rate of transpiration accompanied by sufficient water availability would increase the uptake of plant nutrients through mass flow. Stomata density and leaf chlorophyll content could optimally affect the rate of photosynthesis so that growth and crop production increased.

Nitrogen enhanced the leaf greenness level on 1st mature oil palm at 48 MAP. The leaf greenness response increased with the higher N application rate applied up to 2 905 g N palm^{-1} year^{-1}. The leaf greenness measurements of oil palm using SPAD-502 chlorophyll meters can be used as an indicator to estimate chlorophyll content and N status in the leaves. Higher leaf greenness indicates that the chlorophyll contained in the leaves is also higher [32]. Nitrogen is one of the nutrients that play a role in the synthesis of chlorophyll so that N application rates with appropriate rates can increase the leaf greenness and the chlorophyll content on oil palm [33].

The leaf of frond 17 can be used as an indicator of nutrient content of the oil palm [34]. Application of N fertilizer showed a significant response to the N content in the leaf tissue. Table 2 showed that N status in the leaf tissue was above the critical nutrient level that nutrient status was classified as excess. This indicated that N was absorbed by palm exceeding the optimum limit or the adequacy of palm nutrients. However, growth constraints and production decline began to be seen with the N treatment with application rate of 2178.75 g N palm^{-1} year^{-1} and 2905 g N palm^{-1} year^{-1}

which showed the value of N content in the leaf of 3.18%. The plant allocates a considerable amount of N in leaves so that N content is quite high in leaves [35]. Nitrogen is needed in considerable amounts for plants especially in the photosynthesis process so that N is an important element as a limiting factor for plant growth [36,37]. The optimum N content in the leaf for young oil palm (<6 years) ranged from 2.6% to 2.9% [12]. The optimum N content will increase the photosynthesis rate of plant. However, the excess N content in plant tissues will cause stunted growth and crop production. Nitrogen fertilization with excessive rates causes the disorders of nutrient uptake by plant roots and nutrient balance in plant tissues [38].

Table 2: Physiological responses of 1st mature oil palm to N application rates

N application rates (g N palm^{-1} year^{-1})	Stomata density (stomata mm^{-2})		Leaf greenness (SPAD value)		Leaf N content (%)
	42 MAP	42 MAP	42 MAP	48 MAP	48 MAP
0 (control)	189.6	189.6	72.30	73.65	2.87
726.25	216.1	216.1	73.29	74.56	3.11
1452.5	251.3	251.3	73.83	76.01	3.16
2178.75	211.2	211.2	74.29	76.91	3.18
2905	199.7	199.7	74.60	77.04	3.18
F-value ^	9.58**	36.75**	3.00^{ns}	6.02*	4.08*
Response pattern ¢	Q**	Q**	-	L**	L**

Notes: ^ : ANOVA, ¢: orthogonal polynomial test; **: significant effect at level *P*<0.01, *: significant effect at level *P*<0.05, ns: not significant, Q: quadratic response pattern, L: linear response pattern.

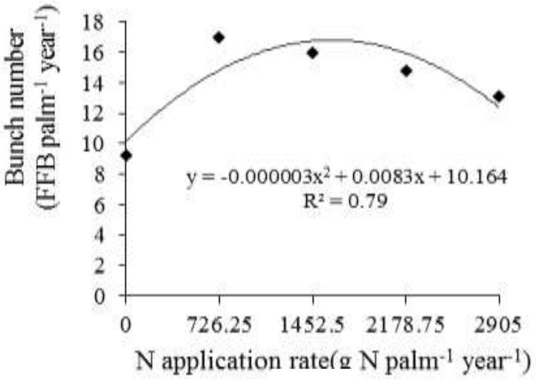
3.4 Yield responses

Application of N fertilizer affected the variables of bunch yield such as bunch number and productivity, but didn't affect the average bunch weight (Table 3). The bunch number and productivity showed a quadratic response pattern to application of N fertilizer up to 2 905 g N palm^{-1} year^{-1}. Nitrogen is one of the important elements of amino acid, amide, protein, and nucleotide structure and plays an important role in the process of chlorophyll formation [39]. The assimilates are transported to the organs such as root, stem, leaf, and fruit. The optimum chlorophyll content increase the photosynthesis rate and the assimilates formation so that the yield increase [10].

Table 3: Yield responses of 1st mature oil palm to N application rates

N application rates (g N palm^{-1} year^{-1})	Bunch number (FFB palm^{-1} year^{-1})	Average bunch weight (kg FFB^{-1})	Productivity (ton FFB ha^{-1} year^{-1})
0 (control)	9.2	10.6	13.0
726.25	17.0	9.7	20.9
1452.5	16.0	9.1	19.0
2178.75	14.8	8.9	17.8
2905	13.1	9.2	15.7
F-value ^	15.25**	1.51^{ns}	10.43**
Response pattern ¢	Q**	-	Q**

Notes: ^ : ANOVA, ¢: orthogonal polynomial test; **: significant effect at level *P*<0.01, ns: not significant, Q: quadratic response pattern.



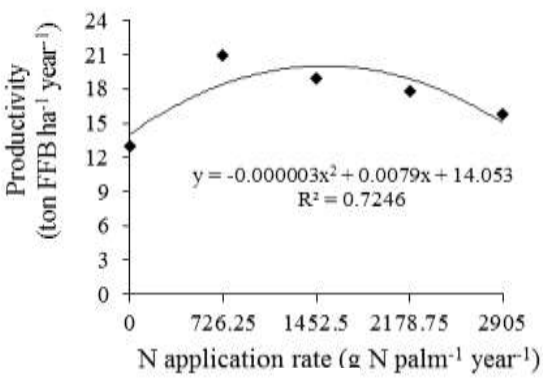


Figure 2: Regression equation and response curve of bunch number (A) and productivity (B) to N application rates on four-year-old oil palm (1st mature oil palm)

3.5 Determination of N fertilizer requirement

A quadratic function that was generated from the observed variables could be used to determine the optimum N application rate by differentiating the regression equation. The response curve represented the amount of N nutrients that could be absorbed optimally by plants and used in metabolic processes. The optimum rate of N fertilizer in this study was determined based on morphological and yield variables that quadratically affected up to 48 MAP. The optimum rate of N fertilizer for four-year-old oil palm (1st mature oil palm) in this study was obtained by 1632 ± 207 g N palm^{-1} year^{-1}. The optimum N application rate was expected to obtain maximum yield. However, application of N fertilizer over the rate range would inhibit palm growth and yield.

Table 4: Regression equations and N optimum rates on four-year-old oil palm (1st mature oil palm)

Variables	Age of palm (MAP)	Regression equations	R^2	Optimum rates (g N palm^{-1} year^{-1})
Palm height	39	$y = -0.0000002x^2 + 0.0007x + 7.0442$	0.97	1750
	42	$y = -0.0000003x^2 + 0.0008x + 7.2609$	0.98	1333
	45	$y = -0.0000003x^2 + 0.001x + 7.4533$	0.97	1667
	48	$y = -0.0000004x^2 + 0.0013x + 7.5957$	0.93	1625
Trunk girth	39	$y = -0.000005x^2 + 0.0198x + 262.34$	0.88	1980
	42	$y = -0.000005x^2 + 0.0179x + 268.25$	0.87	1790
	45	$y = -0.000006x^2 + 0.0214x + 273.28$	0.98	1783
	48	$y = -0.000006x^2 + 0.0205x + 277.24$	0.92	1708
Leaf area of frond 17	45	$y = -0.0000002x^2 + 0.0006x + 5.4252$	0.91	1500
	48	$y = -0.0000002x^2 + 0.0007x + 5.597$	0.88	1750
Bunch number	48	$y = -0.000003x^2 + 0.0083x + 10.164$	0.79	1383
Productivity	48	$y = -0.000003x^2 + 0.0079x + 14.053$	0.72	1317
Average				1632 ± 207

Notes: MAP: months after planting.

4. CONCLUSIONS

Nitrogen plays an important role for the physiology processes, growth, and yield on four-year-old oil palm (1st mature oil palm). Nitrogen fertilizer affects palm height, trunk girth, leaf area, leaf greenness, stomata density, N content in the leaf, bunch number, and productivity, but don't affect frond length and average bunch weight on four-year-old oil palm (1st mature oil palm). The optimum N fertilizer rate is 1632 ± 207 g N palm^{-1} year^{-1} for four-year-old oil palm (1st mature oil palm). The productivity of oil palm increases by 34.89% on the N treatment with fertilizer application rate of 1632 g N palm^{-1} year^{-1} (4.9 tons FFB ha^{-1} year^{-1} higher than control).

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