Australian Journal of Crop Science

AJCS

Aust J Crop Sci. 19(09):928-933 (2025) | https://doi.org/10.21475/ajcs.25.19.09.p25

ISSN:1835-2707

Optimization of compound NPK fertilizer dosage to enhance the productivity of 11-year-old oil palm (*Elaeis guineensis* Jacq.) trees (Mature planting year 8)

Aldi Oktavian[1], Sudradjat[2], Supijatno[2]*

[1]Magister Study Program of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor 16680, West Java, Indonesia
[2]Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor 16680, West Java, Indonesia

***Corresponding author: supijatno@apps.ipb.ac.id**

Submitted: 12/05/2025

Revised: 15/07/2025

Accepted: 25/07/2025

Abstract

Proper fertilization is a key factor in increasing the productivity of oil palm plants. However, excessive use of inorganic fertilizers is often used by farmers. This study aims to determine the optimum dose of NPK fertilizer and its effectiveness in increasing oil palm productivity. This research was conducted from November 2023 to October 2024. The study used one-factor Randomized Complete Group Design, P_0 = control, P_1 = standard fertilizer Urea 2.8 + SP-27 2.4 + KCl 3.4 + Kiserit 1.5 (kg plant^{-1} year^{-1}), compound NPK fertilizer treatment (P_2 = 3.1 kg, P_3 = 6.2 kg, P_4 = 9.3 kg, P_5 = 12.4 kg (plant^{-1} year^{-1})). Observations were made on the number of midribs, sex ratio, leaf tissue nutrient content, fresh fruit bunch weight, number of fresh fruit bunches harvested, average basket weight, productivity, and nutrient balance calculation (N, P, K) of plants. Furthermore, fertilizer effectiveness is calculated using Relative Agronomic Effectiveness. The use of compound NPK fertilizer dose (13-8-27+4MgO+0.65B) of 9.3 kg plant^{-1} year^{-1} (P_4 treatment) increases the weight of fresh fruit bunches, average basket weight and productivity of 11-year-old producing oil palm plants (TM 8), so that the optimum dose obtained quadratically is 8.42 kg plant^{-1} year^{-1}. The highest compound NPK fertilizer effectiveness value was 120.65%, meaning that it was able to increase yield 1.2 times greater when compared to the standard treatments.

Keywords: effectivity of fertilizer; NPK fertilizer; oil palm; productivity; RAE.

Abbreviations: BJR_Average Bunch Weight; BSP_Months After Fertilization; CPO_Crude Palm Oil; K_Kalium; KTK_ Cation Exchange Capacity N_Nitrogen; P_Phosphorus; PBN_State Large Plantations; PBS_Private Large Plantations; RAE_ Relative Agronomic Effectiveness; TBS_Fresh Fruit Bunches; TM_Producing Plantations.

Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a plantation crop that produces the largest vegetable oil, and is Indonesia's leading export commodity, and is used in various industries such as food, textiles, lubricants, cosmetics, soap, pharmaceuticals, and biodiesel. Palm oil is the largest contributor to the country's foreign exchange in the plantation sector. (Dianto et al., 2017). Indonesia's oil palm plantation area in 2024 is 16.8 million hectares with a total CPO production of 48.5 million tonnes. CPO productivity of smallholder oil palm plantations is 2.5 tonnes ha^{-1} year^{-1}, this is still relatively low compared to PBN 4.1 tonnes ha^{-1} year^{-1} and PBS 3.4 tonnes ha^{-1} year^{-1} (Kementerian Pertanian, 2024). This low productivity is caused by various factors, one of which is fertilisation that is not on target in terms of type of fertiliser, time, and dose, resulting in suboptimal nutrient absorption efficiency and production.

One of the efforts in increasing the productivity of oil palm plants is by targeted fertilisation. Fertilisation in plants aims to ensure the availability and balance of nutrients in the soil, so that nutrient absorption can take place optimally in accordance with the physiological needs of plants (Syarovy et al., 2025). In addition, fertilisation is also carried out due to the inability of the soil to provide the availability of nutrients that can ensure certain productivity for plants (Khalida and Lontoh, 2019). Oil palm plants require large amounts of nutrient components to achieve high production. Nutrients N, P, and K play an important role in the physiological processes, growth, and production of oil palm (Corley and Tinker, 2016). If one of these elements is deficient in the plant, the plant will experience impaired growth and production both in quality and quantity (Kurniati et al., 2022).

The fertiliser used for oil palm plants in this study is compound NPK (13-8-27 + 4 MgO + 0.65B). Compound NPK fertiliser is an alternative to increase the availability of nutrients in the soil, compound fertilisers have slow solubility (slow release) so as to increase the effectiveness and efficiency of fertilisation (Ginting et al., 2018). Compound NPK fertilisers contain some or all of the nutrients needed by plants and have the advantage that all nutrients can be applied in one fertiliser rotation. Another advantage of the application of this fertiliser is the ease of packaging, storage, delivery, and use in the field (Riyanti, 2021). Compound NPK application can increase the optimum growth of oil palm plants (Sirait et al., 2021).

The use of inorganic fertilisers that are excessive and not in accordance with the needs of the plant is still applied continuously by farmers in oil palm crops. As a result, the excessive use of inorganic fertilisers can have a negative impact on the environment and the plants themselves. This result is according to research by Dhillon et al., (2020) excessive application of inorganic fertilisers can have significant ecological consequences, including the leaching of essential nutrients from the soil and the disruption of the balance of local ecosystems due to the accumulation of chemical residues that damage soil microorganisms and groundwater quality. Therefore, an optimum dose of fertiliser is needed and in accordance with the needs of plants. The application of fertilisers that is carried out in a balanced, efficient, and effective manner in accordance with the availability of nutrients in the soil to support increased plant productivity requires proper management, namely the right type, time, place, method, and dose (Sudradjat, 2020). This study aims to obtain the optimum dose of compound NPK fertiliser (13-8-27+4MgO+0.65B) and the effectiveness of compound NPK fertiliser (13-8-27+4MgO+0,65B) towards increasing the productivity of oil palm (*Elaeis guineensis* Jacq.) eleven-year-old (TM 8) producing plants.

Results and Discussion

Sex Ratio (%)

The application of compound NPK fertiliser (13-8-27+4MgO+0.65B) had no significant effect on the sex ratio of the palms. The total sex ratio observed ranged from 18.8% to 49.3%, where there were several months where the sex ratio percentage was still relatively low, namely 8 BSP and 9 BSP (Figure 1). It is suspected that the decrease in sex ratio arises from the impact of El Nino, which affects oil palm plants in the flower differentiation phase, which occurs ±1-2 months earlier. This condition is in line with the research of Sukmawan et al., (2015), sex ratio influenced by rainfall that occurred in the previous one to two months, which plays a role in supporting plant growth. Lack of water during the generative phase can result in changes in the sex ratio of flowers, increase the risk of dropping young flowers, and cause damage to fruit bunches (Riski, 2021). Rainfall intensity and frequency of rainy days play a role in determining the sex ratio in oil palm plants, with the effect lasting for 23 months before harvest (Sukarman et al., 2022).

Optimal water availability combined with fertilisation can significantly improve oil palm growth and yield compared to fertilisation without adequate water supply during the dry season. Climate plays an important role in plant physiological processes, especially in the flower-to-fruit development and fertilisation phases. Extreme environmental stress can trigger an increase in male flower production and cause abortion in female flowers. To reduce this impact, the application of irrigation systems during the dry season is an effective solution in maintaining the balance of flower ratios and preventing excessive dominance of male flowers (Harahap et al., 2017).

Fresh Fruit Bunch Weight (kg)

The application of compound NPK fertiliser (13-8-27+4MgO+0.65B) gave results that significantly affected the weight of FFB produced at 10 BSP and 11 BSP (Table 1). Based on the results of the regression equation calculations, the optimum dose of compound NPK fertilizer was found to be 8.65 kg (plant^{-1} year^{-1}) with a TBS weight of 23.6 kg at 10 BSP and 8.62 kg (plant^{-1} year^{-1}) with a TBS weight of 29.7 kg at 11 BSP. Oil palm is a long-lived crop whose growth is strongly influenced by the availability of nutrients. Land as the main source of nutrients has a limited capacity to meet the needs of plants. To overcome this limitation, fertilisation is carried out. Fertilisation is an effort to add one or more nutrients to maintain the availability of these elements while increasing soil fertility (Khalida and Lontoh, 2019). Compound NPK fertiliser (13-8-27+4MgO+0.65B) contains macronutrients needed by plants such as N, P, and K. The elements of nitrogen, phosphorus, and potassium contained in compound NPK fertiliser (13-8-27+4MgO+0.65B) are one of the factors that affect the growth and production of oil palm fresh fruit bunches. The application of a balanced and appropriate dose of compound NPK fertiliser makes oil palm growth more optimal, resulting in fresh fruit bunches with better weight and quality (Utoyo et al., 2022).

Average Basket Weight (BJR)

The application of NPK fertiliser (13-8-27+4MgO+0.65B) gave results that significantly affected the average basket weight at 10 BSP and 11 BSP (Table 2). Based on the results of the regression equation calculations, the optimum dose of compound NPK fertilizer was found to be 8.15 kg (plant^{-1} year^{-1}) with a TBS weight of 22.5 kg at 10 BSP and 8.26 kg (plant^{-1} year^{-1}) with a TBS weight of 23.5 kg at 11 BSP.

This is because potassium is an essential macro nutrient that has an important role in various physiological processes of oil palm plants including in the synthesis of carbohydrates, proteins and improvement of fruit and seed quality and the provision of potassium fertiliser can increase photosynthetic efficiency, transport of photosynthetic products (assimilates) and synthesis of organic compounds. In addition, potassium contributes to fruit filling, fresh bunch quality, and long-term yield stability (Krisdiarto et al., 2017).

Compound NPK fertilizer (13-8-27+4MgO+0.65B) used as a slow-release fertilizer can increase crop production and fruit quality of oil palm plants. The formation of oil palm fruit bunches is strongly influenced by the absorption and distribution of potassium nutrients in the plant. This is in line with the research of Reddi et al., (2016) that adequate nutrient availability is an important factor in optimising the yield potential of oil palm plants. As the age of the plant increases, the weight of oil palm bunches increases because the process of translocation of assimilates to the fruit continues until it reaches physiological maturity. The main objective in oil palm cultivation is to achieve high production through various agronomic measures, ranging from maintenance to fertilisation. However, if fertilisation in oil palm is excessive and not as recommended, it will have a negative impact, both for the plant and the environment. Excess nutrients will cause poisoning for oil palm plants, so the optimum dose needs to be applied to fertilisation (Sudradjat, 2020).

Productivity

The application of compound NPK fertiliser (13-8-27+4MgO+0.65B) gave results that had no significant effect on oil palm productivity (Table 3). However, fertiliser application at a dose of 9.3 kg plant^{-1} year^{-1} had the highest results in increasing oil palm productivity compared to other treatments. This result is in line with research by Arifin et al., (2022) compound NPK fertilisation can increase vegetative growth, fruit bunch production, and nutrient use efficiency in oil palm *(Elaeis guineensis* Jacq.). Fertilisers are one of the main factors that determine the productivity of oil palm plants. Proper fertilisation of oil palm plants involves the use of macro and micro fertilisers in appropriate doses, applied at the right time, and with the correct application method. With an optimal fertiliser strategy, oil palm productivity can be significantly increased in terms of both quantity and quality of yield. The effect of fertilisation on oil palm production and productivity can be measured over many years (Amry et al., 2019).

Nutrient Balance (N, P, K)

The nutrient balance analysis aims to evaluate the availability of nutrients in the soil, the amount of nutrients absorbed by plants, the efficiency of fertiliser use, and the level of nutrient loss during the cultivation process (Table 4). Fertiliser efficiency in N was 59%, P was 7.4%, and K was 19.9%. The percentage of P efficiency is still relatively low, based on research by Sari et al., (2015) showing the efficiency level of compound NPK fertiliser use reached 56.16% for N, 11.06% for P, and 29.90% for K. This can occur because the low soil pH of

Table 1. Weight of TBS per plant harvested under various compound NPK treatments (13-8-27+4MgO+0.65B).

Treatment (plant^{-1}year^{-1})	Fresh fruit bunch weight (kg)						
	5 BSP	6 BSP	7 BSP	8 BSP	9 BSP	10 BSP	11 BSP
Control	25.0	15.0	21.6	23.0	16.0	13.3^{c}	21.6^{c}
Standard	18.6	13.0	25.0	23.5	16.0	19.3^{bc}	24.4^{bc}
3.1 kg	22.0	19.5	16.0	15.0	15.5	17.0^{bc}	26.6^{ab}
6.2 kg	14.0	15.3	26.0	15.0	15.0	20.2^{abc}	28.3^{ab}
9.3 kg	21.0	19.0	24.3	18.0	23.3	28.6^{a}	30.3^{a}
12.4 kg	14.8	15.0	15.0	20.2	25.0	22.4^{ab}	27.9^{ab}
Pr>f	0.436^{tn}	0.580^{tn}	0.311^{tn}	0.130^{tn}	0.247^{tn}	0.016*	0.011*
Pola respons	-	-	-	-	-	Q	Q

Notes: BSP = month after fertilization, *: significantly influential at the α 5% level, **: highly influential at the α 1% level, tn: not significantly influential, L: linear; Q: quadratic.

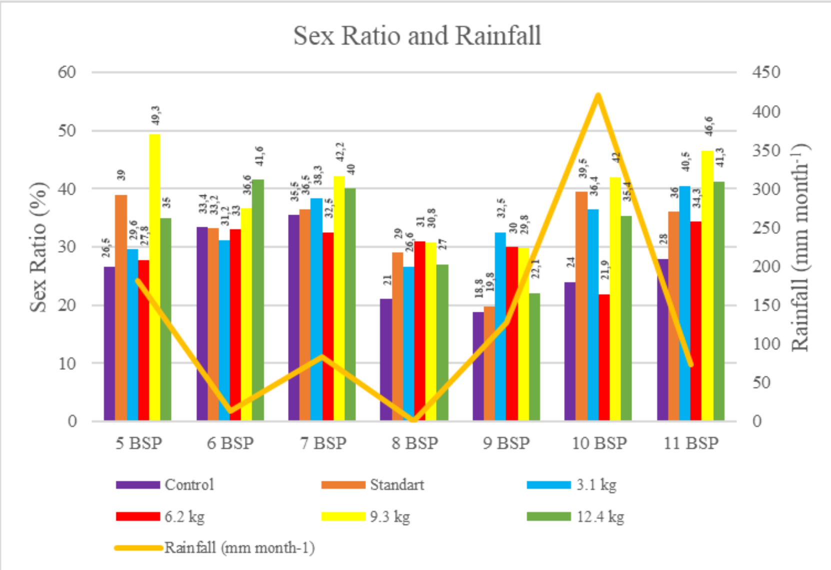

Fig 1. Graph of Sex Ratio and Rainfall at various Compound NPK Fertiliser Treatments (13-8-27+4MgO+0.65B).

Table 2. Average basket weight per plant harvested at different treatments NPK compound (13-8-27+4MgO+0.65B).

Treatment (plant^{-1}year^{-1})	Average basket weight (kg)						
	5 BSP	6 BSP	7 BSP	8 BSP	9 BSP	10 BSP	11 BSP
Controlt	18.8	17.6	20.0	22.0	17.0	10.2^{c}	15.8^{b}
Standard	16.3	10.5	28.9	27.0	20.5	22.7^{ab}	23.5^{ab}
3.1 kg	19.2	19.5	19.2	15.0	15.0	15.1^{bc}	17.8^{b}
6.2 kg	26.0	23.3	19.6	17.0	15.5	18.4^{abc}	20.8^{b}
9.3 kg	21.0	19.5	24.3	19.6	21.5	28.7^{a}	28.6^{a}
12.4 kg	25.3	17.0	15.0	17.7	18.7	16.0^{bc}	18.1^{b}
Pr>f	0.877^{tn}	0.316^{tn}	0.309^{tn}	0.134^{tn}	0.194^{tn}	0.042*	0.025*
Pola respons	-	-	-	-	-	Q	Q

Notes: BSP = month after fertilization, *: significantly influential at the α 5% level, **: highly influential at the α 1% level, tn: not significantly influential, L: linear; Q: quadratic.

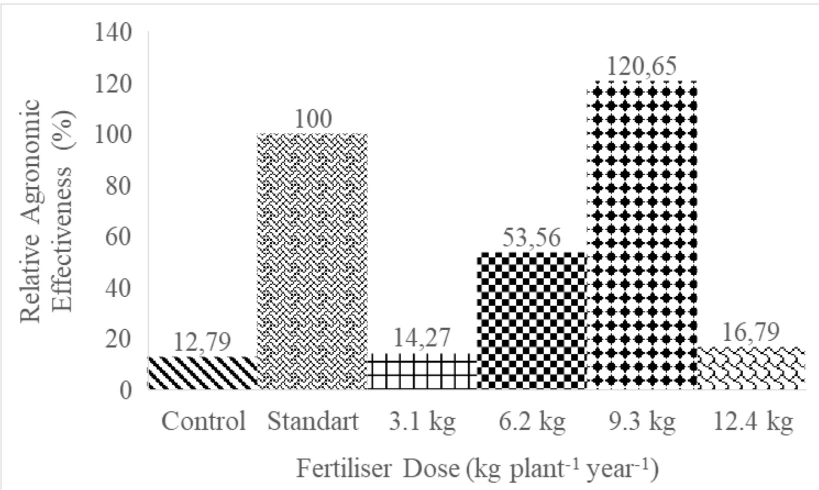

Fig 2. Relative Agronomic Effectiveness (RAE) values on various NPK Compound Fertiliser Treatments (13-8-27+4MgO+0.65).

Table 3. Productivity of oil palm under different NPK compound fertiliser treatments (13-8-27+4MgO+0.65B).

Treatment (plant^{-1}year^{-1})	Productivity (tonnes ha^{-1} year^{-1})
Control	12.79
Standard	24.70
3.1 kg	14.49
6.2 kg	19.17
9.3 kg	27.16
12.4 kg	14.79
Pr>f	0.435^{tn}

Notes: BSP = month after fertilization, *: significantly influential at the α 5% level, **: highly influential at the α 1% level, tn: not significantly influential.

Table 4. NPK nutrient balance in the treatment of 1.5 doses of fertiliser 9.3 kg (plant^{-1} year^{-1}).

Description	Nutrient content (g)		
	N	P	K
Source			
Initial soil nutrient weight (g)	25,716	812	1,570
Nutrient weight of NPK fertiliser (g)	1,209	744	2,511
Total source	26,925	1,556	4,081
Recovery nutrient			
Final soil nutrient weight (g)	28,655	1,322	2,204
Crop uptake (g):			
Root	120	6	180
Trunk	492	48	1,152
Fronds	341	33	968
Leafs	330	21	99
TBS (year)	625	125	1,000
Total Recovery nutrient (g)	1,908	233	3,399
Fertiliser Efficiency (%)	59	7.4	19.9
Fertiliser lost (%)	26.9	43.5	12.8

Table 5. Determination of the optimum dose of NPK Compound(13-8-27+4MgO+0.65B) in oil palm plants based on plant production parameters.

Variable	Age (BSP)	Regression equation	Optimum dose (kg/plant)
TBS Weight	10	$y = -0.1553x^2 + 2.6876x + 11.984$	8.65
TBS Weight	11	$y = -0.1088x^2 + 1.8764x + 21.611$	8.62
BJR Weight	10	$y = -0.2084x^2 + 3.3985x + 8.6543$	8.15
BJR Weight	11	$y = -0.1488x^2 + 2.3452x + 14.29$	8.26
Rata-rata			8.42

Notes: BSP= month after fertilisation. TBS weight= fresh fruit bunches. BJR weight= average bunch weight.

4.32 can reduce the availability of P nutrients. In soils with low pH, P tends to bind with Al and Fe to form insoluble compounds and is difficult to be absorbed by plants. Fertiliser losses based on nutrient balance for N were 26.9%, P 43.5% and K 12.8%, where the percentage of N, P, and K fertiliser losses in this study were higher than the findings reported in Sari et al., (2015) which were 31.66% for N, 33.86% for P, and 54.94% for K. Fertiliser losses refer to various processes that lead to reduced nutrient availability, such as leaching, mobilisation by soil microorganisms and plants, immobilisation through conversion of inorganic elements to organic, volatilisation due to evaporation and denitrification, and fixation through adsorption by soil colloids. This is in line with the research of Mi et al., (2023), nutrient losses from soil can occur through leaching, volatility, denitrification, and immobilisation which contribute to a decrease in the availability of nutrients for plants. Oil palms grow in tropical soils that generally have high acidity and low buffering capacity. Therefore, fertilisation plays a crucial role in supporting plant growth and maintaining optimal productivity. Compound NPK fertiliser plays an important role in providing nutrients for oil palm plants, but this is not enough to support optimal productivity. Therefore, liming is an important step to neutralise soil acidity, increase nutrient availability, and reduce the impact of Al and Fe toxicity. This is in line with Prihantoro's research (2023) that optimal lime application helps increase soil pH, increase cation exchange capacity (KTK), and improve nutrient availability for plants, thus supporting increased crop productivity.

Optimum Dose Determination

The optimum dose for twelve-year-old oil palm plants is determined based on plant production variables, based on regression equations that show a quadratic real response. Based on the results of the analysis, several plant variables show a real quadratic effect. The determination of the optimum dose of fertiliser (13-8-27+4MgO+0.65B) is presented (Table 5).

The variables that follow the quadratic pattern of compound NPK (13-8-27+4MgO+0.65B) can be used to determine the optimum dose by calculating the average of the sum of the observed variables, namely TBS weight at 10 BSP and 11 BSP, with BJR at 10 BSP and 11 BSP. Based on the regression equation of the quadratic response curve, which shows the average of the summation results on the variables of fresh fruit bunch weight and average basket weight, the optimum dose for oil palm plants to produce at eleven years of age (TM 8) is 8.42 kg plant^{-1} year^{-1}.

Relative Agronomic Effectiveness (RAE)

Relative Agronomic Effectiveness (RAE) is a measure of the effectiveness of a fertiliser. Fertiliser can be said to be effective if it has an RAE value ≥ 95%. This value indicates that the fertiliser can increase the yield more when compared to the increase in yield of the comparator fertiliser against the control. The RAE value of Compound NPK fertiliser (13-8-27+4MgO+0.65B) is presented in Figure 2.

The results of the calculation of the RAE value of testing the effectiveness of NPK fertiliser (13-8-27+4 MgO+0.65B) showed that the treatment dose of 9.3 kg plant^{-1} year^{-1} had an RAE value ≥ 95%. This shows that the use of compound NPK fertiliser (13-8-27+4MgO+0.65B) at a dose of 9.3 kg plant^{-1} year^{-1} has the highest RAE value of 120.65%, which means that the treatment is able to increase yields 1.2 times greater when compared to the standard NPK treatment and control. Based on the test, the use of compound NPK fertiliser (13-8-27+4MgO+0.65B) at a dose of 9.3 kg plant^{-1} year^{-1} is more effective in increasing productivity or higher than the control and standard fertiliser.

Materials and Methods

Time and Location

This research will be conducted from November 2023 to October 2024. IPB University Jonggol Oil Palm Education and Research Farm is located in Singasari Village, Jonggol District, Bogor Regency, West Java. The research site is located at coordinates 6° 28' 34.51" N and 107° 1' 56.02" W with an altitude of 113 m above sea, level with soil acidity (pH) averaging 4.3. Analysis of nutrient levels in leaf tissue, initial soil analysis, and final soil analysis at the Testing Laboratory of the Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University.

Materials and Tools

The materials to be used in this research are Urea, KCl, SP-27, Kiserit, compound NPK (13-8-27+4MgO+0.65B) fertiliser, plastic, and Dami Mas variety oil palm plants, which are eleven years old (TM 8). The tools used were a tractor, a wheelbarrow, a hanging scale, a digital scale, a camera, an egrek, a gancu, field Personal Protective Equipment (PPE), a bucket, a knife, and a soil drill.

Conduction of study and experimental design

This study used a completely randomised complete group design (RKLT) with one factor, namely fertiliser dose with treatment arrangement including P_0= control; P_1= standard fertiliser (Urea 2.8 kg plant^{-1}year^{-1} + SP-27 2.4 kg plant^{-1} year^{-1} + KCl 3.4 kg plant^{-1} year^{-1} + Kiserit 1.5 kg plant^{-1} year^{-1}) (Sudrajat, 2020); compound NPK fertilizer treatment (P_2= 3.1 kg plant^{-1}year^{-1}; P_3= 6.2 kg plant^{-1} year^{-1}; P_4= 9.3 kg plant^{-1}year^{-1}; P_5= 12.4 kg plant^{-1}year^{-1}). Based on the number of treatments, each treatment variation was repeated three times, resulting in a total of 18 experimental units. Each experimental unit consisted of 13 plants and 5 sample plants, resulting in a total of 234 plants.

Observation parameter and statistical analysis

Observations were made using observations on plant morphological and physiological responses, namely sex ratio (%). Plant production responses consisted of TBS weight (kg), average basket weight (kg), and TBS productivity (kg ha^{-1}). Calculate the nutrient balance (N, P, K) in plants and calculate the agronomic effectiveness of fertilisers using Relative Agronomic Effectiveness (RAE).

The research data were analyzed using Analysis of Variance (ANOVA). If the F-test results showed a significant effect (α= 5%), then an Orthogonal Polynomial Test was conducted to determine the pattern of the plant response curve to fertilization. Data processing was performed using the RStudio program. The equation of the linear model of the experimental design can be written, i.e.:

$$\mathbf{Y_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij}}$$

Description: Yij = Observation value at the fertiliser dose treatment factor and replication, μ = General mean value, τ_i = Effect of NPK 13-8-27-4MgO-0.65B fertiliser dose treatment (i = 1,2,3,4), βj = Effect of the group (j = 1,2,3), εij = Effect of experimental error on NPK 13-8-27-4MgO-0.65B fertiliser dose treatment.

Conclusion

The use of a dose of compound NPK fertiliser (13-8-27+4MgO+0.65B) of 9.3 kg plant^{-1} year^{-1} can increase TBS weight, BJR and productivity of 11-year-old oil palm plants producing (TM 8), so that the optimum dose obtained for compound NPK fertiliser (13-8-27+4MgO+0.65B) quadratically is 8.42 kg plant^{-1} year^{-1}. Fertilisation with NPK at a dose of 9.3 kg plant^{-1}year^{-1} showed the highest RAE value of 120.65%, meaning that it increased yield 1.2 times greater than the standard treatments.

Acknowledgments

Thank you for the educational and research funding assistance from the Riau Government Merit Scholarship and PT Multidaya Putra Sejahtera (Company).

Reference

Amry IM, Putri LAP, Hanafiah DS. 2019. Respon dan heritabilitas kelapa sawit (*Elaeis guineensis* Jacq.) tipe K++ dan K-- terhadap aplikasi pupuk KCl di pembibitan pre nursery. Jurnal Agroekoteknologi FP USU. 7(1): 66-71 https://doi.org/10.32734/ja.v7i1.2312

Arifin I, Hanafi MM, Roslan I, Ubaydah MU, Karim YA, Tui LC, Hamzah S. 2022. Responses of irrigated oil palm to nitrogen, phosphorus, and potassium fertilizers on clayey soil. Agricultural Water Management J. 274:107922. https://doi.org/10.1016/j.agwat.2022.107922

Corley RHV, dan Tinker PB . 2016. The Oil Palm: Fifth Edition. Oxford (UK): Blackwell Science Ltd.

Dhillon J, Eickhoff E, Aula L, Omara P, Weymeyer G, Nambi E, Oyebiyi F, Carpenter T, dan Raun W. 2020. Nitrogen management impact on winter wheat grain yield and estimated plant nitrogen loss. Agronomy J.112(1): 564-577. https://doi.org/10.1002/agj2.20107

Dianto F, Efendi D, Wachjar A. 2017. Pengelolaan panen kelapa sawit (*Elaeis guineensis* Jacq.) Pelantaran Agro Estate, Kota Waringin Timur, Kalimantan Tengah. Bul Agrohorti. 5(3):410–417. https://dx.doi.org/10.29244/agrob.5.3.410-417

Ginting EN, Rahutomo S, dan Sutarta ES. 2018. Nutrient use efficiency of several types of fertilizers on the oil palm seedling. J Pen Kelapa Sawit. 26(2): 79-90. https://doi.org/10.22302/iopri.jur.jpks.v26i2.38

Harahap IY, Sumaryanto, Taufiq C. Hidayat, Fauzi WR dan Pangaribuan Y. 2017. Production of oil palm sex inflorescence and its response on the treatment of plant exogenous hormone treatment under drought conditions. J Pen Kelapa Sawit. 25(1): 31-46. https://doi.org/10.22302/iopri.jur.jpks.v25i1.23

Kementerian Pertanian Republik Indonesia. 2024. Statistik Perkebunan Jilid I 2022-2024. Jakarta: Kementerian Pertanian RI. diunduh https://ditjenbun.pertanian.go.id/buku-statistik-perkebunan-jilid-i-2022-2024/

Khalida R, Lontoh AP. 2019. Manajemen pemupukan kelapa sawit (*Elaeis guineensis* Jacq.) studi kasus pada Kebun Sungai Sagu Riau. Bul Agrohorti. 7(2): 238-245. https://doi.org/10.29244/agrob.7.2.238-245

Krisdiarto AW, Sutiarso L, Widodo KH. Optimasi kualitas tandan buah segar kelapa sawit dalam proses panen-angkut menggunakan model dinamis. AGRITECH. 37(1):101-107 doi: http://dx.doi.org/10.22146/agritech.17015

Kurniati, Putri DA, Astina, dan Ratnasari D. 2022. The effect of adding shrimp skin waste on the quality of oil palm empty fruits compost to improve soil properties in Majene. Agrotekma J. 7 (1): 1-9 https://doi.org/10.31289/agr.v6i1.9362

Mi W, Ma Q, Cao X and Wu L. 2023. Soil fertility management for sustainable crop production. Agronomy J. 13(4): 1-2. https://doi.org/10.3390/agronomy13041026

Prihantoro I, Permana AT, Suwarto, Aditia EL, Waruwu Y. 2023. Liming effectivity in increasing sorghum (*Sorghum bicolor* (L.) Moench) growth and productivity as feed forage. JIPI. 28 (2): 297-304. https://doi.org/10.18343/jipi.28.2.297

Reddi SG, Maheswarappa HP, Chandravathi B, and Patil DR. 2016. Effect of fertigation on yield and economics of oil palm (*Elaeis guineensis* Jacq.). Farm Sci J. 29(2): 200-202. https://www.researchgate.net/publication/328851800

Riski WF. 2021. Pengaruh cekaman kekeringan terhadap fisiologi dan produksi kelapa sawit. WARTA Pusat Penelitian Kelapa Sawit. 26(3): 142-153. https://doi.org/10.22302/iopri.war.warta.v26i3.45

Riyanti. 2021. Pengaruh pemberian kompos tandan kosong kelapa sawit dan pupuk p terhadap pertumbuhan dan produksi tanaman serai. Juripol. 4(2):116-128. https://doi.org/10.33395/JURIPOL.V4I2.11113

Sari VI. Sudradjat, dan Sugiyanta. 2015. Peran pupuk organik dalam meningkatkan efektivitas pupuk npk pada bibit kelapa sawit di pembibitan utama. J Agron Indonesia. 43 (2): 153-160. http://dx.doi.org/10.24831/jai.v43i2.10422

Sirait BA, Manurung AI, Samosir OM, Marpaung RG, Nurhayati, and Manalu C. 2021. Growth palm oil seedling (*Elaeis guineensis* Jacq.) via NPK fertilization and different frequency of watering. Agronomy J. 20(1):1-8. https://doi.org/10.3923/ja.2021.1.8

Sudradjat. 2020. Kelapa Sawit: Prospek Pengembangan dan Peningkatan Produktivitas. IPB Press. Bogor.

Sukarman, Akhmad R. Saidy, Rusmayadi G, Adriani DE, Primananda S, Suwardi, Wirianata H, Fitriana CDA. 2022. Effect of water deficit of Ultisols, Entisols, Spodosols, and Histosols on oil palm productivity in Central Kalimantan. Journal of Soil Science and Agroclimatology. 19(2):180-191 http://dx.doi.org/10.20961/stjssa.v19i2.65455

Sukmawan Y, Sudradjat, Sugiyanta. 2015. Peranan pupuk organik dan NPK majemuk terhadap pertumbuhan kelapa sawit TBM 1 di lahan marginal. J Agron Indonesia. 43(3): 242–249. https://doi.org/10.24831/jai.v43i3.11251

Syarovy M, Barus ASB, Angelica Hutagalung NA, dan Fauzi WR. 2025. Teknik pemupukan tanaman menghasilkan kelapa sawit menggunakan prinsip empat tepat (4T). WARTA Pusat Penelitian Kelapa Sawit. 30(1): 23-38. https://doi.org/10.22302/iopri.war.warta.v30i1.129

Utoyo B, Usodri KS, Sukmawan Y, Arahman REP, Hamdani dan Sudirman A. 2022. Aplikasi pupuk kno_3 dan NPK pada pertumbuhan bibit kelapa sawit (*Elaeis guineensis* Jacq.) double tone di main-nursery. J Penelitian Pertanian Terapan. 22 (3): 224-231 doi: http://dx.doi.org/10.25181/jppt.v22i3.2600