Journal of Oil Palm Research Vol. 35 (4) December 2023 p. 607-615
DOI: https://doi.org/10.21894/jopr.2022.0074

DYNAMICS OF SUCROSE PHOSPHATE SYNTHASE AND FRUCTOSE BISPHOSPHATE SYNTHASE IN OIL PALMS FERTILISED WITH LOW NITROGEN [$(NH_2)_2CO$] DOSE WITH NPPT-NBPT COATING IN RED-YELLOW PODZOLIC SOIL

EKA TARWACA SUSILA PUTRA[1]*; BENITO HERU PURWANTO[2]; EKO HANUDIN[2] and TAUFAN ALAM[1]

ABSTRACT

One of the predominant deterrents of oil palm cultivation in Indonesia, especially in red-yellow podzolic soils, is nitrogen constraint, which is accelerated by heavy persistent rainfall and severe tropical temperature. This study was conducted with the objective to determine the effect of low-dose urea fertilisation with 0.12% N-(n-propyl) thiophosphoric triamide (NPPT) and N-(n-butyl) thiophosphoric triamide (NBPT) coating on the metabolic characters, the yield components, and the total yield of the oil palm. The field experiment was conducted for twelve months between November 2016 and November 2017 at the Seruyan Tengah Oil Palm Plantation, Seruyan Regency, Central Kalimantan Province, Indonesia. The experimental design utilised a single factor complete randomised block design with three blocks as repeatition. The applications consisted of the untreated one, without [$(NH_2)_2CO$], with 195 kg ha^{-1} [$(NH_2)_2CO$], 195 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT, 156 kg ha^{-1} [$(NH_2)_2CO$], and 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT. The results demonstrated that low-dose fertilisation of 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT elevated the N content of the leaf tissue, nitrate reductase activity (NRA), sucrose phosphate synthase (SPS), fructose biphosphate synthase (FBS), reducing sugar, sucrose, and invertase activity while reducing the dosage of [$(NH_2)_2CO$] by 20.00% in comparison to the high dose treatment of 195 kg ha^{-1} [$(NH_2)_2CO$].

Keywords: NBPT, NPPT, oil palm, red-yellow podzolic, urea fertiliser.

Received: 12 October 2021**; Accepted:** 8 September 2022**; Published online:** 21 November 2022.

INTRODUCTION

One of the principal plantation commodities that reinforces the Indonesian economy is palm oil (Ministry of Agriculture, 2019). Palm oil in Indonesia is predominantly cultivated in the areas that experience heavy and persistent rainfall throughout the year, without a firm dry month, and is spread over the Islands of Sumatra, Kalimantan, Sulawesi, and the West Papua region. Persistent rainfall along with soaring tropical temperature rapidly erodes the parent material, leaving the area covered with low-grade soil with poor nutrient content (Melisa *et al*., 2018; Ministry of Agriculture, 2019; Woittiez *et al*., 2017).

The dominant soil type found in the oil palm plantation area is the red-yellow podzolic (RYP) soil. It is characterised by the low nutrient and acidic cation content (Al^{2+}, Fe^{2+}, Mn^{2+}). Persistent rainfall throughout the year causes leaching of the alkaline cations and in turn accumulates the acidic cations in the soil (Putra *et al*., 2021; Rendana *et al*., 2016; Riyadi *et al*., 2020). The accumulation of acidic cations not only causes poisoning to the oil palm but also nutrients imbalance in the soil

---

[1] Department of Agronomy, Faculty of Agriculture, Universitas Gadjah Mada, 55281 Yogyakarta, Indonesia.

[2] Department of Soil, Faculty of Agriculture, Universitas Gadjah Mada, 55281 Yogyakarta, Indonesia.

* *Corresponding author e-mail: eka.tarwaca.s@ugm.ac.id*

leading to macronutrient deficiency of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) (Gafur and Putra, 2019; Nurwahyuni and Putra, 2021; Sari and Putra, 2019).

The primary macronutrient with reduced availability in the RYP soil is N. The N recurrently dissipates through several pathways such as evaporation in the form of NH_3, leaching as NO_3^-, and denitrifying to form N_2O and N_2, inhibiting its absorption efficiency at 45% and causing environmental pollution that proliferates N_2O, NH_3, and N_2 in the air and NO_3 accumulation in the water (Edy *et al*., 2020; Riyadi *et al*., 2020).

Efficient N uptake in the oil palm along with reduced priming of N fertiliser stabilises the production, thereby inducing a superior yield of the fresh fruit bunches (FFB) in comparison to the higher doses of fertiliser treatment. There are two main enzymes in the oil palm that influences the assimilation production capacity: Sucrose phosphate synthase (SPS) and fructose bisphosphate synthase (FBS). These two enzymes regulate the photosynthesis process in the dark reaction pathway (Anur *et al*., 2020; Bilska-Kos *et al*., 2020; Gesch *et al*., 2002).

One of the most used N fertilisers is urea $[(NH_2)_2CO]$. The loss of N in urea occurs through the evaporation of NH_4^+ to NH_3. Because of its chemical instability, it is prone to rapid decomposition and persistently releases NH_3. This occurs when urease activity in the soil is high and NH_4^+ is not rapidly absorbed by plants or is nitrified to nitrate (Rahman *et al*., 2019; Rasid *et al*., 2014; Sakata *et al*., 2015).

The efficiency of N uptake in RYP soil can be improved by inhibiting the urease activity in the soil (Alpandari *et al*., 2019; Liu *et al*., 2020; Zuki *et al*., 2020). Combining 75% N-(n-butyl) thiophosphate triamide ($NBPT/C_4H_{14}N_3PS$) with 25% N-(n-propyl) thiophosphate triamide ($NPPT/C_3H_{12}N_3PS$) was used at a dose of 0.12% (*w/w* to urea) has been hypothesised to impede the urease activity in the soil. The NBPT and NPPT compounds are proven to bind to the active site of urease, thereby inhibiting urea hydrolysis and minimising ammonia synthesis. This can reduce potential emissions and can lower production costs as well. Efficient application of N fertiliser, with approximately 100% absorption efficiency, has the potential to reduce almost half of the recommended dose while maintaining oil palm productivity at the same level (Dewi *et al*., 2018; Liu *et al*., 2020; Zanin *et al*., 2016).

This research is aimed to investigate the effect of low-dose $(NH_2)_2CO$ fertiliser with 0.12% NPPT and NBPT treatment on the SPS, FBS, and the yield capacity of the FFB of oil palm in the RYP soil. The results of this study will enable us to provide crucial information to the farmers, scientists and oil palm companies regarding the efficiency of using $(NH_2)_2CO$ fertiliser, especially on the RYP soil.

MATERIALS AND METHODS

Study Site

The field experiment was carried out for 12 months between November 2016 and November 2017 at the Seruyan Tengah Oil Palm Plantation, Seruyan Regency, Central Kalimantan Province, Indonesia. The experimental site consisted of RYP mineral soil. Oil palms of 10 years of maturity were selected for sampling because their productivity peaked at this age. Considering, that this research was focused on the implementation of the N fertilisers on oil palms, it was not applied at the study location for the last two years.

Experimental Design and Their Management

The experimental design utilised the randomised complete block design single factor with three blocks as the replicators. The study consisted of a total of five applications firstly the untreated one (without urea $(NH_2)_2CO$), then at 195 kg ha^{-1} of urea $[(NH_2)_2CO]$, 195 kg ha^{-1} of urea $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT, 156 kg ha^{-1} of urea $[(NH_2)_2CO]$, and 156 kg ha^{-1} of urea $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT.

The numbers sampled per treatment per block were five oil palm trees. A total of 45 oil palm trees were chosen for this analysis. The fertiliser P, K and Ca nutrients that were not treatments refer to the Indonesian Oil Palm Research Institute (2017). The fertiliser was spread in a circle slightly away from the base of the tree. Besides fertiliser application, other activities such as weed, pest and disease control were also carried out. The fertiliser dose of 227.50 kg ha^{-1} TSP, 292.50 kg ha^{-1} KCl, and 292.50 kg ha^{-1} dolomite. All the sampled trees received an equal dosage of P, K and Ca nutrients as well. The fertiliser application was carried out in November 2016.

Data Collection

In an order to record the metabolic indicators, the leaf sample of the oil palm was collected twice, that is three (February 2017) and five (April 2017) months after the fertiliser application. Leaf samples collected were mainly the leaflets located in the centre of the 17th leaf midrib of each stand. The leaf samples were pruned evenly from the left and right sides of the midrib stalk. The metabolic indicators consisted of various parameters such as the N content of the leaf tissue (King *et al*., 1992), nitrate reductase activity (NRA) (Hartiko *et al*., 1982), SPS activity (Kohler *et al*., 1988), FBS activity (Harrison *et al*., 1998), invertase activity (Arai *et al*., 1991), total sugar content (Chow and Landhausser, 2004), reducing sugar content (Takahashi *et al*., 2018) and the sucrose content (Takahashi *et al*., 2018).

The oil palm yield was based on the weight of the FFB harvested from the research site during the 10 months between February and November 2017. The FFB yields of 10 months were then converted into various observation parameters such as the average number of FFB per tree per year, average weight per FFB, FFB productivity per hectare per year and the ratio of FFB productivity between each treatment to the FFB productivity of the untreated oil palms.

Data Analysis

The parameters observed are required to be normally distributed with homogeneity assumptions before the analysis of variance (ANOVA). The data that fulfilled the assumptions were analysed using the ANOVA ($p<0.05$) and continued with the LSD-Fisher test ($p<0.05$) as a post hoc test (Hinkelman and Kempthorne, 2008; Welham *et al*., 2015). The interaction pattern amongst the observed variables was determined with the partial least square structural equation modelling (PLS-SEM) and the stepwise regression analysis (Suryanto *et al*., 2020; 2022; Widyawan *et al*., 2020). The ANOVA and the stepwise regression analysis were carried out using SAS software version 9.4 for Windows with PROC GLM and REG (SAS Institute Inc, 2013). PLS-SEM was performed using SmartPLS 3 software (Smith *et al*., 1993; Suryanto *et al*., 2022).

RESULTS AND DISCUSSION

The Effects of NBPT and NPPT as Coating for [$(NH_2)_2CO$] on the Oil Palm

Nitrogen plays a key role in plant metabolism. It is the principal component of plant protein, enzymes, amino acids, and chlorophyll. However, it is also dynamic and mobile in both the soil and the plant tissues. In the case of oil palms, the dynamic nature of N in the soil heightens the risk of its deficiency, where it rapidly converts to an inaccessible form. Therefore, to strengthen the efficiency of the N fertiliser absorption, a potential need for technological innovation is critical (Liu *et al*., 2020; Zanin *et al*., 2016; Zuki *et al*., 2020). One of them is the urease activity inhibition technology, which delays the hydrolysis of [$(NH_2)_2CO$] by overlaying a mixture of 75% NBPT + 25% NPPT as a coating in the proportion of 0.12% by weight of the fertiliser.

The incorporation of 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT remarkably elevated the N content of the leaf tissue in comparison to the other treatments (*Table 1*). The N content of oil palm leaves with 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT application was equivalent to the oil palm treated with 195 kg ha^{-1} [$(NH_2)_2CO$] without the coating. However, oil palm primed with 195 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT recorded the highest leaf N content. These results illustrate the potential reduction in the dosage of [$(NH_2)_2CO$] from 195 to 156 kg ha^{-1} in the oil palm plantations, contingent to sustain the amount of leaf N at the same level.

The coating mixture consisting of 75% NBPT + 25% NPPT in the proportion of 0.12% by weight [$(NH_2)_2CO$] inhibited the rate of fertiliser hydrolysis by the urease enzyme that suppressed the loss of N due to volatile NH_3. Since the coating material impedes the urease activity significantly, the hydrolysis process of [$(NH_2)_2CO$] occurs at a slower rate and provides the right form of available N by the plant needs, thereby increasing the absorption rate and reducing the risk of N loss (Liu *et al*., 2020; Zanin *et al*., 2016; Zuki *et al*., 2020).

Application of 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT also considerably escalated the NRA in comparison to the oil palm that was left untreated and the one that was treated with 156 kg ha^{-1} [$(NH_2)_2CO$] without the coating. The value of NRA treated with 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT was also equivalent to the oil palm administered with 195 kg ha^{-1} [$(NH_2)_2CO$] without the coating. Meanwhile, oil palms covered with 195 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT had the highest leaf NRA. Based on the results, it can be concluded that reducing the dose of [$(NH_2)_2CO$] from 195 to 156 kg ha^{-1} in oil palm while sustaining the leaf NRA at the same level is attainable.

The results indicate that the presence of coating in the form of a combination of 75% NBPT + 25% NPPT in the proportion of 0.12% by weight of [$(NH_2)_2CO$] were significantly able to maintain the NRA at the same level between the low-dose coated and the high dose without the coating. This is in line with the requirements for the leaf N content of the oil palms. Oil palms could absorb N in two forms, namely NH_4^+ and NO_3^-. However, N uptake of oil palms in the form of NO_3^- is more dominant when compared to NH_4^+ (Liu *et al*., 2020; Zanin *et al*., 2016; Zuki *et al*., 2020).

Meanwhile, in crop tissues, the most functional form of N for metabolism is NH_4^+ instead of NO_3^-. Because the N availability in the tissues is more dominated by NO_3^-, a massive conversion of the N form from NO_3^- to NH_4^+ is required, to fulfil the NH_4^+ metabolic needs. The conversion process of NO_3^- to NH_4^+ occurs through the denitrification process. The NO_3^- is reduced to NH_4^+ by an electron donor derived from the nicotinamide adenine dinucleotide (NADH). The conversion of NO_3^- to NH_4^+ is assisted by the enzyme nitrate reductase, also known as NRA (Rahman *et al*., 2019; Rasid *et al*., 2014; Sakata *et al*., 2015).

The oil palms without [$(NH_2)_2CO$] have the lowest SPS and FBS activities. The [$(NH_2)_2CO$]

with a standard dose of 195 kg ha^{-1} considerably stimulated better SPS and FBS activities than the crops that were not applied with $[(NH_2)_2CO]$ (*Table 1*). However, SPS and FBS capacities of oil palms incorporated with 195 kg ha^{-1} $[(NH_2)_2CO]$ were the same as other crops primed at a lower dose of 156 kg ha^{-1} when $[(NH_2)_2CO]$ was coated with 0.12% NPPT and NBPT. The treatment incorporating 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NBPT and NPPT also resulted in a noteworthy SPS and FBS capacity when compared to the oil palms treated with the same dose of $[(NH_2)_2CO]$ without the coating. Meanwhile, the application of 195 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT resulted in the highest SPS and FBS activities in the oil palm.

The controlling factor of sucrose metabolism in the crop tissues is the sucrose biosynthesis-related protein. Two forms are categorised under the sucrose biosynthetic enzymes, namely SPS and FBS. The SPS enzyme plays a key role in catalysing the reaction to form sucrose-6-phosphate (S6P) from the substrate fructose-6-phosphate (F6P). Meanwhile, FBS contributes to the synthesis of F6P from the fructose-1.6-bisphosphate (FBP) substrate. These two enzymes are the key enzymes in the Calvin cycle, with carbohydrates as the final product (Anur *et al*., 2020; Bilska-Kos *et al*., 2020; Gesch *et al*., 2002).

The implementation of low-dose $[(NH_2)_2CO]$ (156 kg ha^{-1}) triggered the SPS and FBS activities that were equivalent to the high doses (195 kg ha^{-1}) only if the application of low doses of $[(NH_2)_2CO]$ were coated (*Table 1*). The coating materials were a combination of 75% NBPT and 25% NPPT, with a concentration of $[(NH_2)_2CO]$ at only 0.12% by weight of the fertiliser. This was in line with the value of leaf N content and the leaf NRA which were also equivalent between oil palms treated with high doses (195 kg ha^{-1}) and the low doses (156 kg ha^{-1}) of $[(NH_2)_2CO]$, provided that at the low doses, the materials were coated.

The adequacy of N at the same level, even when primed at a lower dose of [(NH2)2CO] (156 kg ha^{-1}), was caused by the increased nutrient uptake efficiency triggered by the presence of the coating materials. The N availability will trigger the Calvin cycle, thereby modulating the performance of the SPS and the FBS activities.

The prominent efficiency of the FBS can also be characterised by reducing sugar content, its by-product. Meanwhile, the performance of SPS can be characterised by the number of products available in the form of sucrose. Total sugar is a combination of sucrose and reduced sugar. This means that the total sugar is generated from the synergy between the FBS and the SPS (Anur *et al*., 2020; Bilska-Kos *et al*., 2020; Gesch *et al*., 2002).

The untreated oil palm had the lowest production capacity for reduced sugar, sucrose, and total sugar (*Table 1*). Priming the oil palm using $[(NH_2)_2CO]$ at 195 kg ha^{-1} elevated the production capacity of reducing sugar, sucrose, and total sugar in comparison to the untreated ones. However, the production capacity of the reducing sugar, sucrose, and total sugar of oil palm applied with 195 kg ha^{-1} $[(NH_2)_2CO]$ were the same as for the other plants treated with a lower dose of 156 kg ha^{-1} when $[(NH_2)_2CO]$ was coated with 0.12 % NPPT and NBPT. Incorporation of 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT also resulted in a much better production capacity for reducing sugar, sucrose, and total sugar than oil palm manuring with $[(NH_2)_2CO]$ at the same dose without the coating.

Meanwhile, the oil palm that was treated with 195 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT was able to produce the highest reducing sugar, sucrose, and total sugar. This is in line with the high capacity of the SPS and the FBS in the oil palm primed with a lower dose of $[(NH_2)_2CO]$ (156 kg ha^{-1}) as long as the fertiliser was coated with NPPT and NBPT. The increased efficiency of the SPS and the FBS was the result of the maximum production capacity of the reducing sugar, sucrose, and total sugar.

Oil palm applied with 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT was able to produce sucrose equivalent to plants primed with 195 kg ha^{-1} $[(NH_2)_2CO]$ without the coating and much higher than other crops that were left untreated or the ones applied with 156 kg ha^{-1} $[(NH_2)_2CO]$ without the coating. The sucrose production capacity of this treatment was only inferior to the plants incorporated with 195 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT, which was indeed a much higher dose and also was evenly coated. The high sucrose production capacity at 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT enabled the plants to elevate the invertase enzyme activity. Invertase is an enzyme that converts sucrose into reducing sugars (Anur *et al*., 2020; Bilska-Kos *et al*., 2020; Gesch *et al*., 2002).

Invertase enzyme activity tends to accelerate if the cell contains an increased amount of sucrose substrate. Therefore, oil palm primed with 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT had invertase enzyme activity equivalent to 195 kg ha^{-1} $[(NH_2)_2CO]$ treatment without the coating and much higher than the untreated one or the one with 156 kg ha^{-1} $[(NH_2)_2CO]$ without the coating. This was related to the high sucrose production in the oil palm applied with 156 kg ha^{-1} $(NH_2)_2CO$ + 0.12% NPPT and NBPT. However, the invertase enzyme activity of the oil palm administered with 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT was reduced in comparison to the plants fertilised with 195 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT as the dose was far higher and both were coated evenly. In addition, the oil palm primed with 195 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT did produce significantly more sucrose when compared to 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT.

TABLE 1. THE EFFECTS OF NBPT-NPPT AS COATING FOR [$(NH_2)_2CO$] ON OIL PALM LEAF METABOLIC ACTIVITIES AT THREE MONTHS AFTER FERTILISER APPLICATION

Variables	[$(NH_2)_2CO$] fertiliser				
	Without	195 kg ha^{-1} of [$(NH_2)_2CO$]	195 kg ha^{-1} of [$(NH_2)_2CO$] + 0.12% NPPT and NBPT	156 kg ha^{-1} of [$(NH_2)_2CO$]	156 kg ha^{-1} of [$(NH_2)_2CO$] + 0.12% NPPT and NBPT
N content in the leaf tissue (%)	1.24^d	2.85^b	3.65^a	2.00^c	2.90^b
NRA (μm NO_2^- g^{-1} h^{-1})	2.32^d	3.44^b	4.00^a	2.84^c	3.50^b
SPS activity (μm sucrose mg^{-1} s^{-1})	3.22^d	5.46^b	7.20^a	4.21^c	5.78^b
FBS activity (μm fructose mg^{-1} s^{-1})	3.00^d	4.90^b	6.99^a	3.95^c	5.10^b
Reduction of sugar (%)	0.35^c	0.45^b	0.68^a	0.37^c	0.44^b
Sucrose (%)	3.00^d	4.54^b	5.64^a	3.68^c	4.62^b
Total sugar (%)	3.50^d	5.01^b	6.34^a	4.05^c	5.06^b
Invertase activity (mM fructose^{-1} mg s^{-1})	0.08^c	0.20^b	0.35^a	0.10^c	0.25^b

Note: Numbers in the same row with similar letters were not significantly different by the LSD-Fisher test ($p<0.05$).

Table 2 represents the metabolic characteristics of the oil palm five months after the fertiliser application. The trend of the leaf N content, NRA, SPS, FBS, reducing sugar content, sucrose, total sugar, and the invertase enzyme activity was in line with the characters as described in *Table 1*. All the characters in the two tables showed the same trend, whereas all the characters in the same treatment trended to be smaller than the variables as presented in *Table 1*. The oil palms are required to be treated with a fertiliser specifically at the same dose every six months due to which [$(NH_2)_2CO$] application was carried out a few rounds in a year (Gafur and Putra, 2019; Nurwahyuni and Putra, 2020; Sari and Putra, 2019).

In *Table 2*, oil palm administered with 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NBPT and NPPT sustained the leaf N levels, NRA, SPS, FBS, reducing sugar content, sucrose, total sugar, as well as the invertase enzyme activity, at an equivalent level in comparison to the plants manured with 195 kg ha^{-1} [$(NH_2)_2CO$] without coating, and for a much higher value than other plants that were not incorporated with 156 kg ha^{-1} [$(NH_2)_2CO$] without the coating. The capacity of the plants in this treatment was only inferior to the plants that were given fertiliser at 195 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT, which had a much higher dose, and both were evenly coated. This shows that NPPT and NBPT as the coating on [$(NH_2)_2CO$] could reduce the N loss and in turn, increasing the absorption efficiency. The elevated N absorption efficiency compensated for the N requirement of the oil palm due to the low dose of [$(NH_2)_2CO$] (156 kg ha^{-1}). At this dose, the adequacy of N remained equivalent to the administration of high doses (195 kg ha^{-1}), which is the standard dose for oil palm, but so far, it has been given without coating.

The FFB sampling was conducted to record the yield after three months of fertiliser application based on the presumption that the three months of fertiliser application would be sufficient to ensure that the FFB harvested was the tree's response to the applied fertiliser. Harvesting was carried out for a total of ten months. The FFB productions garnered for ten months were then converted into oil palm productivity per hectare per year (Melisa *et al*., 2018; Riyadi *et al*., 2020).

The average number of FFB per year per tree for the untreated [$(NH_2)_2CO$] treatment was only five FFB ha^{-1}, which is considerably low compared to the treated plants with the quantity of 156 kg ha^{-1} and 195 kg ha^{-1} [$(NH_2)_2CO$] (*Table 3*). Oil palm primed with 195 kg ha^{-1} [$(NH_2)_2CO$] also generated remarkably more FFB when compared to 156 kg ha^{-1} [$(NH_2)_2CO$]. However, decreasing the dose of [$(NH_2)_2CO$] from 195 kg ha^{-1} to 156 kg ha^{-1} sustained the average amount of FFB per tree per year equivalent to a higher dose considering the fertiliser was coated with 0.12% NPPT and NBPT. The treatment of 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT produced coequal amounts of FFB per stem per year in comparison to the application of 195 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT. This demonstrates that the incorporation of coatings in the form of NPPT and NBPT could substantially increase the efficiency of N uptake in the oil palm as well as indicate that even a lower dosage of the fertiliser at 156 kg ha^{-1} [$(NH_2)_2CO$] was sufficient to provide the optimal amount of FFB per tree.

TABLE 2. THE EFFECTS OF NBPT-NPPT AS COATING FOR $[(NH_2)_2CO]$ ON OIL PALM LEAF METABOLIC ACTIVITIES AT SIX MONTHS AFTER FERTILISER APPLICATION

Variables	$(NH_2)_2CO$ fertiliser				
	Without	**195 kg ha^{-1} of $[(NH_2)_2CO]$**	**195 kg ha^{-1} of $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT**	**156 kg ha^{-1} of $[(NH_2)_2CO]$**	**156 kg ha^{-1} of $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT**
N content in the leaf tissue (%)	1.20^d	2.75^b	3.42^a	1.80^c	2.81^b
NRA (µm NO_2^- g^{-1} h^{-1})	2.12^d	3.00^b	4.10^a	2.72^c	3.20^b
SPS activity (µm sucrose mg^{-1} s^{-1})	3.01^c	5.16^b	6.25^a	3.46^c	5.19^b
FBS activity (µm fructose mg^{-1} s^{-1})	2.78^d	4.30^b	5.86^a	3.35^c	4.29^b
Reduction of sugar (%)	0.30^c	0.40^b	0.59^a	0.33^c	0.42^b
Sucrose (%)	2.71^d	4.44^b	5.54^a	3.26^c	4.36^b
Total sugar (%)	3.10^d	4.88^b	6.01^a	3.70^c	4.80^b
Invertase activity (mM fructose mg s^{-1})	0.10^c	0.25^b	0.42^a	0.14^c	0.26^b

Note: Numbers in the same row with similar letters were not significantly different by LSD-Fisher test ($p<0.05$).

TABLE 3. THE EFFECTS OF NBPT AND NPPT AS COATING FOR $[(NH_2)_2CO]$ ON THE TOTAL YIELD AND ITS COMPONENTS

Variables	$[(NH_2)_2CO]$ fertiliser				
	Without	**195 kg ha^{-1} of $[(NH_2)_2CO]$**	**195 kg ha^{-1} of $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT**	**156 kg ha^{-1} of $[(NH_2)_2CO]$**	**156 kg ha^{-1} of $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT**
Total number of FFB (trunk yr^{-1})	5.00^c	13.00^{ab}	15.00^a	10.00^b	13.00^{ab}
FFB weight average (kg)	10.50^c	20.10^{ab}	21.20^a	17.40^b	20.50^{ab}
Yields (tonnes ha^{-1} yr^{-1})	15.60^c	24.50^{ab}	26.00^a	18.40^b	25.00^{ab}
Yield each treatment per Yield without $(NH_2)_2CO$	1.00^b	1.57^a	1.67^a	1.12^b	1.60^a

Note: Numbers in the same row with similar letters were not significantly different by the LSD-Fisher test ($p<0.05$).

The average weight per FFB also had a trend in line with the average FFB per tree per year. Oil palm manured with 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT increased the average weight per FFB, in comparison to the untreated trees. Application of 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT was also able to produce FFB with the same average weight as the other trees that received higher doses of 195 kg ha^{-1} $[(NH_2)_2CO]$ without or with 0.12% NPPT and NBPT coating when treated with 156 kg ha^{-1} $[(NH_2)_2CO]$ as long as the fertiliser was coated using 0.12% NPPT and NBPT. Results indicated that the application of 195 kg ha^{-1} was not essential because even the coated one gives the same average weight per FFB as the low-dose treatment of 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT (Liu *et al.*, 2020; Zanin *et al.*, 2016; Zuki *et al.*, 2020).

The oil palm productivity trend was in line with the indicators of the average number of FFB per tree per year and the average weight per FFB. Oil palm fertilised with 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT had much higher productivity than the untreated or the treated one with 156 kg ha^{-1} $[(NH_2)_2CO]$ but without the coating. Treatment with a dose of 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT also generated a productivity equivalent to a higher dose of fertiliser, namely 195 kg ha^{-1} $[(NH_2)_2CO]$ without the coating and 195 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT. This illustrated that the use of low doses of fertiliser along with the NPPT and NBPT coating $[(NH_2)_2CO]$ (156 kg ha^{-1}) not only can elevate the efficiency of N absorption but also optimally fulfils the requirements of these elements (Alpandari *et al.*, 2019; Dewi *et al.*, 2018; Liu *et al.*, 2020), coequally as growing N with the higher fertiliser dose (195 kg ha^{-1}). Thus, the productivity of oil palm at a dose of 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT was optimal and equivalent to the dose of 195 kg ha^{-1} $[(NH_2)_2CO]$ without or with 0.12% NBPT and NPPT coating. The study concludes that the lower dose of fertiliser $[(NH_2)_2CO]$ was ample for optimal productivity of the oil palm.

The productivity ratio of oil palm fertilised with 156 kg ha^{-1} $[(NH_2)_2CO]$ + 0.12% NPPT and NBPT and the trees that were left untreated with $[(NH_2)_2CO]$ was 1.60. This value was not significantly different from the fertiliser treatment ratio of 195 kg ha^{-1} $[(NH_2)_2CO]$

without or with 0.12% NPPT and NBPT coating, which had a ratio of 1.57 and 1.67, respectively (Anur *et al*., 2020; Bilska-Kos *et al*., 2020; Gesch *et al*., 2002).

The Relationship between the Metabolism Characters, the Yield Components and the Total Yield of Oil Palm

The results illustrated a notable interaction between the N metabolism and the sugar metabolism ($p<0.000$) and the yield component ($p<0.000$), while the total effect displayed that N metabolism had a considerable influence on the sugar metabolism ($p<0.000$), the yield component ($p<0.000$), and the total yield ($p<0.000$) (*Figure 1*). The conclusion of the stepwise regression analysis showed that the yield per hectare of oil palm (Y) was determined by the elevated level of N content in the leaf tissue with enhanced SPS activity and a reduction in the FBS. The regression equation was Y = 10.11 + 5.48 NC** – 3.44 FBS** + 2.78 SPS* ($R^2 = 0.993$**).

The tissue content, uptake and utilisation of N are correlated with the availability of sugar in the plants, which in turn is interlinked with the carbon assimilation that requires adequate N. The N deficiency leads to accumulation of the unstructured carbohydrates and changes the distribution of the assimilation between various plant organs (Geiger *et al*., 1999). In addition, the high N content influenced several reductions in the main sugar levels of the leaves (sorbitol, sucrose, glucose) which is interconnected to the assimilation competition due to rapid shoot growth. Furthermore, excessive use of N can reduce the carbohydrates, thereby increasing respiration, and consequently impacting the crop yield (Zhang *et al*., 2021).

CONCLUSION

The study illustrated that an increase in the nitrogen content of the leaf tissue of the oil palm with improved sucrose phosphate synthase (SPS) and a reduction in the fructose bisphosphate synthase (FBS), contributed to generating a comparatively higher yield per hectare of the oil palm. The results signified that the application of fertiliser even at a lower dose of 156 kg ha^{-1} [$(NH_2)_2CO$] + 0.12% NPPT and NBPT was capable of enhancing not only the N content of the leaf tissue, but also the NRA, SPS, FBS, reducing sugar, sucrose, and the invertase activity, while reducing the treatment rate of the same by 20% compared to the high dose at 195 kg ha^{-1} [$(NH_2)_2CO$] in the RYP soil.

ACKNOWLEDGEMENT

The research for this article was fully funded by BASF Company (2016-2017).

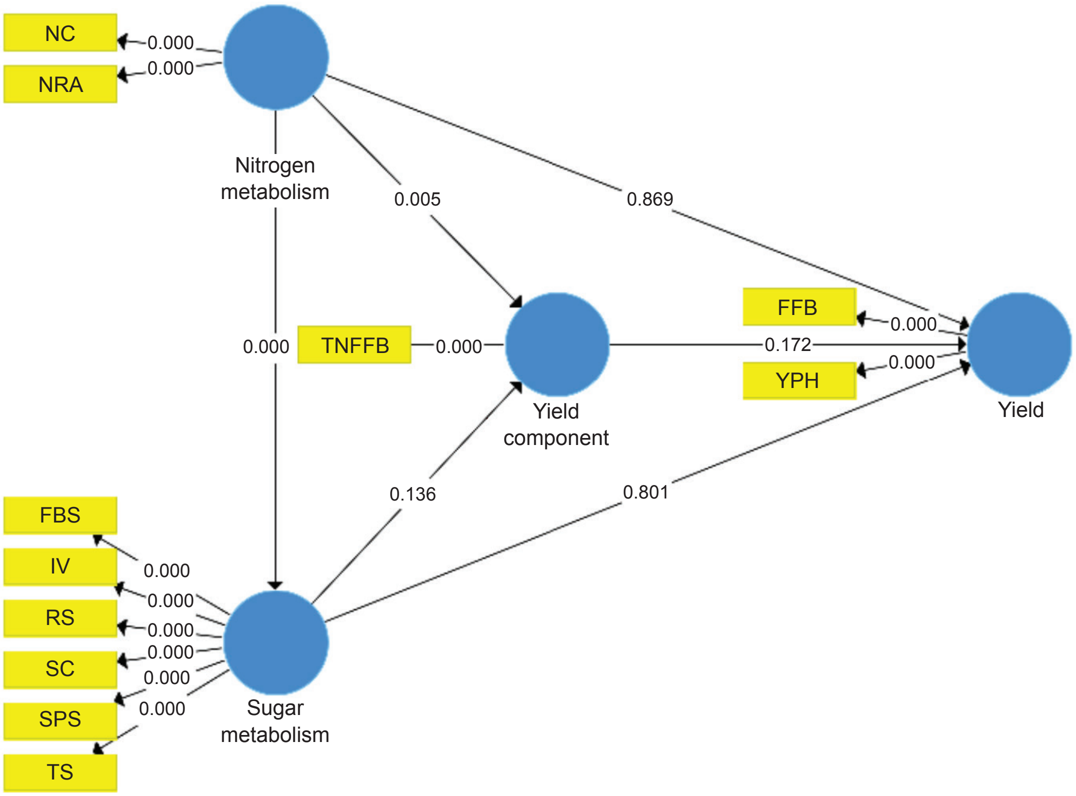

Figure 1. The relationship between the metabolism characters, the yield components and the total yield of oil palm.

REFERENCES

Alpandari, H; Putra, E T S and Wulandari, C (2019). Response of corn (*Zea mays*) growth and yield to urea fertilization techniques on vertisol in Playen, Gunungkidul. *Agric. Sci.*, *4*: 117-122.

Anur, R M; Mufithah, N; Sawitri, W D; Sakakibara, H and Sugiharto, B (2020). Overexpression of sucrose phosphate synthase enhanced sucrose content and biomass production in transgenic sugarcane. *Plants*, *9*: 200.

Arai, M; Mori, H and Imaseki, H (1991). Roles of sucrose 4-metabolizing enzymes in growth seedlings, purification of acid invertase from growing hipocotyls of mung bean seedlings. *Plant Cell Physiol.*, *32*: 1292-1298.

Chow, P S and Landhäusser, S M (2004). A method for routine measurements of total sugar and starch content in woody plant tissues. *Tree Physiol.*, *24*: 1129-1136.

Dewi, F C; Putra, E T S and Wulandari, C (2018). The effect of urease inhibitors coated urea on the growth, physiological activities and yield of maize (*Zea mays* L.) in inceptisol Jogonalan, Klaten. *IPAS*, *3*: 160-165.

Edy, N; Yelianti, U; Irawan, B; Polle, A and Pena, R (2020). Differences in root nitrogen uptake between tropical lowland rainforests and oil palm plantations. *Front. Plant Sci.*, *11*: 92.

Gafur, M A and Putra, E T S (2019). Effect of drought stress in physiological oil palm seedling (*Elaeis guineensis* Jacq.) using calcium application. *Asian J. Biol. Sci.*, *12*: 550-556.

Geiger, M; Haake, V; Ludewig, F; Sonnewald, U and Stitt, M (1999). The nitrate and ammonium nitrate supply have a major influence on the response of photosynthesis, carbon metabolism, nitrogen metabolism and growth to elevated carbon dioxide in tobacco. *Plant Cell Environ.*, *22*: 1177-1199.

Gesch, R W; Vu, J C V; Boote, K J; Junior, L H A and Bowes, G (2002). Sucrose-phosphate synthase activity in mature rice leaves following changes in growth CO_2 is unrelated to sucrose pool size. *New Phytol.*, *154*: 74-84.

Harrison, E P; Willingham, N M; Lloyd, J C and Raines, C A (1997). Reduced sedoheptulose-1,7-bisphosphatase levels in transgenic tobacco lead to decreased photosynthetic capacity and altered carbohydrate accumulation. *Planta*, *204*: 27-36.

Hartiko, H; Del Rosario, E J and Carlos, J T (1982). Leaf and root nitrate reductase activities of coconut (*Coconut nucifera* L.) cultivars and hybrids. *JIPI*, *3*: 227-235.

Hinkelman, K and Kempthorne, O (2008). *Design and Analysis of Experiments*. 2nd edition. John Wiley and Sons, USA. 688 pp.

Indonesian Oil Palm Research Institute (2017). *Optimum Fertilizer Dose to Maximize Productivity of Oil Palm Superior Progeny*. Indonesian Oil Palm Research Institute, Indonesia. 36 pp.

King, T V V; Clark, R N; Calvin, W M; Sherman, D M and Brown, R H (1992). Evidence for ammonium-bearing minerals on Ceres. *Science*, *255*: 1551-1553.

Kohler, E K J; Thom, M and Maretzki, A (1988). Activity of sucrose phosphate synthase in sugarcane leaves. *Phyto. Chemistry*, *27*: 1605-1608.

Bilska-Kos, A B; Mytych, J; Suski, S; Magoń, J; Ochodzki, P and Zebrowski, J (2020). Sucrose phosphate synthase (SPS), sucrose synthase (SUS) and their products in the leaves of *Miscanthus giganteus* and *Zea mays* at low temperature. *Planta*, *252*: 23.

Liu, G; Yang, Z; Du, J; He, A; Yang, H; Xue, G; Yu, C and Zhang, Y (2020). Adding NBPT to urea increases N use efficiency of maize and decreases the abundance of N-cycling soil microbes under reduced fertilizer-N rate on the North China Plain. *PLoS ONE*, *28*: 13.

Melisa, P; E T S and Hanudin, E (2018). Effects of urease inhibitor and nitrification inhibitor on the nitrogen losses, physiological activity and oil palm yield on red-yellow podzolic. *Agric. Sci.*, *3*: 127-134.

Ministry of Agriculture (2019). *Tree Crop Estate Statistics of Indonesia 2018-2019*. Directorate General of Estate Crops. Jakarta, Indonesia. 68 pp.

Nurwahyuni, E and Putra, E T S (2020). Calcium addition improving pectin level in oil palm seedlings (*Elaeis guineensis* Jacq.). *J. Penelitian Kelapa Sawit*, *28*: 168-179.

Nurwahyuni, E and Putra, E T S (2021). The role of calcium in drought stress response induced through antioxidant activity in oil palm (*Elaeis guineensis* Jacq.) seedlings. *Menara Perkebunan*, *89*: 51-61.

Putra, E T S; Purwanto, B H; Wulandari, C and Alam, T (2021). Metabolic activities of eight oil palm progenies grown under aluminium toxicity. *Biodiversitas*, *22*: 3146-3155.

Rahman, N; Bruun, T B; Giller, K E; Magid, J; Ven, G W J and Neergaard, A (2019). Soil greenhouse gas emissions from inorganic fertilizers and recycled oil palm waste products from Indonesian oil palm plantations. *GCB Bioenergy*, *11*: 1056-1074.

Rasid, M N A; Chek, T C and Redzuan, A F (2014). Effectiveness of urea-coated fertilizer on young immature oil palm growth. *Adv. Agric. Technol.*, *1*: 56-59.

Rendana, M; Rahim, S A; Idris, W M R; Lihan, T and Rahman, Z A (2016). Mapping nutrient status in oil palm plantation using geographic information system. *Asian J. Agric. Res.*, *10*: 144-153.

Riyadi, A S; Putra, E T S and Hanudin, E (2020). The influence of urease and nitrification inhibitor on loss of N and oil palm harvest in peat. *IPAS, 5*: 110-116.

Sakata, R; Shimada, S; Arai, H; Yoshioka, N; Yoshioka, R; Aoki, H; Kimoto, N; Sakamoto, A; Melling, L and Inubushi, K (2015). Effect of soil types and nitrogen fertilizer on nitrous oxide and carbon dioxide emissions in oil palm plantations. *Soil Sci. Plant Nutr.*, *61*: 48-60.

Sari, N Y and Putra, E T S (2019). Contribution of calcium to changes leaf anatomy character of oil palm seedlings (*Elaeis guineensis* Jacq.) under drought stress. *Agric. Sci.*, *4*: 23-32.

SAS Institute (2013). *SAS System for Windows 9.4*. SAS Institute, Inc., North Carolina, USA.

Smith, J L; Halvorson, J J and Papendick, R I (1993). Using multiple variable indicator kriging for evaluating soil quality. *Soil Sci. Soc. Am. J.*, *57*: 743-749.

Suryanto, P; Faridah, E; Nurjanto, H H; Putra, E T S; Kastono, D; Handayani, S; Boy, R; Widyawan, M H and Alam, T (2022). Short-term effect of *in situ* biochar briquettes on nitrogen loss in hybrid rice grown in an agroforestry system for three years. *Agron.*, *12(3)*: 564.

Suryanto, P; Faridah, E; Triyogo, A; Kastono, D; Suwignyo, B; Nurmalasari, A I and Alam, T (2020). Designing of soil quality and climate assessment tool for sustainable production of signalgrass (*Brachiaria brizantha*) silvopasture system in mountain ecosystems. *Aust. J. Crop Sci.*, *14*: 614-621.

Takahashi, H; Xiaohua, Q; Shimamura, S; Yanagawa, A; Hiraga, S and Nakazono, M (2018). Sucrose supply from leaves is required for parenchymatous phellem formation in hypocotyl of soybean under waterlogged conditions. *Ann. Bot*, *121*: 723-732.

Welham, S J; Gezan, S A; Clark, S J and Mead, A (2015). *Statistical Methods in Biology: Design and Analysis of Experiments and Regression*. CEC Press, Boca Raton, USA. 602 pp.

Widyawan, M H; Hasanah, A; Sayekti, R R R S; Wulandari, R A; Alam, T; Taryono and Pramana, A A C (2020). Multivariate analysis unravel genetic diversity and relationship between agronomic traits, protein, and dietary fiber in yardlong bean (*Vigna unguiculata* subsp. *sesquipedalis* Verdc.). *Biodiversitas*, *21*: 5662-5671.

Woittiez, L S; van Wijk, M T; Slingerland, M; van Noordwijk, M and Giller, K E (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *Eur. J. Agron.*, *83*: 57-77.

Zanin, L; Venuti, S; Tomasi, N; Zamboni, A; Francisco, R M D B; Varanini, Z and Pinton, R (2016). Short term treatment with the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) alters urea assimilation and modulates transcriptional profiles of genes involved in primary and secondary metabolism in maize seedlings. *Front. Plant Sci.*, *7*: 845.

Zhang, L; Sun, S; Liang, Y; Li, B; Ma, S; Wang, Z; Ma, B and Li, M (2021). Nitrogen levels regulate sugar metabolism and transport in the shoot tips of crabapple plants. *Front. Plant Sci.*, *12*: 626149.

Zuki, M M; Md. Jaafar, N; Sakimin, S Z and Yusop, M K (2020). N-(n-butyl) thiophosphoric triamide (NBPT)-coated urea (NCU) improved maize growth and nitrogen use efficiency (NUE) in highly weathered tropical soil. *Sustain.*, *12*: 8780.