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Research Article

Fertilizer Application And Efficient Use Of N Fertilizer To Increase Growth, Yield, And Quality Of Dragon Fruit (*Hylocereus Polyrhizus*)

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ABSTRACT

In tropical and subtropical regions, dragon fruit, a distinctive tropical fruit, is highly popular. Dragon fruit productivity is influenced by soil nutrient availability, which requires fertilizer input. However, there is limited study on how nitrogen (N) fertilizer efficiency affects dragon fruit growth, production, and quality. The research was conducted in Solok, West Sumatra, Indonesia, from 2021-2022. The study consisted of two stages: a factorial randomized block design with N fertilizer at four dose levels (0, 100, 200, and 300 kg ha^{-1}) and phosphate (P) fertilizer at four dose levels (0, 100, 200, and 300 kg ha^{-1}) with three replicates at the vegetative stage; and a complete randomized block design with N fertilizer at doses of 0, 200, 300, and 400 kg ha^{-1} with four replicates at the generative stage. The study found that adding N fertilizer at different rates significantly affected dragon fruit's vegetative (plant height and shoot numbers) and generative stages (shoot numbers, number of flowers, number of fruits, and fruit production). Applying N fertilizer at rates of up to 200 kg ha^{-1} was effective and more efficient than other treatments since it increased the total amount of flowers, fruits, and fruit production. This study revealed a positive correlation between fruit production and shoot numbers, the total number of flowers, and fruits. The PFP_N parameter showed significant differences, with the maximum PFP_N observed at N 200 kg ha^{-1} and the lowest at N 400 kg ha^{-1}; however, the AE_N parameter values showed no significant difference.

Keywords: agronomic efficiency, dragon fruit, N fertilizer, partial factor productivity, fruit production.

INTRODUCTION

Dragon fruit is a tropical fruit from the *Hylocereus* genus that thrives in northern South America and Mexico (Britton and Rose, 1920), which can be referred to as strawberry pear, pitaya, or night blossoming (Perween *et al.*, 2018). This plant is known as a semi-epiphytic type that thrives in a dry tropical or subtropical region with typical temperatures of 21–29°C, requires 350–2000 mm of rainfall, and elevations from a few meters to 1840 meters above sea level (Ortiz-Hernández and Carrillo-Salazar, 2012; Hossain *et al.*, 2021). These plants (*Hylocereus polyrhizus*, *Hylocereus undatus*, and *Hylocereus costaricencis*) are commercially grown in over 20 tropical and subtropical countries, including Indonesia since they have their own commercial significance, nutritional value, tolerance to high temperatures, salinity, droughts, light intensity, and health benefits (Nie *et al.*, 2015; Mercado-Silva, 2018; Muniz *et al.*, 2019). Pitaya (*Hylocereus sp.*), as one of the exotic tropical fruits, is generally referred to for its attractive coloring, fruit flesh, and unique shapes. Ortiz-Hernández and Carrillo-Salazar (2012) and Muniz *et al.*, 2019) identified four *Hylocereus* species: *Hylocereus polyrhizus* is distinguished by red flesh and pink skin; *Hylocereus megalanthus* possesses white flesh and yellow skin;

Hylocereus costaricencis contains purple-red flesh and red skin; and *Hylocereus undatus* features pink-colored skin and white flesh. Dragon fruit is known to be high in fiber, minerals, vitamins, antioxidants (Moo-Huchin *et al.*, 2017; Perween *et al.*, 2018), betacyanins, alkaloids, phenolics, polyphenols, carotenoids, alkaloids, saponins, steroids, and betalains (Kanchana *et al.*, 2018; Mahdi *et al.*, 2018).

Balancing productivity and fruit quality is challenging, especially with the risks of climate change and weather unpredictability. Soil nutrient availability significantly impacts plant productivity and quality, requiring the application of fertilizers as essential nutrients for the plant (Eissa and Roshdy, 2018; Abou-Zaid and Eissa, 2019). Plants require more additional nitrogen (N) and phosphorus (P) fertilizers as macro fertilizers compared to micro fertilizers, and the application of these fertilizers to different commodities revealed their impact on plant growth and production (Ahmed *et al.*, 2017; Harfe, 2017; Negash *et al.*, 2018; Batista *et al.*, 2020). The addition of N and P fertilizers has been reported to enhance soil quality, carbon accumulation, soil microorganisms, soil fertility, and plant biomass (Razaq *et al.*, 2017; Chen *et al.*, 2018), colonization of the arbuscular mycorrhizal fungi (AMF) and its symbiotic relationship between plants and AMF (Lin *et al.*, 2020), yield and quality (Michopoulos and Solomou, 2019; Fiaz *et al.*, 2021; Solomou *et al.*, 2021).

Since both nitrogen and phosphorus fertilizers have been thoroughly studied in many crops, little is known about the positive impact of N and P fertilizer use on dragon fruit. There have been previous attempts to assess the comparative efficiency of the two fertilizers, regardless of the addition of these nutrients. Some researchers have utilized fertilizer to improve dragon fruit growth and yield by applying foliar nutrients that are sprayed on the plant's root and shoot areas (Then, 2013; Then, 2014a), as well as inorganic fertilizers and compost (Then, 2014b; Huang *et al.*, 2019; Alves *et al.*, 2021). Utilization of fertilizer on dragon fruit, which has increased plant growth and productivity, such as the use of compost at 12 kg pillar $^{-1}$year^{-1} and combined fertilizers of N, P, and K, with Mg at 1.2 and 1.8 kg pillar^{-1}year^{-1} enhanced fruit production on dragon fruit (Then, 2014b), respectively. N fertilizer at 540 g pillar^{-1}, P at 310 g pillar^{-1}, and K at 250 g pillar^{-1} produced the greatest number of fruits, length and width, weight, and dragon fruit production (Chakma *et al.*, 2014). In addition, Moreira *et al.* (2016) reported that applying P fertilizer improved dragon fruit plant growth.

NPK fertilizer, in combination with vermicompost, was used to improve the vegetative growth (height of plant, canopy of plant, and shoot numbers) of the dragon fruit (*Hylocereus polyrhizus*) (Kumar *et al.*, 2018). The mixture of organic fertilizer, NPK fertilizer, and bio-fertilizer improved the vegetative stage of dragon fruit (*Hylocereus undatus*) (Verma *et al.*, 2019). According to Perween and Hasan (2018), employing N 450 g pillar^{-1}, P_2O_5 250 g pillar^{-1}, and K_2O 300 g pillar^{-1} resulted in the highest number of fruits, fruit weight, and production of dragon fruit (*Hylocereus costaricensis*). The use of N fertilizer at a dose of 300 g plant^{-1} on dragon fruit (*Selenicereus megalanthus*) and N fertilizer at a dose of 170-190 g plant^{-1} on *Hylocereus polyrhizus* and *Hylocereus undatus* species resulted in enhanced fruit yield and quality (Alves *et al.*, 2021).

Nutrient efficiency and utilization are the most fundamental restrictions to increasing plant productivity. Nitrogen deficiency in agricultural soils leads to farmers using large amounts of nitrogen fertilizer, posing environmental and economic risks and poor recovery efficiency due to inappropriate timing and excessive use, causing significant ecological losses (Varinderpal-Singh *et al.*, 2021). Nitrogen fertilizers have a limited efficacy of 40–45% in meeting plant fertilizers, which leads to rises in greenhouse gas emissions, mainly nitrous oxide (N_2O), causing global concern (Abeydeera *et al.*, 2019).

Nutrients and their use efficiency significantly limit plant yield. Improved nutrient efficiency is critical for agriculture, necessitating an understanding of optimal fertilizer rates and required nutrients (Rawal *et al.*, 2021). Previous studies indicate that advanced fertilizers, as well as application methods, are being invented to minimize the loss of nitrogen and enhance fertilizer efficiency (Jiang *et al.*, 2019; Agyin-Birikorang *et al.*, 2020; Bindraban *et al.*, 2020; Dhakal *et al.*, 2020). Therefore, practical nitrogen fertilizer application is necessary to improve productivity and the environment (Huang *et al.*, 2018).

Nitrogen use efficiencies (NUE) refers to the ratio of the amount of N taken up to the quantity applied to crops, with low N use indicating inadequate uptake or exceeding plant requirements (Govindasamy *et al.*, 2023). NUE is generally estimated using factors such as agronomic efficiency (AE), internal efficiency (IE), partial factor productivity (PFP), recovery efficiency (RE), partial nutrient budget (PNB), and physiological efficiency (PE) (Dobermann, 2007; Ray *et al.*, 2017; Rawal *et al.*, 2021). Govindasamy *et al.* (2023) stated that crop traits, environmental variability, and management approaches significantly impact agronomic NUE. A previous study revealed that some commodities require extensive efforts to enhance NUE. For example, arbuscular mycorrhizal fungi (AMF) enhance the response of plants to drought-related stress and increase nitrogen uptake and NUE (Tang *et al.*, 2022), applying silicon to the soil improves the growth and nitrogen use efficiency of coffee plants (Parecido *et al.*, 2022), NUE and productivity in relation to N dosage treatment and time in maize (*Zea mays* L.) (Gheith *et al.*, 2022), and maximizing production and NUE in a double cropping system in rice plants (Xu *et al.*, 2022). However, information on the efficacy of NUE on dragon fruit is restricted. Therefore, a study was conducted to determine the optimal quantities of N-dose fertilizers concerning NUE, besides their effect on plant growth, fruit yield, and their quality on dragon fruit.

MATERIALS AND METHODS

Research set-up and treatment

The study was conducted on a farmer's field that had not previously grown dragon fruit at Solok, West Sumatera, Indonesia, from 2021 to 2022, at an elevation of ± 450 meters above sea level. The study employed dragon fruit (*Hylocereus polyrhizus*) cuttings around 40 cm long. Dragon fruit cuttings were transplanted into a single-pillar system, with four planted per pillar. The planting distances, line spacings, and planting holes were 3 x 3 m, 2.5 m, and 60 x 60 x 40 cm, respectively.

The study consisted of two experiments. The first experiment was carried out during the vegetative stage in the first year and the generative stage in the first two years. The first experiment used a randomized block design with two factors and three replications. Factor 1 of the treatments included four doses of nitrogen fertilizer (0, 100, 200, and 300 kg N ha^{-1}) and factor 2 contains four dosages of P fertilizer (0, 100, 200, and 300 kg P ha^{-1}). Each treatment in one replication has three pillars (4 plants per pillar). Urea and triple superphosphate (TSP) were used as nitrogen and phosphorus fertilizers. N and P fertilizers were applied at planting time at around 25%, with the rest of the additional treatments occurring every four months at around 25% per application. Manure was added as a base fertilizer twice a year at a rate of 10 kg $pillar^{-1}$, and potassium chloride (KCL) was used as a K fertilizer at a dose of 160 kg ha^{-1} every four months, or approximately 25% for each application. The second experiment included four treatments: 0, 200, 300, and 400 kg N ha^{-1}. This study employed a completely randomized block design with five replications. Nitrogen fertilizer was administered every four months, approximately 25% for each application. As a basic fertilizer, P 300 kg ha^{-1} and KCL 400 kg ha^{-1} were applied every four months at 25% per application, whereas cow manure was utilized twice a year at a rate of 10 kg $pillar^{-1}$. Before planting dragon fruit cuttings, eight mixed soil samples were obtained using the zigzag sampling method, ranging in depth from 0 to 20 cm. The soil samples were ground up and allowed to air dry, and their pH, cation exchange capacity (CEC), total N, P-available, exchangeable bases, and soil organic carbon (SOC) content were assessed. Soil pH was determined with a pH meter (Rhoades *et al*., 1999), and SOC concentration was calculated by the wet oxidation method (Walkley and Black, 1933). The total nitrogen was measured with the Kjeldahl method (Bremner, 1965), while the Olsen method assessed the P-available (Olsen *et al*., 1954). After dissolving with an ammonium acetate liquid to extract CEC and exchangeable bases, the exchangeable bases were assessed using a flame photometer for K and atomic absorption spectroscopic measurements of Ca and Mg (Polemio and Rhoades, 1977). Table 1 indicates the study's soil characteristics.

Table 1. Soil characteristics.

Soil characteristics	Values	Rating	Reference
pH	4.68	Acid	Hazelton and Murphy, (2007)
SOC (%)	2.03	Moderate	Hazelton and Murphy, (2007)
N (%)	0.06	Low	Hazelton and Murphy, (2007)
C/N	33.83	High	Hazelton and Murphy, (2007)
P_2O_5 (ppm)	3.12	Very low	Hazelton and Murphy, (2007)
CEC (cmol(+)kg^{-1})	14.98	Moderate	Hazelton and Murphy, (2007)
Exc. K (cmol(+)kg^{-1})	0.82	High	Hazelton and Murphy, (2007)
Exc. Ca (cmol(+)kg^{-1})	2.45	Low	Hazelton and Murphy, (2007)
Exc. Mg (cmol(+)kg^{-1})	0.82	High	Hazelton and Murphy, (2007)

Exc.: exchangeable bases.

During the first research study, an average monthly temperature of 27.6°C, an average monthly rainfall of 188.6 mm, and an average relative humidity of 78.4% were observed. In the second experiment, we recorded a mean annual rainfall of 144.2 mm, a mean relative humidity of 82.0%, and average monthly temperatures of 26.0°C.

Data collection

Plant growth parameters, such as plant height (cm), were determined using a ruler, and shoot numbers were counted and documented for each plant per pillar during the study. The number of flowers was counted and recorded for each plant per pillar across the study. Fruit weight (g) was calculated by weighing individual fruit at every harvest time. Fruit production (kg) was measured by weighing the total of individual fruit during harvesting, while total soluble solids (TSS) (°Brix) were recorded after fruit harvesting and assessed in the laboratory to determine fruit quality by hand refractometry. The plant tissue's N and P nutrient content was assessed at the end of the study. After harvesting, the middle part of the shoots were collected and sliced into little pieces. They were then cleaned with distilled water to remove soil and dust particles, put into an empty paper envelope, and dried in the oven at around 60°C for 68 hours. Once dried in the oven, the samples were ground to a powdered form and placed through a 0.5 mm screen filter. The Kjeldahl and spectrophotometry methods determined plants' N and P content. NUE is measured in terms of nitrogen agronomic efficiency (AE_N) (kg kg^{-1}) and nitrogen partial factor productivity (PFP_N) (kg kg^{-1}) using (Dobermann, 2007) equations, as follows:

$$AE_N = (Y - Yo)/F \quad (1)$$

$$PFP_N = Y/F \quad (2)$$

Where “Y” denotes the yield with N nutrients applied (kg ha^{-1}); ”Yo” denotes yield with no N treatment (control) (kg ha^{-1}); and “F” denotes the quantity of N fertilizer utilized (kg ha^{-1}).

Statistical analysis

The data was analyzed using analysis of variance (ANOVA), and if there was a significant difference between treatments, the least significant difference (LSD) was applied at the 5% level. Regression analysis was utilized to establish the relationship between the measured parameters and the N and P fertilizer doses. Pearson’s correlation was used to analyze the correlation between parameters using the SPSS 16.0 software.

RESULTS AND DISCUSSION

Effect of N and P fertilizers on plant growth at vegetative and generative stages

At the vegetative stage, a single factor of the varying N levels applied to dragon fruit produced significant variations in plant height and shoot numbers, whereas P fertilizer dose treatments showed no significant difference (Table 2). Table 2 revealed no interaction between nitrogen and phosphorus fertilizers and plant height. Regarding the plant height variable, the statistical analysis of single-factor N fertilizer indicated significant differences from the control but no significant changes from the other treatments.

The average increase in plant height across all N fertilizer treatments varied from 168.19 to 175.55 cm (12.19–17.25% larger than the control), which differed significantly from the control (149.91 cm) (Table 2). This result is in line with the results reported by Chakma *et al*. (2014) and Siddiqua *et al*. (2021), who found that applying nitrogen fertilizer enhanced the plant height of dragon fruits, and this fertilizer treatment promotes plant height by releasing nutrients and growth-stimulating chemicals excreted, which are linked to nitrogen-fixing bacteria, solubilization, and nutrient mobilization. Using N fertilizer positively affected the plant height and growth of dragon fruit (Almeida *et al*., 2014; Moreira *et al*., 2016; Samant *et al*., 2023). Adding N fertilizer improved plant growth significantly (plant height and root diameter) compared to the absence of fertilizer application (Razaq *et al*., 2017). Treatment with N fertilizer improved plant height and productivity (Harfe, 2017; Eissa and Roshdy, 2018; Batista *et al*., 2020). In addition, N fertilizer significantly affected plant height because of increased vegetative growth, enhanced nutrient absorption, assimilation, and internal re-translocations (Souri *et al*., 2019). Increasing the N dose applied led to increasing the plant height, and this study showed the relationship between N-dose fertilizer and plant height by generating an equation with $y = -0.0005 x^2 + 0.2159 x + 149.91$ and $R^2 = 0.7699$ (Fig. 1a).

The application of N fertilizer in the soil could be leached, evaporated, and absorbed by the plants. In this study, the amount of N fertilizer used influenced the accessibility of N nutrients. The accessibility of N nutrients influences the rates at which they are absorbed. The higher the N fertilizer dosage, the more N is available in the soil and plants. Chen *et al*. (2018) found that applying N, NP, NK, and NPK fertilizer increased N content and raised it more than without fertilizer treatment. In addition, Wang *et al*. (2018) and Xiong *et al*. (2018) revealed that N fertilizer affected N concentration, N:P ratio, P content, and N content. Furthermore, the N content of the plants increased considerably during treatment with NPK and organic fertilizers compared to the control (Sofyan *et al*., 2019). This study established the relationship between the application fertilizer dose of N and the nutrient content of N in the plant, showing an equation with $y = -0.00001 x^2 + 0.0048 x + 0.7318$ and $R^2 = 0.6412$ (Fig. 2a).

Table 2 shows that increasing a single factor dosage of N fertilizer raised the shoot numbers by 14.66 to 18.06 (125.94–155.15%) compared to the control. The single dose factor of N fertilizer with the highest shoot numbers was found in the treatment of N fertilizer at dose 300 kg ha^{-1}, i.e., 29.7 shoots, significantly different from N fertilizer at dose 100 kg ha^{-1}, approximately 26.3 shoots, and control 11.64 shoots. However, there was no significant difference from the treatment of N fertilizer at a dose of 200 kg ha^{-1}, approximately 29.28 shoots. This result, in line with Eissa and Roshdy (2018), found that shoots increased as fertilizer N rates were applied. In addition, Siddiqua *et al*. (2021) showed that shoot numbers increased significantly with fertilizer containing N in pink and white flesh dragon fruits. In addition, Souri and Hatamian (2018) and Souri *et al*. (2019) revealed that applying N in the soil enhances rapid meristematic activity, increasing plant height because it promotes cell division and elongation. Applying balanced fertilizers stimulates the proliferation of cells and elongation, leading to increased plant height and number of shoots. This study found a relationship between N-dose fertilizer and shoot numbers by producing an equation $y = -0.0004 x^2 + 0.164 x + 12.096$ with $R^2 = 0.9258$ (Fig. 1b).

Statistically, the use of different doses of P fertilizer exhibited no influence on shoot numbers, and there was no interaction between fertilizer application and shoot numbers at the vegetative phase. On the other hand, utilizing P fertilizer allows the plant's P content to rise. Adding P fertilizer promotes plant P content, consistent with Chen *et al*.'s (2018) result that applying P in combination with N or N and K fertilizer improves P content compared to no treatment. According to Sofyan *et al*. (2019), applying a P mix containing N, K, and organic fertilizers increased the P content of the plant considerably when compared to no treatment. The study's findings demonstrated the relationship between the dose of P fertilizer and the nutrient P content in the plant, showing an equation with $y = 0.0002 x + 0.1323$ and $R^2 = 0.6112$ (Fig. 2b).

Table 3 revealed significant differences in shoot numbers due to applying N-dose fertilizer at the generative phase. The N dose at 300 kg ha^{-1} showed the maximum shoot numbers, significantly different from the control and revealed no significant difference between treatment 200 and 400 kg ha-1. In line with the study conducted by Moreira *et al.* (2016) and Siddiqua *et al.* (2021), adding fertilizer to dragon fruit (*Hylocereus undatus*) improved the number of shoots significantly. According to Kumar *et al.* (2018), using N and P fertilizers on dragon fruit (*Hylocereus polyrhizus*) enhanced shoot numbers and length. The application of nitrogen and phosphorus fertilizer dosages has significant effects on shoot numbers (Negash *et al.*, 2018). A combination of N with P and K fertilizer treatment with organic matter and bio-fertilizer on dragon fruit (*Hylocereus undatus*) increased growth parameters (plant height and shoot numbers) (Verma *et al.*, 2019). This study found a relationship between N-dose fertilizer and shoot numbers by performing an equation $y = -0.0003x^2 + 0.1923x + 19.606$ with $R^2 = 0.9885$ (Fig. 3a).

Table 2. Effect of N and P fertilizer on the plant height and shoot numbers at the vegetative stage.

Treatment (kg ha-1)	Plant height (cm)	Shoot number
N		
0	149,91 b	11,64 a
100	168,19 a	26,30 b
200	173,50 a	29,28 bc
300	175,55 a	29,70 c
P		
0	164,40 a	22,47 a
100	167,95 a	23,80 a
200	171,22 a	25,22 a
300	163,81 a	25,41 a
Significance		
N	*	*
P	ns	ns
N X P	ns	ns

N: N fertilizer, P: P fertilizer, ns: not significant, *: $p \le 0.05$, **: $p \le 0.01$.

Table 3. Effect shoot number as a function of soil application of N doses fertilizer in the generative phase.

N (kg ha-1)	Shoot numbers
0	19.40 b
200	46.80 a
300	48.30 a
400	47.90 a

N: N fertilizer, means with an identical letter across a column are not statistically significant according to the LSD test at $p < 0.05$.

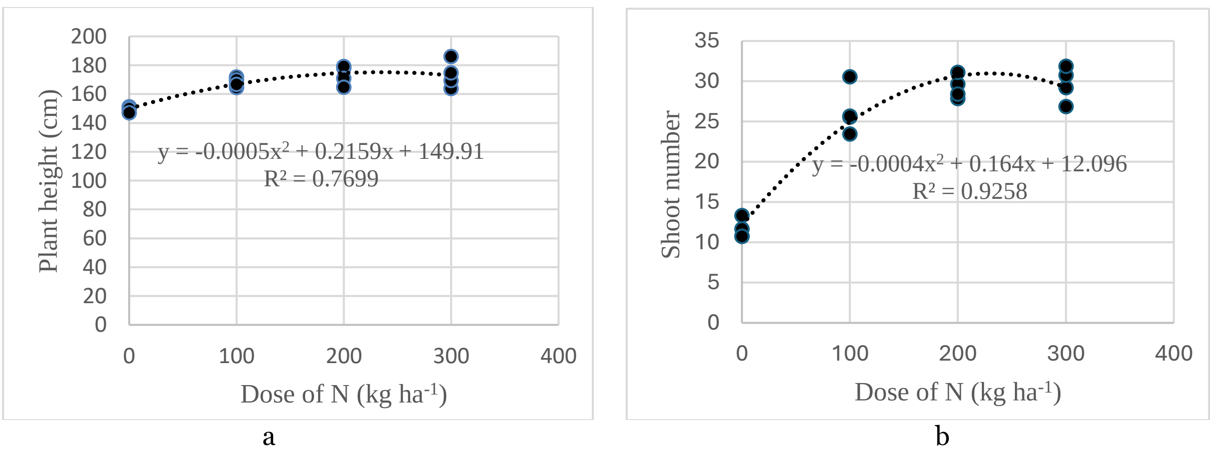
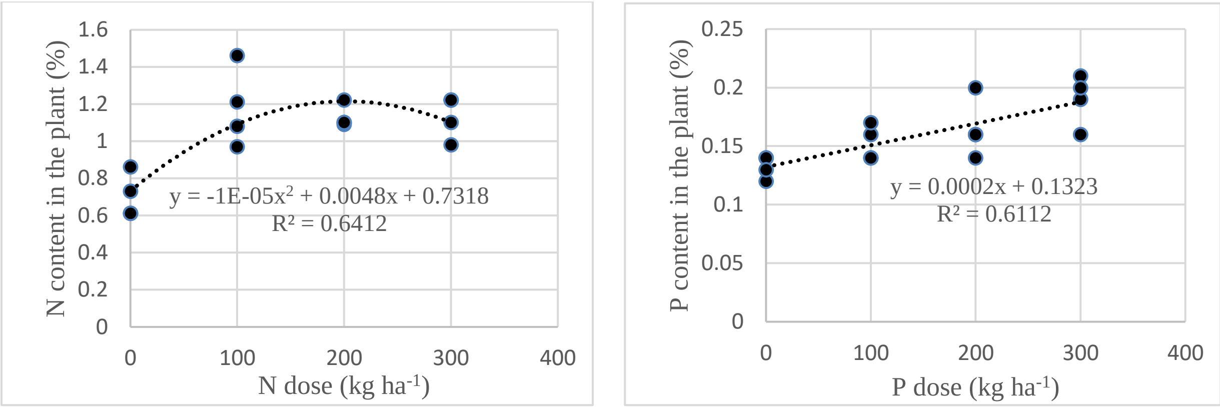
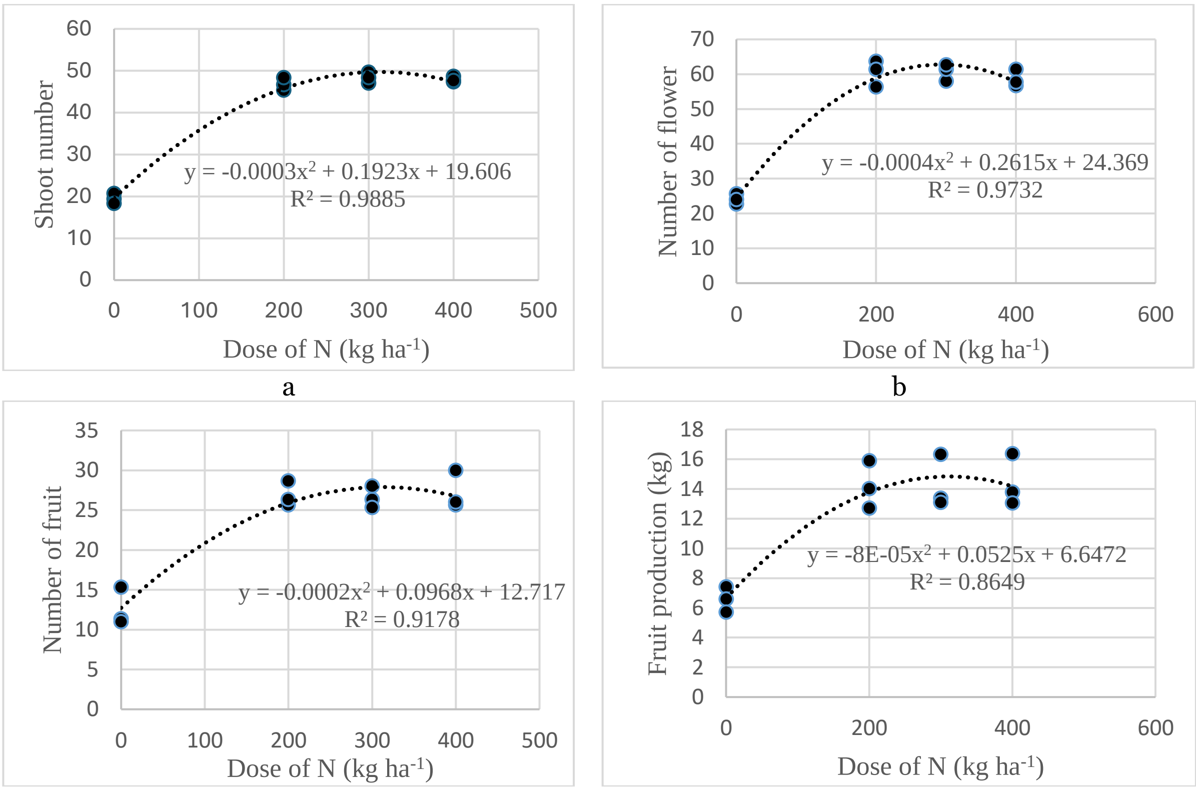


Figure 1. The relationship between the dose of N fertilizer and the plant height (a) and shoot number (b).



a b

Figure 2. The relationship between N dose and N content in the plant (a) and P dose with P content in the plant (b).



c d

Figure 3. The relationship between N dose with the number of shoots (a), number of flowers (b), number of fruits (c), and fruit production.

Effects of N fertilizer on yield, quality, and fruit production

During the first two years of the generative phase, the parameters of the number of flowers and fruits, weight of fruit, production, and TSS were measured. As a result, N fertilizer doses showed a significant difference in the number of flowers, fruits, and fruit production but not in fruit weight or TSS (Table 4).

Table 4. Number of flowers, number of fruits, fruit production, and TSS as a function of soil application of N-dose fertilizer.

Parameter	N (kg ha-1)			
	0	200	300	400
Number of flowers	24.10 b	60.40 a	60.70 a	58.55 a
Number of fruits	12.55 b	26.88 a	26.55 a	27.22 a
Fruit weight (g)	528.39 a	527.24 a	535.91a	528.14 a
Fruit production (kg)	6.57 b	14.20 a	14.26 a	14.39 a
TSS (°Brix)	13.70 a	13.40 a	13.90 a	13.94 a

N: N fertilizer means with the identical letter inside a line are not statistically different based on the LSD ($p < 0.05$).

The number of flowers differed significantly across all N dosages (Table 4). N used at 300 kg ha^{-1} produced the maximum number of flowers around 60.70 and differed significantly from the control, but there was no significant difference with 200 and 400 kg ha^{-1}. The crop needs adequate nutrients during the long-term floral stage to maintain its development and growth. Therefore, fewer fertilizers were applied at this stage, resulting in early premature fruit drops and lower fruit setting. The study indicated that adding nitrogen up to 200 kg ha^{-1} to dragon fruit enhanced the number of flowers, which is consistent with prior research by Then (2014a, 2014b) and Ahmed *et al.* (2017), who reported that fertilizer improved floral initiation and increased flower measurements in red pitaya plants and chrysanthemum. Perween and Hasan (2018) found that N applied with P and K produced earlier flowering, approximately 15 days, compared to no treatment. In addition, the research conducted by de Souza *et al.* (2018) and Pradeepkumar *et al.* (2020) demonstrated that fertilizer application enhances flowering, specifically N and P fertilizers. A relationship between N-dose fertilizer and the number of flowers by generating an equation $y = -0.0004 x^2 + 0.2615 x + 24.369$ with $R^2 = 0.9732$ was found in the study (Fig. 3b).

The treatment of N at 400 kg ha^{-1} raised the most significant number of fruits and fruit production parameters, which were statistically different from no treatment, and there was no significant difference with N doses applied between 200 and 300 kg ha^{-1} (Table 4). The number of fruits is a key component for achieving an adequate yield. The fewer fruits caused lower yields in this study due to the smaller number of flowers used for the N and P fertilizers. A decreased number of fruits is shown not only by fewer flowers produced but also by less fertilizer treatment (Goenaga *et al.*, 2020). Chakma *et al.* (2014) and Gonzaga *et al.* (2017) also observed a similar ability to increase fruit production with increasing fertilizer rates for certain types of fertilizer application. The relationship concerning the N-dose fertilizer and the number of fruits with an equation $y= -0.0002 x^2 + 0.0968 x +12.717$ with $R^2 = 0.9178$ was established in the study (Fig. 3c). Alves *et al.* (2021) found that applying nitrogen fertilizer enhanced yields and fruit quality in three species of dragon fruit (*Hylocereus polyrhizus*, *Hylocereus undatus*, and *Selenicereus megalanthus*). A similar study found that nitrogen fertilizer enhanced plant growth, fruit production, and dragon fruit quality (Chakma *et al.*, 2014; Then, 2014b; Siddiqua *et al.*, 2021). A relationship between N-dose fertilizer and fruit production, showing an equation with $y = -0.00008 x^2 + 0.0525 x + 6.6472$ and $R^2 = 0.8649$, was found in the study (Fig. 3d).

On the other hand, the study found that both fruit weight and TSS showed no significant difference across all N dosages (Table 4). The study's results, consistent with Chakma *et al.* (2014), revealed that fruit weight decreased significantly concerning the treatments (NPK fertilizer) used. In addition, fruit weight reduction to a few per stem resulted in higher fruit size and weight (Goenaga *et al.*, 2020) and showed no significant difference. The TSS content suggested that more fruit sweetness caused a larger °Brix and a gradual rise in N dosages used in this research revealed no significant difference in the TSS variable (Table 4). Gonzaga *et al.* (2017) found that nitrogen application had an adverse impact on TSS parameters and resulted in lower sucrose or soluble solid content since a large amount of nitrogen fertilizer was applied. Similar results have been reported by Alves *et al.* (2021), showed that applying N fertilizer had no influence on the soluble solid parameter dragon fruit varieties (*Hylocereus polyrhizus*, *Hylocereus undatus*, and *Selenicereus megalanthus*) over the first to third fruit production period.

Dragon fruit is known as non-climacteric and classified into five different categories: first (>500 g), second (380–500 g), third (300–380 g), fourth (260–300 g), and fifth (below 260 g) (Shah *et al.*, 2023). According to these fruit grade requirements, the research produced weights ranging from 527.24 to 535.91 g, including first grade. Since this study found that treatment without N fertilizers produced first grade, we also found that utilization without N fertilizers generated lower and significant differences in shoot numbers, number of flowers, number of fruits, and fruit production compared to application with N fertilizers (Tables 3 and 4).

Correlations are essential indicators, and the significant correlations between the analyzed parameters under study indicate that their effects are well-synchronized (Bojović *et al.*, 2019). The study's results indicate significant positive correlations across all of the variables utilized in the study (Table 5). The study revealed correlations between fruit production and various variables. Table 5 shows the correlation between fruit production and the shoot numbers (r = 0.933), number of fruit (r = 0.9982), and number of flowers (r = 0.951). The findings from this study showed that increasing fruit production leads to an increase in the number of shoots, the number of fruits, and the number of flowers. The study's results, in line with Hariyanto *et al.* (2023), found a positive correlation between yield and the number of flowers, shoots, and fruits affected by N and P fertilizer applied to dragon fruit.

Table 5. Pearson correlation between the parameters utilized in the study.

	SN	NFL	NF	FP	FW	TSS
SN	1					
NFL	0.983**	1				
NF	0.962**	0.972**	1			
FP	0.933**	0.951**	0.982**	1		
FW	0.357	0.372	0.345	0.340	1	
TSS	0.068	-0.021	0.098	0.019	-0.209	1

SN: shoot number, NFL: number of flowers, NF: number of fruits, FP: fruit production, FW: fruit weight, TSS: total soluble solid, ** = a significant correlation occurs at 0.01 levels.

Partial factor productivity of N and agronomic efficiency of N

PFP_N is a practical approach to comparing the economic effects of N fertilization. PFP_N levels increased with low N application rates and declined with increasing N levels. According to Jiang *et al.* (2018) and Agyin-Birikorang *et al.* (2020), increased PFP_N values indicate reduced nitrogen loss. The research finding, the PFP_N parameter, revealed a significant difference, with the highest PFP_N (71.01 kg kg^{-1}) of dragon fruit recorded with the application of N 200 kg ha^{-1} and the lowest (35.99 kg kg^{-1}) obtained with N applied at a dose of N 400 kg ha^{-1} (Table 6). This result is consistent with Khalili *et al.* (2018) and Rawal *et al.* (2021 and 2022), who found significant differences in PFPN due to the N-rate fertilizer applied. According to Dobermann (2007), the value of PFP_N was around 40 to 80 kg kg^{-1}, with PFP_N > 65 kg kg^{-1} indicating effectively managed systems with low N fertilizer or minimal soil N application. The research found a relationship between N-dose fertilizer and PFP_N, achieving an equation $y = -0.7005 x + 104.04$ with $R^2 = 0.8566$.

Table 6. PFP_N and AE_N as influenced by different levels of N fertilizer in dragon fruit.

N (kg ha^{-1})	PFP_N (kg kg^{-1})	AE_N (kg kg^{-1})
200	71.01 a	38.13 a
300	47.53 b	25.60 a
400	35.99 b	19.55 a

N: N fertilizer, means the identical letters inside a column are not significant according to the LSD ($p < 0.05$).

AE_N measures the amount that yield increases for each additional unit of nutrients (N fertilizer). According to Jiang *et al.* (2019) and Agyin-Birikorang *et al.* (2020), increased AE_N values represent a decline in nitrogen loss. In this research, the values of the AE_N parameter ranged from 19.55 to 38.13 kg kg^{-1} and revealed no significant difference among all treatments (Table 6). This finding coincides with Rawal *et al.* (2021), who observed no significant changes in AE_N due to N-rate fertilizer application. Dobermann (2007) stated that AE_N varies between 10 and 30 kg kg^{-1}, with AE_N over 25 kg kg^{-1} in properly controlled systems with low N fertilizer application quantities or insufficient soil N input.

Conclusion

The study indicated that nitrogen fertilizer greatly improved plant height and shoot numbers during the vegetative phase. The highest plant height and shoot numbers were observed at N doses of 300 kg ha^{-1}. At the generative stage, the highest shoot numbers and number of flowers were 47.90 shoots and 60.70 flowers at N dose 300 kg ha^{-1}, while the more significant number of fruit and fruit production was found in treatment 400 kg N ha^{-1}, and all these parameters showed significant differences with no treatment but no significant difference with other treatments. No significant differences were found in fruit weight and TSS across all treatments in the study. The study also found a positive correlation between fruit production and shoot numbers, the number of fruits, and flowers. The PFP_N parameter showed significant differences, with the highest PFP_N (71.01 kg kg^{-1}) of dragon fruit recorded with N 200 kg ha^{-1} and the lowest (35.99 kg kg^{-1}) with N 400 kg ha^{-1}, while AE_N parameter values showed no significant difference.

Conflict of interest

The authors declare no financial or personal interests that may have influenced the work presented in this study.

Author contributions

The concepts and methods were designed by Jumjunidang, Irwan Muas, and Bambang Hariyanto. The research and data collection were carried out by Bambang Hariyanto, Eliza Mayura, Tri Cahyono, Rahadian Mawardi, Surianto Sipi, and Irma Oktavia. The data analysts were Bambang Hariyanto Surianto Sipi, and I Ketut Suwitra. Written by Tri Cahyono, Rahadian Mawardi and Irma Oktavia, the manuscript was reviewed and revised by Bambang Hariyanto, Irwan Muas, Jumjunidang, Eliza Mayura, and I Ketut Suwitra.

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