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Research Article

Effect of ethephon stimulation and fertilizer applications on nutrient dynamics of rubber clones in South Sumatra, Indonesia

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ABSTRACT

Soil is a critical factor in determining fertilizer efficiency. Rubber tree requires a stable environment to achieve optimal growth and production. The research aimed to evaluate how fertilization and ethephon stimulation affected the nutrient dynamics of rubber in various clones. The Indonesian Rubber Research Institute experimental field in South Sumatra served as the site for the research. Three replications of the experiment were set up using a split-plot design with three factors. The rubber clones were the primary plot, with ethephon stimulation and fertilization rate as subplots. The rubber clones used in this research, namely GT 1, BPM 24, PB 260, and IRR 112, were planted in 2011 (8 years) with a 6 x 3 m planting spacing on the existing rubber plantation. Several rates of fertilization were used in the experiment: 50% recommended rate (50 RR), 100% recommended rate (100 RR), 150% recommended rate (150 RR), and control (no fertilizer). During the observation period, ethephon stimulation was administered at a rate of S/2 d3 ET2.5% 6/y (half spiral cut, tapped downward every 3 days with ethephon stimulation of 2.5% active ingredient and application of 1 g per tree on groove, six times per year at monthly intervals) every two months. Observation parameters were soil nutrient analysis (soil pH, cation exchange capacity (CEC), C-Organic, total nitrogen, available phosphorus, and exchangeable bases (K, Ca, Mg), and leaf nutrient analysis (N, P, K). Results showed that soil properties were improved by fertilization after a year of treatment. Organic-C, CEC, total nitrogen, available phosphorus, and exchangeable cation increased across rubber clones. Tissue analysis in leaves and nutrient content also showed significant differences between fertilization and stimulation treatments in all clones. Further research is required on which chemical fertilizers with biological fertilizers can induce low nutrient availability in poor soil conditions.

Keywords: fertilization; growth; soil properties; ultisol

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INTRODUCTION

Rubber is an export commodity that contributes to the increase in Indonesia's foreign exchange. In recent years, Indonesian rubber exports have consistently increased, resulting in positive foreign exchange. The human desire for durable and elastic goods and equipment drives the demand for rubber, which is expected to grow and increase in tandem with the growth of the automotive industry, hospital equipment, medical devices, household needs, and other related sectors. Future prediction indicates a continued increase in rubber demand. This presents a significant opportunity for Indonesia to export rubber and its processed rubber products to other countries (Siahaan, 2024).

Soil is one of the determining factors in fertilizer efficiency. Adding fertilizers to plants with low levels of clay and low cation capacity results in a higher fertilizer efficiency than using basic fertilizers alone. However, in clay soil with a high cation exchange capacity, adding fertilizers separately is not more effective than doing so at the same time right before planting. Soil and climatic conditions greatly affect plant growth and the production of rubber (Wijaya, 2008). Low soil fertility due to low organic matter, soil pH, and availability of potassium (K) and phosphorus (P) becomes obstacles in marginal land.

Ultisol is one of the marginal dry lands with constraints such as low soil fertility, high soil acidity (pH <4.50), high Al saturation, low macronutrient content, especially P, K, Ca, and Mg, low organic matter, high solubility of Fe and Mn. Furthermore, the fixation of Al and Fe ions can decrease the availability and P deficiency. Tufaila et al. (2014) suggest that land improvement (amelioration), fertilization, and the application of organic matter can enhance marginal land productivity. Enhancing soil aggregation and applying soil and water conservation systems to land use management can enhance physical properties.

Indonesian Rubber Research Institute concludes the key to success in rubber plantation is good management practices, i.e., fertilization, the use of superior clones, and appropriate harvest time. Application of stimulants improves physiological changes like those in sucrose, inorganic phosphate, thiol, and dry rubber content (D'Auzac & Jacob, 1984; Gohet et al., 2008). Since latex growth and production utilize assimilates and other nutrients (Silpi et al., 2006; Chantuma et al., 2006), the balancing of nutrient levels is necessary for effective stimulation.

Rubber tree growth and latex production have a negative correlation; if the growth rate is high, latex production tends to be low (Silpi et al., 2006; Chantuma et al., 2006). However, the ability of each clone to mobilize assimilates varies, resulting in the different distribution of assimilates according to the required sinks as indicated by the ratio of source to sink by clones (Silpi et al., 2007; Chantuma et al., 2009). Silpi et al. (2006) pointed out that rubber trees applied with stimulants require a higher total amount of assimilates used for growth and latex production. We conducted this study to evaluate how fertilization and ethephon stimulation affected the nutrient dynamics of rubber in various clones.

MATERIALS AND METHODS

The study used the experimental field of the Indonesian Rubber Research Institute in South Sumatra (2.9275° South and 104.5386° East). The 12-month research, which covered material preparation, field experiments, and laboratory analyses, was conducted from September 2018 to August 2019.

The rubber clones used GT 1, BPM 24, PB 260, and IRR 112 that were planted in 2011. All clones had similar 6 x 3 m of plant spacing. The recommended rate (RR) was predetermined before the experiment, as part of a routine analysis in the field. Based on soil and leaves analysis, the recommended dosage of fertilizers per tree was 510 g of urea (46% N), 200 g of TSP (Triple superphosphate) (46% P_2O_5), and 400 g of KCl (Potassium chloride) (60% K_2O).

The factorial study was set up using a split-plot design with three factors and three replications. The rubber clones formed the main plot, while the fertilization rate and ethephon stimulation were subplots. There were 32 plots in total treatment combinations. The first factor was rubber clones (GT 1, BPM 24, PB 260, and IRR 112); the second factor was fertilizer dosage (control, 50% recommended rate-50 RR, 100% recommended rate-100 RR, and 150% recommended rate-150 RR); and third factor was ethephon stimulation (control, stimulation 2.5%). Ethephon stimulation was used every two months at a rate of S/2 d3 ET2.5% 6/y (half spiral cut, tapped downward every 3 days, ethephon stimulation of 2.5% active ingredient and application of 1 g per tree on groove, six times per year at monthly intervals).

Observation parameters included soil nutrient analysis (soil pH, cation exchange capacity (CEC), Organic-C, total N, available P, and exchangeable bases (K, Ca, and Mg)), and leaf nutrient analysis. Analysis methods are presented in Table 1.

Table 1. Laboratory methods for nutrient analysis.

Parameter	Method of analysis	References
Plant tissue		
Total N	Modified Kjeldahl	Chapman, 1965
Total P	Dry ashing, colorimetry	Chapman, 1965
Total K	Dry ashing, flame photometer	Chapman, 1965
Soil properties		
pH	1: 1 ratio, potentiometric	Peech, 1965
Organic carbon	Walkey and Black	Chapman, 1965
Total N	Modified Kjeldahl	Chapman, 1965
Available P	Bray No.2	Dewis and Freitas, 1970
Exc. K, Ca, Mg	AAS, extract with 1N NH_4Oac, pH 7	Chapman, 1965
CEC	Ammonium Acetate pH 7	Chapman, 1965

The following formula uses an allometric equation to calculate the biomass of a rubber tree:

$$\text{Dry weight} = 0.11\ \pi\ D\ 2.62$$

where,
π = rubber wood density
D = rubber wood diameter

This study determined the nutrition in latex, specifically nitrogen, phosphorus, and potassium. Following the same method as for leaf analysis, the rubber produced by each plot was weighed, and samples of freshly coagulated latex were separated, dried at 60 °C, ground, and sent for chemical analysis to ascertain the nutrient contents (Sarruge & Haag, 1974). Measurement was conducted once a month. Experimental data was analyzed using SAS (version 9.0), and mean comparisons were performed using Tukey's test at a 5% significance level.

RESULTS AND DISCUSSION

Site characterization

The experiment evaluated the soil profile to determine the soil's capacity to support rubber growth. The site has Ultisol order, which makes up around 25% of Indonesia's total land area and the largest portion of its dryland regions. The soil was classified as Typic Tropoudults (Table 2).

Table 2. Soil profile description of the experimental area.

Horizon	Depth (cm)	Description
Ap1	0-14	Dark brown (7.5 YR 4/4) moist, sandy clay loam; weak medium subangular blocky structure; many very fine pores; clear smooth boundary; pH 4.5.
Ap2	14-24	Strong brown (7.5 YR 5/2) moist, sandy clay loam; weak coarse subangular blocky structure; very few fine pores; clear smooth boundary; pH 4.6.
Bt1	24-49	Strong brown (7.5 YR 7/8) moist, clay; moderate medium subangular blocky structure; no pores; no roots; clear smooth boundary; pH 4.7.
Bt2	49-73	Yellowish red (5 YR 6/8) moist, clay loam; prismatic breaking into weak fine subangular blocky structure; no pores; no roots; clear smooth boundary; pH 4.8.
BC	73-115	Yellowish red (5 YR 7/8) moist, clay; moderate prismatic structure; no pores; no roots; clear smooth boundary; pH 4.8.
C	115 below	Reddish yellow (5 YR 7/8) moist, clay; massive; no pores; no roots; pH 4.8.

As roots were visible at this depth (Table 2), the effective rooting depth was only 24 cm. The low fertility level of the soil was indicated by the reddish-yellow color of the subsurface. Low organic matter, low base saturation, high Al content, low productivity levels, and a clay-to-sandy clay texture are some Ultisol traits. The soil was estimated to have a bulk density of 1.3 to 1.5 g cm^{-3} and a low pH (acidic) (Hardjowigeno, 2003). Ultisol had a low CEC due to low levels of basic cations of Ca, Mg, Na, and K.

Soil nutrient dynamics

Soil pH. The pH of the soil in the study area showed that the pH value was around 4.23-4.57 (Table 2). When soil pH is very low, appreciable amounts of Al, Fe, and Mn are highly soluble, and plants may suffer from toxicity due to these elements. Tan (1991) stated that the pH of the soil provides information related to the essential nutrients for plants. Soil pH in the study area was classified as acidic, thus affecting nutrient availability in the soil. Soil acidity limits nutrient uptake and plant growth (Mengel & Kirkby, 2001). Problems with Ultisol include acid reaction, low base saturation, and the presence of base cations such as Ca, Mg, and K. Ultisol is characterized by a high Al content and limited availability of Mo, Cu, and Zn, leading to P fixation, which in turn contributes to poor growth due to limited nutrient uptake (Haynes & Mokolobate, 2001). In turn, the high Al availability makes the soil toxic for plant growth. Moreover, pH and bulk density can affect nitrous oxide (N_2O) emissions from soils (Cui et al., 2016). Calcium carbonate buffering systems can keep pH high for > 150 years (Zhu et al., 2018). Zhang et al. (2017) found no discernible difference in the availability of N, K, or organic matter between the degraded and healthy soils.

Organic C. The organic C value of the soil in the study area was between 1.57–2.87%, and it was classified as low. This agrees with Hardjowigeno (2003), who stated that Ultisol soil had low organic C content. Ultisol soils typically exhibit low levels of organic matter (less than 1%); and excessive N fertilizer has little effect on soil organic matter (Brown et al., 2014; Gong et al., 2015; Yang et al., 2015).

Cation Exchange Capacity (CEC). The CEC of the soil in the study area ranged from 5.33 to 10.52 cmol(+) kg^{-1} and was classified as moderate. According to Mukhlis and Hanum (2011), several factors determine the amount of CEC in soil: 1) soil texture - soil with a clay texture will have a higher CEC value than soil with a sandy texture (i.e., clay is colloidal soil); 2) organic matter-organic matter is topsoil that functions as colloidal soil, and the more organic material present, the higher the CEC soil; 3) the type of clay minerals in the soil - the type of mineral clay determines the amount of CEC soil. Al-Fe and oxide-hydrate fraction-dominated soils typically exhibit a low negative charge on colloidal surfaces (Sposito, 2010), leading to low soil CEC. Mineral soils (dry land) with wet tropical climates are frequently related to this condition. On the other hand, CEC levels are generally higher in soils with moderate to high organic matter than in those with low one (Suriadikarta et al., 2002).

Total Nitrogen. The total nitrogen of the soil in the study area was around 0.05-0.56%. Low total nitrogen content was due to low C-organic content in the soil, which might be caused by leaching, evaporation, and harvesting. Hakim et al. (1986) reported that the loss of N by evaporation was greater than the loss by leaching.

Available Phosphorus. Available phosphorus ranged from 10.21 to 15.21 ppm. The Ultisol soil has low amounts of SOM, N, P, K, Ca, and Mg; and less than 24 cmol(+) kg^{-1} of CEC (Hardjowigeno, 2003).

Exchangeable Cations. The soil in the study area had a K content of 0.27 to 0.68 cmol(+) kg^{-1}. According to Naher et al (2011), the cation exchange capacity values of the soil denote a comparatively high chemical activity of soil.

The Ca content ranges from 0.97 to 1.74 cmolc kg^{-1}. Exchangeable Ca influences plant metabolism. The Mg content in the research area is 0.03-0.13 cmol(+) kg^{-1}. The clay-classified soil texture condition also influences the availability of Mg in the soil. Supriyadi (2007) asserts that the subsoil's increasing clay content increases the concentration of Mg^{2+}. The soil texture analysis in the study area was clay loam.

N, P, and K content in leaves

Nitrogen (N). A significant difference was observed between N content in leaves of treatment combinations after a year of application (Table 3). GT 1 clone with 100 RR and ethephon had the highest N content (3.66%), while the PB 260 clone with control fertilizer and no stimulation had the lowest N (1.05%). N levels in the GT 1 clone were considered optimal. Thomas (2015) conducted a study and found that the N content of rubber leaves ranged from 3.50 to 4.30%, considered an optimal category. The treatment of fertilizers and stimulation provided nutrient stability in rubber plants. This had a positive impact on latex results. GT 1 clone was in the low category in rubber production, but it increased latex production with a combination of fertilization and stimulation.

Table 3. N, P, and K content of rubber leaves at different fertilizer and ethephon levels at a year of application.

Clone	Fertilizer recommendation (%)	Stimulation	Nutrient concentration in leaves (%)		
			N	P	K
BPM 24	0	0/y	2.84gh	0.22abcdef	1.25ef
		6/y	2.97fg	0.22abcdef	1.12ijkl
	50	0/y	2.27j	0.16f	1.34cd
		6/y	2.76hi	0.24abcd	1.16hi
	100	0/y	1.05o	0.21abcdef	1.06lm
		6/y	2.97fg	0.21abcdef	1.25ef
	150	0/y	2.76hi	0.24abcd	1.25ef
		6/y	2.94fg	0.19cdef	1.07klm
GT 1	0	0/y	3.17e	0.22abcde	1.48b
		6/y	2.66hi	0.23abcd	1.55a
	50	0/y	3.46bc	0.26a	1.48b
		6/y	3.40cd	0.20bcdef	1.07klm
	100	0/y	2.42j	0.21abcdef	0.96n
		6/y	3.66a	0.22abcdef	1.09klm
	150	0/y	3.25de	0.18def	1.08klm
		6/y	2.67hi	0.22abcdef	1.44b
IRR 112	0	0/y	2.75hi	0.16f	1.15hi
		6/y	3.22de	0.25ab	1.59a
	50	0/y	1.74mn	0.19cdef	1.08klm
		6/y	1.74mn	0.16f	1.29de
	100	0/y	3.09ef	0.22abcdef	1.06m
		6/y	2.60i	0.17ef	1.36c
	150	0/y	1.86lm	0.22abcde	1.15hi
		6/y	1.73mn	0.20bcdef	1.19gh
PB 260	0	0/y	2.72hi	0.21abcdef	0.94n
		6/y	1.57n	0.19cdef	1.15hij
	50	0/y	1.95kl	0.19cdef	1.10jklm
		6/y	2.35j	0.19cdef	0.93n
	100	0/y	3.61ab	0.24abc	0.96n
		6/y	2.08k	0.19cdef	1.13ijk
	150	0/y	2.62i	0.20bcdef	1.22fg
		6/y	3.16e	0.23abcd	1.23fg

Note: Values in a column followed by the same letter(s) were not significantly different at Tukey test α=5%.

Figure 1 shows that the combination of fertilization with clones gave the highest result in N level in the GT 1 with 100 RR of 3.35%. N is needed in growth as a constituent component of various forms including chlorophyll, amino acids, enzymes, coenzymes, vitamins, and hormones (Poerwanto, 2003). Li et al. (2019) revealed that excessive N can get unsatisfactory yields because of poor fertilizer management. N can increase photosynthetic rate and chlorophyll content (Zhang et al., 2015; Luo et al., 2018). A similar trend is also found in durian, a tropical fruit (Poovarodom et al., 2001), and after reaching the optimal N rate, increasing N application caused a decreasing trend (Tung et al., 2018;

Sun et al., 2020). Rubber plants receiving fertilizer can achieve an increased concentration of N.

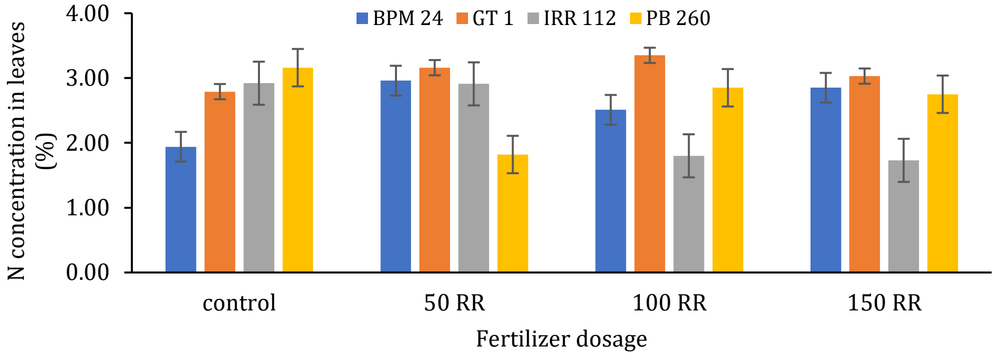

Figure 1. N concentration in leaves for a year as affected by fertilization and clone.

Phosphorus (P). There was a significant difference in the P content of different treatment combinations (Table 3). The GT 1 clone with 50 RR and without ethephon stimulation had the highest P content at 0.26%, while the IRR 112 clone with control fertilizer and without ethephon stimulation had the lowest P content at 0.16%. The P concentration in the IRR 112 clone was relatively high. This is in agreement with Thomas (2015), who stated that the P level in the rubber tree between 0.233 - 0.236% is optimal, and > 0.237% is high. Fertilizer applications can also contribute to high P levels by increasing plant nutrient availability. Marschner (1995) states leaf age determines nutrient levels due to changes in function as a sink and source. Young leaves function as sinks, so they must import mineral nutrients and photosynthates from other organs leading to high nutrient concentrations in younger leaf tissue. On the other hand, mature leaves function as a source.

Figure 2 shows that the combination of fertilization with clones had the highest P level (0.22%) of the GT 1 clone with 50 RR. In addition, changes in the growth phase change in nutrients of leaves where leaf nutrients decrease in generative phases due to older leaves translocating their nutrients to younger organs or fruit. N, P, and K are relatively mobile in plants (Burton & Kemanian, 2022).

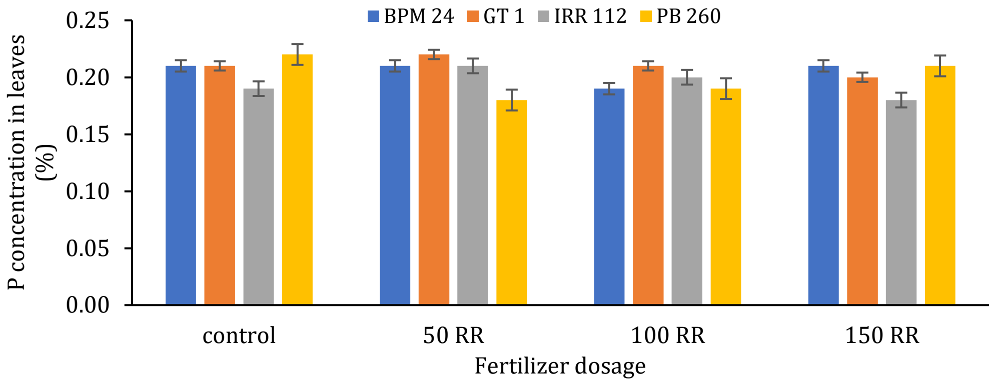

Figure 2. P concentration in leaves for a year as affected by fertilization and clone.

Potassium (K). K content in the leaves was significantly different among treatments (Table 3). The GT 1 clone with 50 RR and without ethephon stimulation had the highest K content at 1.55%, while the PB 260 clone with control fertilizer and without ethephon stimulation had the lowest K content at 0.94%. K nutrient concentration before treatment was classified as low. However, after a year of observation, the K nutrient concentration reached its optimal level. This follows Thomas' research (2015), which states that K nutrient content in rubber plants between 1.31-1.40% is optimal and >1.41% is high. Fertilization positively impacted K nutrients, but adding a stimulant did not alter their concentration. Optimal K nutrient conditions and stimulant application produced higher rubber production than controls.

Figure 3 showed that the combination of fertilization with clones had the highest results at the K concentration of IRR 112 clones with 50 RR of 1.47%. Sumner (1977) reported that the N, P, and K levels in soybeans decrease with increasing age of growth, while the levels increase when the leaf position approaches the shoots. In mangosteen, leaves in the middle and bottom sectors do not show significant differences in the concentration of N, P, and K; only the concentration of N from the east differs, being higher than that from the west, south, and north (Poovarodom et al., 2001). The formation of new leaves after the fall phase of the natural leaves of rubber plants resulted in a decrease in latex production.

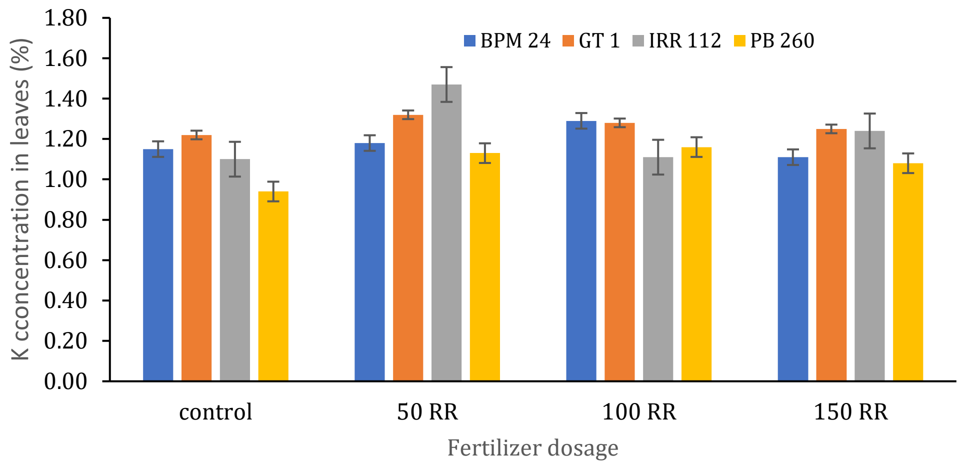

Figure 3. K concentration in leaves for a year as affected by fertilization and clone.

N, P, and K nutrient uptake

Nitrogen (N). There was a significant difference in the N uptake of different treatment combinations (Figure 4). The PB 260 clone with 100 RR and without ethephon stimulation showed the highest N uptake content at 1.08 mg per tree, while the PB 260 clone with control fertilizer and ethephon stimulation showed the lowest at 0.25 mg per tree. Plants that received fertilizer and stimulants showed significant differences in nutrient uptake. According to Zubachtirodin et al. (2004), optimal nutrient status, nutrient concentration, and N, P, and K uptake in plant tissue reflect healthy plant development. GT 1 and PB 260 clones showed the highest N uptake during one year of observation. The addition of N to the soil, following a 100 RR treatment, disrupted the balance between NO^{3-} and NH^{4+} in the soil solution, enabling direct absorption of both ions by plant roots or mass flow processes. The N rate could be reduced by 25% compared to the N rate under maximum yield (Wang et al., 2017). This process involves the transfer of nutrients from the soil to the plant's root surface in tandem with water movement.

Figure 5 shows N uptake in various clones. GT 1 showed the highest N nutrient uptake at 0.77 mg per tree and the lowest at 0.63 mg per tree in the BPM 24 clone. Miza (2009) states that at low temperatures, NH_4^+ absorbs more quickly than NO_3^-, in contrast to at high temperatures. At neutral pH, ammonium is absorbed well, and its absorption decreases with decreasing pH, while NO_3^- is absorbed more quickly at low pH values (Miza, 2009; Zhou et al., 2016). Hu et al. (2016) found that rice plants treated with chemical fertilizers accumulate a higher content of available nitrogen (NH^{4+} and NO^{3-}) and reduced soil bacteria (Wei et al., 2018). N uptake by grain and straw was higher in high N efficiency genotypes (Vijayalakshmi et al., 2015).

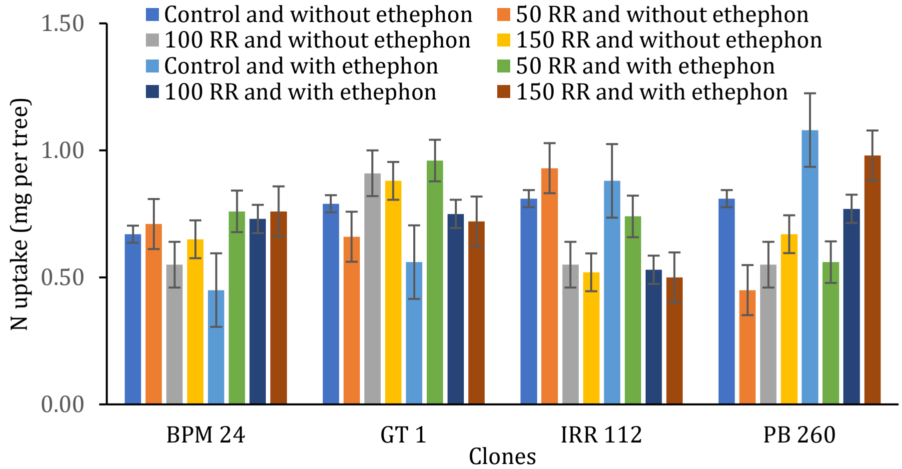

Figure 4. Nitrogen uptake (mg per tree) as affected by fertilization and ethephon stimulation (* = significant at 5% significance level).

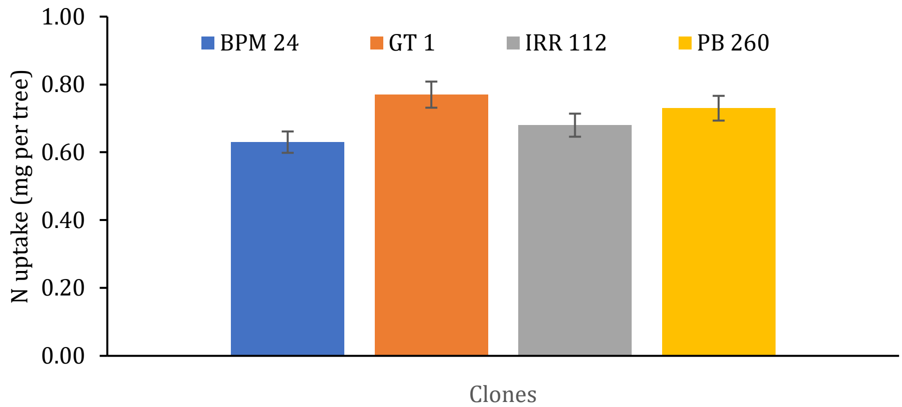

Figure 5. N uptake in a year as affected by clone.

Phosphorus (P). A significant difference was observed in the P uptake of different treatment combinations (Figure 6). The PB 260 clone with 150 RR and ethephon showed the highest P uptake content at 0.07 mg per tree, while the BPM 24 clone with 50 RR and no ethephon stimulation showed the lowest at 0.04 mg per tree. P supplement application increased P uptake. The PB 260 and IRR 112 clones appeared to have a high P nutrient uptake when treated with 150 RR and ethylene. High P uptake by P application is likely due to fertilizers being in balance condition and their placement at newly formed root hairs, which speeds up root absorption. Hardjowigeno (2003) stated that root absorption ability decreases by increasing root length.

Figure 7 shows P uptake on various clones. The PB 260 clone exhibited the highest P nutrient uptake at 0.06 mg per tree, while the BPM 24 clone had the lowest uptake at 0.06 mg per tree. Plants convert some absorbed phosphorus into phytate, a difficult-to-use nutrient (Zul et al., 2006). The form of N also influences the uptake of phosphorus. If N is added as NO_3^-, more negatively charged particles are taken up than positively charged particles. This causes OH^- to leave the root and make the pH on the root surface higher than the soil solution's pH, allowing P to be taken up. If N is added in the form of NH^+, cation uptake is greater than the anion so that H+ is released from the root, and the root surface pH becomes more acidic than the soil solution (Miza, 2009). According to studies by Zhu et al. (2016) and Akram et al. (2017), harvest index and biomass increased grain and chili yield. Modifications of nutrient management other than NPK are likely required to sustain higher yield levels (Mussgnug et al., 2006).

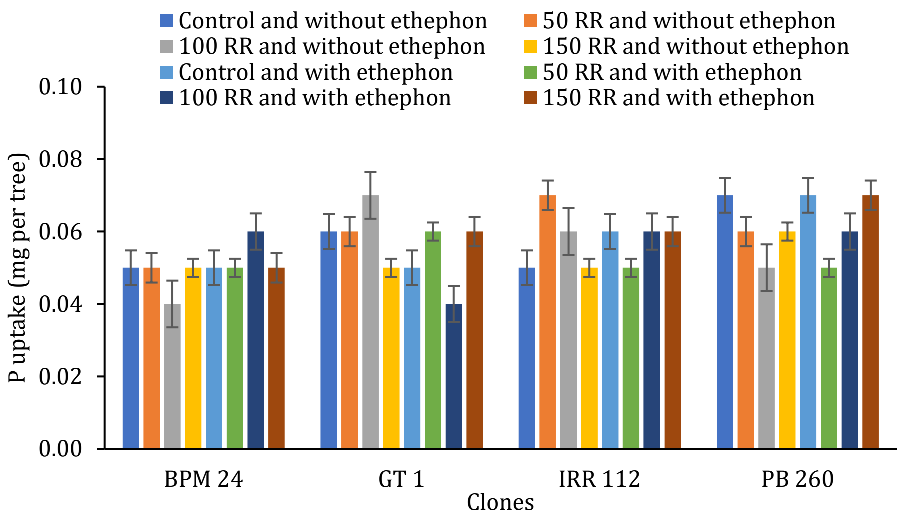

Figure 6. Phosphorus uptake (mg per tree) as affected by fertilization and ethephon stimulation (* = significant at 5% significance level).

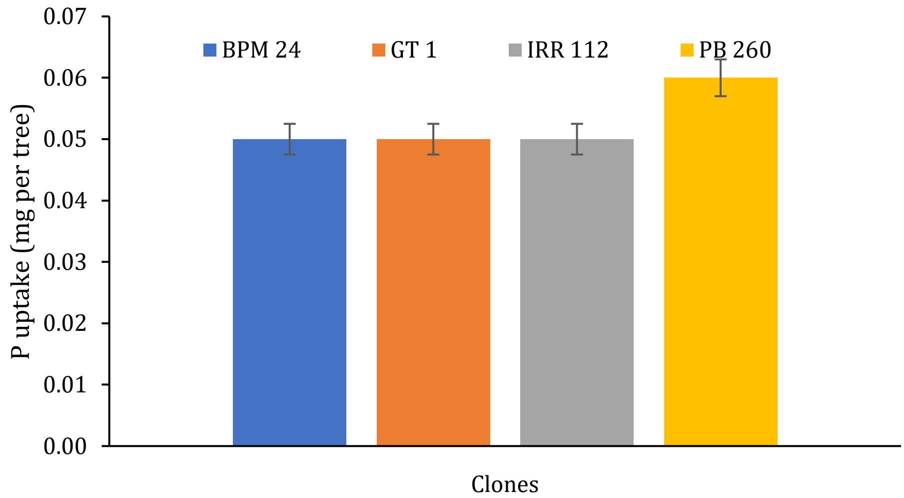

Figure 7. P uptake in a year as affected by clone.

Potassium (K). There was a significant difference in the potassium uptake of different treatment combinations (Figure 8). The GT 1 clone with 50 RR and without ethephon stimulation had the highest K uptake content at 0.46 mg per tree, while the PB 260 clone with control fertilizer and no ethephon stimulation had the lowest at 0.22 mg per tree. Excessive nutrients can harm the plant, disrupting its growth and development. The K nutrient uptake indicates that fertilized plants absorb more nutrients. GT 1 clone had greater K uptake than BPM 24, IRR 112, and PB 260 clones. The GT 1 clone's research location had a moderate CEC content, making the K in the soil solution the highest available to plants. Adding K element through fertilizer in soil solution can increase the amount of K exchangeable. Sutedjo (2008) reports that there are three forms of K in the soil: unavailable, instantly available, and slowly available.

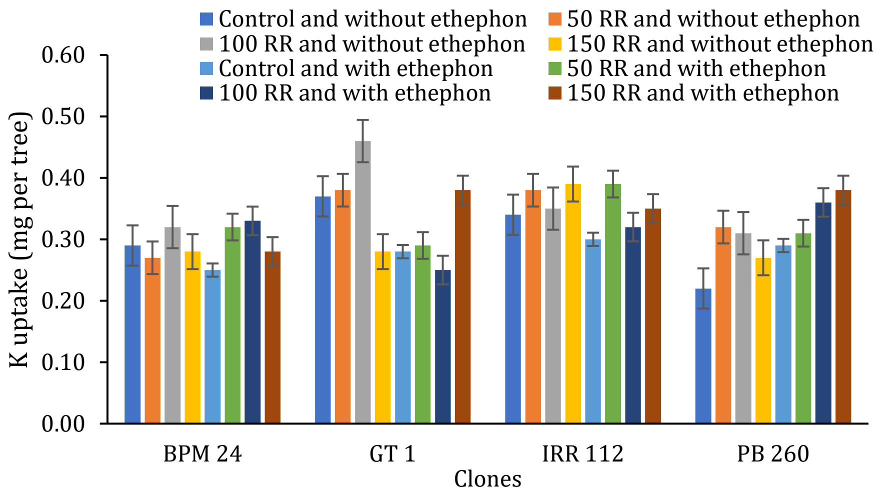

Figure 8. Potassium uptake (mg per tree) as affected by fertilization and ethephon stimulation (* = significant at 5% significance level).

Figure 9 shows K uptake in various clones. IRR 112 showed that the highest K nutrient uptake was 0.36 mg per tree, and the lowest was at BPM 24 clone of 0.29 mg per tree. Munawar (2011) noted that plants primarily utilize exchangeable K cation (K-dd), with a negligible amount being dissolved. However, because K-dd and K dissolve in balance, if the concentration of dissolved K decreases due to absorption by plants, there will soon be a supply of K from K-dd. Thus, experts recommended an optimum dose of potassium for maintaining adequate K for plants (Bista & Bhandari, 2019; Ojha et al., 2021). Diffusion regulates the movement of K^+ from the soil solution to the plant roots, and the rubber plant roots primarily absorb the K nutrients in the soil solution and those added. K application increased the proportion of biomass (Hu et al., 2015). Lester et al. (2010) recommended foliar K fertilization and various K forms.

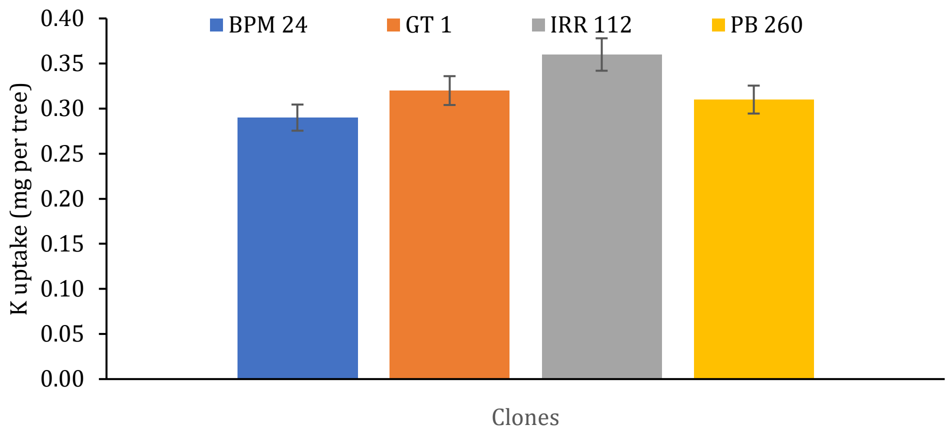

Figure 9. K uptake in a year as affected by clone.

CONCLUSIONS

Soil properties were improved by fertilization. Organic-C, CEC, total nitrogen, available phosphorus, and exchangeable cation increased across GT 1, BPM 24, PB 260, and IRR 112 rubber clones. Tissue analysis and nutrient content significantly differed between fertilization and stimulation in all clones. Fertilization recommendations are needed yearly to analyze crop nutrient deficiencies so that nutritional needs can be amended through fertilization. Further research needs to be done on which chemical fertilizers with biological fertilizers can induce nutrient availability in poor soil conditions that are relatively low in nutrient availability.

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REFERENCES

Akram, M., Hussain, S., Hamid, A., Majeed, S., Chaudary, S. A., Shah, Z. A., Yaqoob, A., Kayani, F., Arif, U., Fareed, K., Jamil, F., Mehmood, Z., Basher, S., Arif, A. A., & Akhter, N. (2017). Interactive effect of phosphorus and potassium on growth, yield, quality and seed production of chili (*Capsicum annuum* L.). *Journal of Horticulture, 4*(1), 192. https://doi.org/10.4172/2376-0354.1000192

Bista, B., & Bhandari, D. (2019). Potassium fertilization in potato. *International Journal of Applied Sciences and Biotechnology*, *7*(2), 153-160. https://doi.org/10.3126/ijasbt.v7i2.24636

Brown, K. H., Bach, E. M., Drijber, R. A., Hofmockel, K. S., Jeske, E. S., Sawyer, J. E., Castellano, M. J. (2014). A long-term nitrogen fertilizer gradient has little effect on soil organic matter in a high-intensity maize production system. *Global Change Biology, 20*(4), 1339–1350. https://doi.org/10.1111/gcb.12519

Burton, A. B., & Kemanian, A. R. (2022). Assessing a century of maize and soybean polyculture for silage production. *Agronomy Journal, 114*(3), 1615–1626. https://doi.org/10.1002/agj2.21006

Chantuma, P., Lacointe, A., Kasemsap, P., Thanisawanyangkura, S., Gohet, E., Clement, A., Guilliot, A., Ameglio, T., & Thaler, P. (2009). Carbohydrate storage in wood and bark of rubber trees submitted to different levels of c demand induced by latex tapping. *Tree Physiology, 29*(8)*,* 1021-1031. https://doi.org/10.1093/treephys/tpp043

Chantuma, P., Thanisawanyangkura, S., Kasemsap, P., Gohet, E., & Thaler, P. (2006). Distribution patterns of latex sucrose content and concurrent metabolic activity at the trunk level with different tapping systems and in latex production bark of *Hevea brasiliensis*. *Kasetsart Journal (Natural Science), 40,* 634-642.

Chapman, H. D. (1965). Cation exchange capacity*.* In A. G. Norman (Ed.), *Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties, 9.2* (pp. 891-901). ASA. https://doi.org/10.2134/agronmonogr9.2.c6

Cui, P., Fan, F., Yin, C., Song, A., Huang, P., Tang, Y., Zhu, P., Peng, C., Li, T., Wakelin, S. A., & Liang, Y.(2016). Long-term organic and inorganic fertilization alters temperature sensitivity of potential N_2O emissions and associated microbes. *Soil Biology & Biochemistry, 93,* 131–141. https://doi.org/10.1016/j.soilbio.2015.11.005

D'auzac., & Jacob. J. L. (1984). Physiology of the laticiferous system in hevea basis and application to productivity. *Proceeding of Intl. Rubb. Res. Dev. Board Coll. Expl. Physiol. Am. Hevea*, *1*(2).

Dewis, J., & Freitas, F. (1970). *Physical and Chemical Methods of Soil and Water Analysis*. FAO Soils Bulletin 10.

Gohet, E., Scomparin, C., Cavaloc, E., Balerin, Y., Benites, G., Dumortier, F., Williams, H., Permadi, H. P., Ginting, E., De Rostolan, E., Uche, E., Chegbene, P., Hocepied, E., Echimane, P., Saumahoro, M., Sargeant, H. J., Suyatno., Najera, C.A., Saumahoro, B., Lacote, R., & Eschbach, J. M. (2008). Influence of ethephon stimulation on latex physiological parameter and consequences on latex diagnosis implementation in rubber agro-industry. In M.Y.S. Irrdb (Ed.). *IRRDB Workshop: Latex Harvesting Technology* (pp. 1 – 11).

Gong, L., Ran, Q., He, G., & Tiyip, T. (2015). A soil quality assessment under different land use types in Keriya river basin, Southern Xinjiang, China. *Soil and Tillage Research, 146*(B)*,* 223–229. https://doi.org/10.1016/j.still.2014.11.001

Hakim, N., Nyakpa, M. Y., Lubis, A. M., Nugroho, S. G., Saul, M. R., Diha, M., Hong, G. B., & Bailey, H. H. (1986). *Basic Soil Science*. Lampung University.

Hardjowigeno, S. (2003). The development of peatlands for agriculture is an opportunity and a challenge. Scientific Oration Professors of Soil Science Faculty of Agriculture, Bogor Agricultural University

Haynes, R. J., & Mokolobate, M. S. (2001). Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanism involved. *Nutrient Cycling in Agroecosystems, 59,* 47-63. https://doi.org/10.1023/A:1009823600950

Hu, W., Yang, J., Meng, Y., Wang, Y., Chen, B., Zhao, W., Oosterhuis, D. M., & Zhou, Z. (2015). Potassium application affects carbohydrate metabolism in the leaf, subtending the cotton (*Gossypium hirsutum* L.) boll and its relationship with boll biomass. *Field Crops Research, 179,* 120–131. https://doi.org/10.1016/j.fcr.2015.04.017

Hu, X. F., Cheng, C., Luo, F., Chang, Y. Y., Teng, Q., Men, D. Y., Liu, L., & Yang, M. Y. (2016). Effects of different fertilization practices on the incidence of rice pests and diseases: a three-year case study in Shanghai, in subtropical southeastern China. *Field Crops Research, 196,* 33–50. https://doi.org/10.1016/j.fcr.2016.06.004

Lester, G. E., Jifon, J. L., & Makus, D. J. (2010). Impact of potassium nutrition on postharvest fruit quality: melon (*Cucumis melo* L) case study. *Plant and Soil, 335*, 117–131. https://doi.org/10.1007/s11104-009-0227-3

Li, S., Lei, Y., Zhang, Y., Liu, J., Shi, X., Jia, H., Wang, C., Chen, F., & Chu, Q. (2019). Rational trade-offs between yield increase and fertilizer inputs are essential for sustainable intensification: a case study in wheat–maize cropping systems in China. *Science of The Total Environment, 679*, 328–336. https://doi.org/10.1016/j.scitotenv.2019.05.085

Luo, Z., Liu, H., Li, W., Zhao, Q., Dai, J., Tian, L., & Henzong, D. (2018). Effects of reduced nitrogen rate on cotton yield and nitrogen use efficiency as mediated by application mode or plant density. *Field Crops Research, 218,* 150–157. https://doi.org/10.1016/j.fcr.2018.01.003

Marschner, H. (1995). *Mineral nutrition in higher plants.* Academic Press.

Mengel, K., & Kirkby, E. A. (2001). *Principles of Plat Nutrition 5th Edn*. Elsevier Academic Publisher.

Miza. (2009). *Analysis of gm and ps-ipb 1 sugar cane of N and P elements which expressed by phytase gene*. [Bachelor's Thesis, Bogor Agriculture University]. Bogor Agricultural University Digital Repository.

Mukhlis. S., & Hanum, H. (2011). *Soil Chemistry, Theory, and Application*. USU Press.

Munawar, A. (2011). *Soil Fertility and Plant Nutrition*. IPB Press.

Mussgnug, F., Becker, M., Son, T. T., Buresh, R. J., & Vlek, P. L. G. (2006). Yield gaps and nutrient balances in intensive, rice-based cropping systems on degraded soils in the Red River Delta of Vietnam. *Field Crops Research, 98*(2–3), 127–140. https://doi.org/10.1016/j.fcr.2005.12.012

Naher, N., Uddin, M. K., & Alam, A. K. M. M. (2011). Impacts of salinity on soil properties of coastal areas in Bangladesh. *Agrivita Journal of Agricultural Science, 33*(2), 161-172.

Ojha, R. B., Shrestha, S., Khadka, Y. G., & Panday, D. (2021). Potassium nutrient response in the rice-wheat cropping system in different agro-ecozones of Nepal. *PLoS One, 16*(3), e0248837.. https://doi.org/10.1371/journal.pone.0248837

Peech, M. (1965). Hydrogen-ion activity. In C. A. Black et al. (Eds.). *Methods of soil analysis Part 2* (pp. 914-926), ASA.

Poerwanto, R. (2003). *Fruit Cultivation Teaching Material Module VII.* Horticulture Study Program, Faculty of Agriculture, Bogor Agriculture University.

Poovarodom, S., Mairaing, S., Ketsayom, P., Tawinteung, N., & Prasittikhet, J. (2001). Seasonal variations in nutrient concentrations of durian (*Durio zibethinus* Murr.) leaves. *Acta Horticulturae, 564*, 235-242. https://doi.org/10.17660/ActaHortic.2001.564.27

Sarruge, J. R., & Haag, H. P. (1974). *Análises químicas em plantas.* Piracicaba: USP/ESALQ – Depto. de Química.

Siahaan, M. (2024). *Rubber industry in Indonesia – statistics & facts*. Statista. https://www.statista.com/topics/8041/rubber-industry-in-indonesia

Silpi, U., Lacointe, A., Kasempsap, P., Thanysawanyangkura, S., Chantuma, P., Gohet, E., Musigamart, N., Clément, A., Améglio, T., & Thaler, P. (2007). Carbohydrate reserves as a competing sink: evidence from tapping rubber trees. *Tree Physiolog*y, 27(6), 881-889. https://doi.org/10.1093/treephys/27.6.881

Silpi, U., Thaler, P., Kasemsap, P., Lacointe, A., Chantuma, A., Adam, B., Gohet, E., Thanisawanyangkura, S., & Ameglio, T. (2006). Effect of tapping activity on the dynamics of radial growth of *Hevea brasiliensis* trees. *Tree Physiology, 26*(12), 1579-1587. https://doi.org/10.1093/treephys/26.12.1579

Sposito, G. (2010). *The Chemistry of Soils.* Oxford Univ. Press.

Sumner, M. E. (1977). Preliminary N, P, and K foliar diagnostic norms for soybeans. *Agronomy Journal, 69*(2), 226-230. https://doi.org/10.2134/agronj1977.00021962006900020008x

Sun, J., Li, W., Li, C., Chang, W., Zhang, S., Zeng, Y., Zeng, C., & Peng, M. (2020). Effect of different rates of nitrogen fertilization on crop yield, soil properties and leaf physiological attributes in banana under subtropical regions of China. *Frontiers Plant Science, 11*, 613760. https://doi.org/10.3389/fpls.2020.613760

Supriyadi. (2007). *The availability of Macronutrients in Agricultural Land in Pacitan Regency*. LPPM UNS.

Suriadikarta, D. A., Prihatini, T., Setyorini, D., & Hartatiek, W. (2002). Management of soil organic materials technology. In A. Adimiharja (Ed.), *Dry land management technology towards productive and environmentally friendly agriculture*. Center for Land and Agro-climate Research and Development.

Sutedjo, M. M. (2008). *Fertilizers and Fertilizing Methods*. Rineka Cipta Press.

Tan, K. H. (1991). *Basic soil chemistry*. Gadjah Mada University Press. Yogyakarta.

Thomas, T. (2015). *Recommendations for Fertilizing Rubber Plants in Sembawa Research Center*. Indonesian Rubber Research Institute.

Tufaila, T., Leomo, M. S., & Alam, S. (2014). *Marginal Land Management Strategy*. Unhalu Press.

Tung, S. A., Huang, Y., Ali, S., Hafeez, A., Shah, A. N., Song, X., Ma, X., Luo, D., & Yang, G. (2018). Mepiquat chloride application does not favor leaf photosynthesis and carbohydrate metabolism as well as lint yield in late-planted cotton at high plant density. *Field Crops Research, 221*, 108–118. https://doi.org/10.1016/j.fcr.2018.02.027

Vijayalakshmi, P., Vishnukiran, T., Kumari, B. R., Srikanth, B., Rao, I. S., Swamy, K. N., Surekha, K., Sailaja, N., Subbarao, L. V., Rao, P. R., Subrahmanyam, D., Neeraja, C. N., & Voleti, S. R. (2015). Biochemical and physiological characterization for nitrogen use efficiency in aromatic rice genotypes. *Field Crops Research, 179,* 132–143. https://doi.org/10.1016/j.fcr.2015.04.012

Wang, H., Zhang, Y., Chen, A., Liu, H., Zhai, L., Lei, B., & Ren, T. (2017). An optimal regional nitrogen application threshold for wheat in the North China Plain considering yield and environmental effects. *Field Crops Research, 207*, 52–61. https://doi.org/10.1016/j.fcr.2017.03.002

Wei, W., Yang, M., Liu, Y., Huang, H., Ye, C., Zheng, J., Guo, C., Hao, M., He, X., & Zhu, S. (2018). Fertilizer N application rate impacts plant-soil feedback in a sanqi production system. *Science of the Total Environment, 633*, 796–807. https://doi.org/10.1016/j.scitotenv.2018.03.219

Wijaya, W. (2008). *Soil and Climate Sustainability for Rubber Plant.* Sembawa Research Centre.

Yang, J., Gao, W., & Ren, S. (2015). Long-term effects of combined application of chemical nitrogen with organic materials on crop yields, soil organic carbon, and total nitrogen in fluvo-aquic soil. *Soil Tillage Resource, 151*, 67–74. https://doi.org/10.1016/j.still.2015.03.008

Zhang, H., Wang, R., Chen, S., Qi, G., He, Z., & Zhao, X. (2017). Microbial taxa and functional genes shift in degraded soil with bacterial wilt. *Scientific Reports, 7*, 39911. https://doi.org/10.1038/srep39911

Zhang, S., Gao, P., Tong, Y., Norse, D., Lu, Y., & Powlson, D. (2015). Overcoming nitrogen fertilizer over-use through technical and advisory approaches: a case study from Shaanxi Province, northwest China. *Agricultural Ecosystem and Environment, 209*, 89–99. https://doi.org/10.1016/j.agee.2015.03.002

Zhou, M., Zhu, B., Bruggemann, N., Dannenmann, M., Wang, Y., & Butterbach-Bahl, K. (2016). Sustaining crop productivity while reducing environmental nitrogen losses in the subtropical wheat-maize cropping systems: a comprehensive case study of nitrogen cycling and balance. *Agriculture Ecosystem and Environment, 231*, 1–14. https://doi.org/10.1016/j.agee.2016.06.022

Zhu, G., Peng, S., Huang, J., Cui, K., Nie, L., & Wang, F. (2016). Genetic improvements in rice yield and concomitant increases in radiation and nitrogen use efficiency in middle reaches of Yangtze River. *Science Reports, 6,* 21049. https://doi.org/10.1038/srep21049

Zhu, Q., Liu, X., Hao, T., Zeng, M., Shen, J., Zhang, F., & de Vries, W. (2018). Modeling soil acidification in typical Chinese cropping systems. *Science of the Total Environment, 614*, 1339–1348. https://doi.org/10.1016/j.scitotenv.2017.06.257

Zubachtirodin., Buntan, A., Saenong, S., Subandi., & Hipi, A. (2004). *Rationalization of N, P, and K fertilization for Corn in a Dry Climate in East Lombok*. Agricultural Technology Study Center.

Zul, R. H., Purwito, A., & Santosa, D. A. (2006). Effect of addition of bap and kinetin to media on regeneration and growth of cane calli var. CB 6979. In S. Sujiprihati et al. (Eds.). *Proceedings of the National Seminar on Biotechnology and Plant Breeding* (pp. 454–457). Department of Agronomy and Horticulture, Faculty of Agriculture Bogor Agricultural University.