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Establishment of a fertilizer formula for plant pineapple (*Ananas comosus* L.) cultivated in acid sulfate soil

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Abstract

The objective of the current study was to (1) construct an optimal fertilizer formula for plant pineapple in acid sulfate soil in Hau Giang and (2) evaluate the capacity of the acid sulfate soil to supply nutrients (N, P, K, Ca, and Mg) that can enhance plant pineapple growth and yield. A completely randomized block design was applied with 8 treatments and 4 replications each. The treatments were as follows: (1) no fertilization, (2) NPKCaMg: full fertilization of N, P, K, Ca, and Mg, (3) PKCaMg: fertilization omitting N, (4) NKCaMg: fertilization omitting P, (5) NPCaMg: fertilization omitting K, (6) NPKMg: fertilization omitting Ca, (7) NPKCa: fertilization omitting Mg, and (8) FFP: farmers' fertilizer practice. The calculated fertilizer formula for plant pineapple in acid sulfate soil in Hau Giang was 488 N-359 P_2O_5-407 K_2O-1108 CaO-568 MgO kg/ha. The N, P, K, Ca, and Mg supplying capacities were 44.4, 11.9, 42.3, 10.2, and 13.1 kg/ha, respectively. Meanwhile, the group with SSNM fertilization increased growth and consequently enhanced plant pineapple yield by 30.2% higher than the group with FFP fertilization. The new recommended fertilizer formula should be applied to the indigenous soil for sustainable local pineapple cultivation.

Keywords: Acid sulfate soil, Plant nutrition, Plant pineapple, Site-specific nutrient management

1. Introduction

Pineapple (*Ananas comosus* L.) is known as one of the major fruits worldwide, ranking the third after banana and citrus [1]. Pineapple fruit is undeniably healthy because it contains several types of vitamins, especially an enzyme of bromelain which aids in protein digestion [2]. In addition, by-products from pineapple can be utilized domestically or exported in cans; that is, pineapple waste can be fed to cattle, and pineapple stem and leaves can be recycled as paper powder [3]. The pineapple can be divided into two types of fruiting. The first one is the plant pineapple growing from crowns and suckers planted on a new field. The other is the ratoon pineapple growing from shoots of a central stalk that has been cut down [4,5]. The optimum condition for pineapple growth differs among varieties. However, generally, it should be grown in high humidity (above 70%), in moderate temperature (22-32°C), in acidic soil (pH = 4.5-5.5), and with a fertilizer formula (6-10 g N, 1-4 g P_2O_5, and 4-15 g K_2O per plant) [6]. In Vietnam, pineapple is mainly grown in acid sulfate soil and concentrated in Hau Giang, where low soil fertility is a limiting factor for pineapple yield [7]. The acid sulfate soil is well known to be low in pH (2.5-2.62) and poor in nutrients (61.7-78.5 mg NH_4^+ kg^{-1}, 21.7-38.3 mg NO_3^- kg^{-1}, 3.69-5.24 mg P kg^{-1}, 0.09-0.14 meq K^+ 100 g^{-1}, 2.18-2.62 meq Mg^{2+} 100 g^{-1}, 1.12-1.45 meq Ca^{2+} 100 g^{-1}, and 3.58-3.77%) [8]. Meanwhile, for planting pineapple (after plantation), plants highly require nutrients, and this rises dramatically from the 7th to the 12th month [9]. Thus, fertilizer is a vital factor that maintains and increases yield as well as productivity of crops [10]. Still, farmers usually cause imbalance in nutrient supply over a long period of time, resulting in a change in soil fertility and consequently lower pineapple yield and fruit quality [11]. As summarized by Souza and Reinhardt [6], the requirement for nutrients of pineapples is ranked as K > N > P > Mg > Ca. K plays a key role in fruit quality. When the soil lacks K, yellow spots appear and expand on leaves, peduncle is weak, and fruits are small,

less acidic, and less aromatic. N and P play a role in fruit productivity. Lacking N and P results in lower pineapple yield. Mg and Ca affect pineapple growth as chlorophyll content and shoot development, respectively. However, excessive amounts of N fertilizer could result in reductions in the fruit quality aspect. Therefore, assessing a suitable portion for each nutrient for pineapples is extremely vital. The specific-site nutrient management (SSNM) is a popular approach to quantify the amounts of nutrients required for plants based on their demands and the nutrient-providing capacity of soil. It also contributes to enhancing fertilizer use efficiency and benefiting people's finances [12]. Furthermore, this fertilizing method helps reduce excessive amounts of fertilizer over the recommendation, which inhibits adverse effects on the environment and emissions of greenhouse gases [13]. Nevertheless, the SSNM method has not been applied to constructing fertilizer formulas for planting pineapples in Hau Giang province. Therefore, the current study aimed to (1) establish a fertilizer formula for pineapple cultivated in acid sulfate soil in Hau Giang and (2) evaluate the ability of acid sulfate soil to supply nutrients that can enhance plant pineapple growth and yield.

2. Materials and methods

2.1 Materials

In Tan Tien commune, Vi Thanh city, Hau Giang province, the experiment was conducted in acid sulfate soil from November 2019 to May 2021. Acid sulfate soil specified for growing pineapple was utilized, and its characteristics at the beginning of the crop are introduced in Table S1. It was propagated from slips derived from the local Queen pineapple cultivar. Fertilizers of urea (46% N), DAP (18% N, 46% P_2O_5), potassium chloride (60% K_2O), lime (60% CaO), and magnesium (92% MgO) were utilized.

2.2 Methods

The experiment was designated as completely randomized blocks, containing four replications. In particular, there were eight treatments: (1) unfertilized, (2) NPKCaMg: fully fertilized with N, P, K, Ca, and Mg, (3) PKCaMg: nitrogen (N) omitted fertilization, (4) NKCaMg: phosphorus (P) omitted fertilization, (5) NPCaMg: potassium (K) omitted fertilization, (6) NPKMg: calcium (Ca) omitted fertilization, (7) NPKCa: magnesium (Mg) omitted fertilization, and (8) FFP: farmers' fertilizer practice. The size of each experimental plot was 5 m × 5 m. The plant density was 0.40 m × 0.55 m. It was 450 N-320 P_2O_5-360 K_2O-1000 CaO-500 MgO kg/ha, with 113 plants in each plot, while that in the FFP treatment was 720 N-540 P_2O_5 kg/ha. Soil samples collected from the soil depth of 0-20 and 20-40 cm at harvesting were analyzed and summarized by Sparks et al. [14].

For growth evaluation, twenty plant pineapples were collected at harvesting to determine growth parameters. Plant height (cm) was measured from the ground to the peak of the highest leaf; leaves number on a plant (leaves) was counted as the total number of leaves on a pineapple plant; D-leaf length (cm) was measured between both ends of a leaf; D-leaf width (cm) was measured at the widest position of a D-leaf; peduncle length (cm) was measured between both ends of a peduncle; peduncle diameter (cm) was measured at three spots (head, middle, and bottom) of a peduncle and averaged; crown length (cm) was measured from the bottom to the peak of a crown; and crown diameter (cm) was measured at the head of a crown.

At harvesting, twenty pineapple fruits were collected to determine fruit length (cm, measurement between both ends of a fruit), fruit diameter (cm, the mean of measurements at the head, the middle, and the bottom of a fruit), and fruit yield (t/ha, conversion from fruit weight in 5 m^2 of each treatment to t/ha).

Twenty pineapple fruits at harvesting were analyzed for water content (mL, quantified juice extracted from fruit), Brix index (%, measurement by a refractometer), pH (measurement by a pH meter), TA content (titration with 0.01 N NaOH after being extracted with distilled water at 1:25 ratio), vitamin C content (after extracted with HCl and 1% oxalic acid, titration with 0.001 N 2,6 dichlorophenolindophenol-DIP, and colors (L^*, a^*, and b^*, measurement at the head, the middle, and the bottom of fruit by CR-20 color reader).

From each treatment, five plant samples at harvesting were collected and dried to analyze contents of N, P, K, Ca, and Mg in the crown, pulp, core, shell, slips, peduncle, stem, and leaves of pineapple following the methods summarized by Houba et al. [15].

This was determined as multiplication of nutrient uptakes in stovers of pineapple including stem, leaves, crown, peduncle, slips, shell, pulp, and core in the treatment unfertilized with each of N, P, K, Ca, and Mg, and dry biomass in these corresponding stovers.

This was determined as yield obtained in the plot with full fertilization of NPKCaMg and yield in the plot omitting each of N, P, K, Ca, and Mg.

This was determined as responses of yield and amounts of fertilizers from each nutrient. FX (kg/ha) = (FY-FY_{0X}) AE_X^{-1}, where X is nutrients of N, P, K, Ca, and Mg, FX is the nutrient required for the desired yield, FY is the desired yield, FY_{0X} is the yield in the treatment unfertilized with a corresponding nutrient (t/ha), and AE_X is

the agronomic efficiency ($kg_{pineapple}$ $kg_{fertilizer}^{-1}$) [16]. The SPSS software, version 13.0, was utilized for performing variance analysis and comparison between differences of means of different treatments via Duncan's post-test.

3. Results

3.1 Effects of site-specific nutrient management on chemical characteristics of soil for plant pineapple cultivation

In Table S2, the treatments omitting each of N, P, K, and Ca resulted in lower concentrations of NH_4^+, $P_{soluble}$, K^+, and Ca^{2+}, corresponding to 20.0, 23.7 mg/kg and 0.153, 0.60 meq 100 g^{-1}, compared to the treatment with full fertilization of NPKCaMg (40.2, 38.1 mg/kg and 0.183, 3.49 meq 100 g^{-1}). In addition, the treatment with P fertilization resulted in reduced Al^{3+} toxin content (3.50-4.19 meq 100 g^{-1}), as against the treatment omitting P (4.42 meq 100 g^{-1}), while the treatments without fertilization of each of P and Ca possessed higher Fe^{2+} content, compared to treatments which had P and Ca fertilization. The soil chemical properties in the depth of 20-40 cm are recorded in Table S3.

3.2 Effects of site-specific nutrient management on dry biomass in plant pineapple

Dry biomass in crown, pulp, core, shell, slips, peduncle, stem, and leaves in the treatment with SSNM-following fertilization resulted in the highest results (510.7, 1935.5, 422.6, 1807.4, 574.1, 313.5, 903.9, and 6926.4 kg/ha, respectively) and the treatment with no fertilization had the lowest ones (189.9, 698.5, 171.9, 753.8, 146.9, 138.1, 415.9, and 3485.1 kg/ha, respectively). Furthermore, the results in the treatment omitting N fertilization were lower than those in the treatments omitting each fertilization of P, K, Ca, and Mg (Table 1).

Table 1 Effects of fertilizing N, P, K, Ca, and Mg on dry biomass in plant pineapple grown in acid sulfate soil.

Treatment	Dry biomass (kg/ha)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
No fertilizer	189.9^{g}	698.5^{e}	171.9^{f}	753.8^{f}	146.9^{f}	138.1^{e}	415.9^{g}	3485.1^{h}
NPKCaMg	510.7^{a}	1935.5^{a}	422.6^{a}	1807.4^{a}	574.1^{a}	313.5^{a}	903.9^{a}	6926.4^{a}
PKCaMg	291.5^{f}	1231.9^{d}	322.9^{d}	1059.1^{e}	157.7^{f}	209.0^{d}	769.4^{c}	4442.4^{g}
NKCaMg	394.9^{d}	1615.7^{b}	325.0^{cd}	1443.9^{c}	359.5^{e}	223.6^{c}	663.4^{e}	5535.6^{e}
NPCaMg	313.9^{e}	1340.8^{c}	258.0^{e}	1558.3^{b}	440.9^{d}	230.3^{bc}	853.6^{b}	6239.9^{c}
NPKMg	422.2^{bc}	1632.0^{b}	346.0^{b}	1430.2^{cd}	446.3^{cd}	244.5^{b}	745.3^{d}	6058.0^{d}
NPKCa	406.3^{cd}	1586.7^{b}	336.6^{bc}	1383.1^{d}	472.6^{c}	240.2^{b}	762.1^{cd}	6518.6^{b}
FFP	441.4^{b}	1292.6^{c}	253.9^{e}	1395.1^{de}	511.9^{b}	236.2^{bc}	569.5^{f}	5253.1^{f}
Significance level	*	*	*	*	*	*	*	*
CV (%)	3.87	2.33	2.86	1.80	4.72	4.21	1.90	1.34

3.3 Effects of site-specific nutrient management on total nutrient uptakes in plant pineapple

The concentrations of N, P, K, Ca, and Mg are recorded in Tables S4-S8. These contents were utilized for calculations for each corresponding uptake part (Tables S9-S13). When NPKCaMg was fully fertilized, total N, P, K, Ca, and Mg uptake peaked at 94.3, 17.1, 85.3, 21.8, and 18.4 kg/ha, respectively. Moreover, the treatments omitting each of N, P, K, Ca, and Mg fertilization resulted in reduced uptake by 52.9, 30.4, 50.4, 53.2, and 28.8%, respectively, as against the treatment with full fertilization of NPKCaMg (Table 2).

Table 2 Effects of fertilizing N, P, K, Ca, and Mg on total N, P, K, Ca, and Mg uptakes in plant pineapple grown in acid sulfate soil.

Treatment	Total N, P, K, Ca, and Mg uptakes in plant (kg/ha)				
	N	P	K	Ca	Mg
No fertilizer	30.2^{f}	5.95^{f}	20.9^{g}	5.08^{g}	6.68^{f}
NPKCaMg	94.3^{a}	17.1^{a}	85.3^{a}	21.8^{a}	18.4^{a}
PKCaMg	44.4^{e}	10.2^{e}	49.3^{e}	12.9^{d}	10.0^{e}
NKCaMg	64.1^{d}	11.9^{d}	56.1^{d}	14.1^{c}	11.6^{d}
NPCaMg	71.5^{c}	13.8^{c}	42.3^{f}	16.8^{b}	14.4^{b}
NPKMg	82.4^{b}	15.8^{b}	65.4^{b}	10.2^{f}	13.4^{c}
NPKCa	72.7^{c}	15.3^{b}	61.7^{c}	16.8^{b}	13.1^{c}
FFP	70.3^{c}	12.6^{d}	50.3^{e}	11.3^{e}	11.6^{d}
Significance level	*	*	*	*	*
CV (%)	6.49	6.16	4.77	5.25	3.16

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan's post-test. *: different at significance level 5% (p<0.05); ns: different insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

The potency of the acid sulfate soil in providing N, P, K, Ca, and Mg for plant pineapple was 44.4, 11.9, 42.3, 10.2, and 13.1 kg/ha, respectively, in Vi Thanh city, Hau Giang province (Table 3).

Table 3 Nutrient supply ability of acid sulfate soil for plant pineapple in providing N, P, K, Ca, and Mg.

INS	IPS	IKS	ICaS	IMgS
44.4	11.9	42.3	10.2	13.1

Note: INS: indigenous nitrogen supply ability. IPS: indigenous phosphorus supply ability. IKS: indigenous potassium supply ability. ICaS: indigenous calcium supply ability. ImgS: indigenous magnesium supply ability.

3.4 Effects of site-specific nutrient management on the growth of plant pineapple

For plant height, leaf length, peduncle length, and peduncle parameter in the treatment with full NPKCaMg fertilization, the results were 77.1, 63.8, 21.9, and 2.32 cm, respectively, higher than the treatment omitting each of N, P, K, Ca, and Mg fertilization with 5.19-9.47, 5.17-9.87, 7.31-20.1, and 13.4-19.8%. Furthermore, leaf number, leaf width, crown length, and crown width in the treatment omitting N fertilization increased by 14.8, 13.0, 26.6, and 9.32%, as against the treatment with full NPKCaMg fertilization (Table S14).

3.5 Effects of site-specific nutrient management on yield components and yield of plant pineapple

Fruit length and fruit diameter in the treatments omitting each of N, P, K, Ca, and Mg fertilization went down by 8.99-20.8 and 3.06-6.56%, respectively, as against the treatment with full NPKCaMg fertilization (Table 4). Consequently, pineapple yield in the treatment with full NPKCaMg fertilization was the highest with 31.5 t/ha, and that in the treatment with no fertilization was the lowest with 10.3 t/ha. Additionally, the treatment with SSNM-following fertilization helped pineapple yield increase by over 30.2%, as against the treatment with FFP-following fertilization (Figure 1).

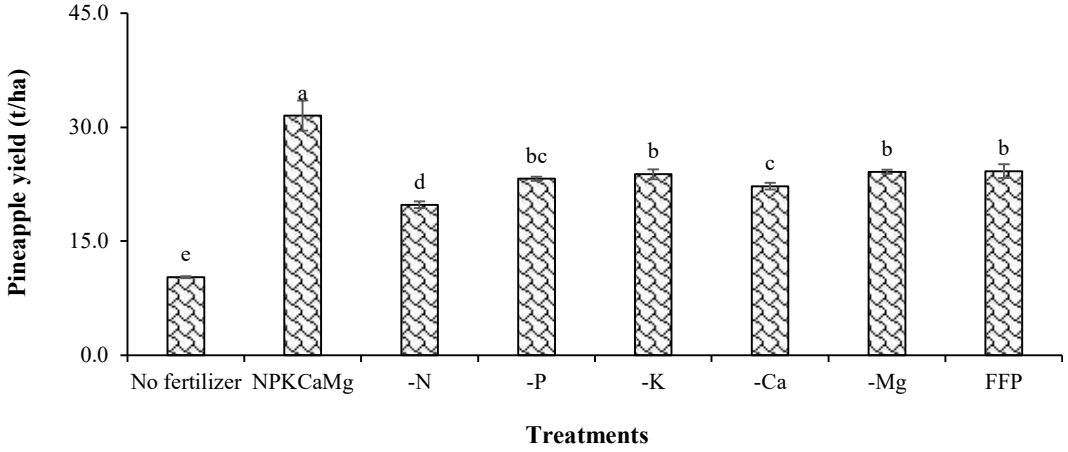

Figure 1 Effects of site-specific nutrient management on yield of plant pineapple in acid sulfate soil. Lower case letters indicate significant differences between bars ($p < 0.05$).

Table 4 Effects of fertilizing N, P, K, Ca, and Mg on yield components and yield of plant pineapple grown in acid sulfate soil.

Treatment	Fruit length (cm)	Fruit diameter (cm)
No fertilizer	8.90^{d}	7.41^{d}
NPKCaMg	17.8^{a}	9.14^{a}
PKCaMg	14.1^{c}	8.83^{bc}
NKCaMg	15.6^{b}	8.86^{b}
NPCaMg	16.2^{b}	8.69^{bc}
NPKMg	15.7^{b}	8.54^{c}
NPKCa	15.9^{b}	8.78^{bc}
FFP	15.9^{b}	8.84^{bc}
Significance level	*	*
CV (%)	3.55	2.19

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan's post-test. *: different at significance level 5% (p <0.05); ns: different insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

Figure 2 (A) illustrates that yield responses to N fertilizer were the highest with 11.7 t/ha whereas those to Mg fertilizer were the lowest with 7.40 t/ha. Moreover, in Table 5 and Figure 2 (B), the agronomic efficiency of N and P fertilizers outweighed that of K, Mg, and Ca fertilizers, with 26.1, 25.9, 21.4, 14.8, and 9.30 $kg_{pineapple}/kg_{fertilizer}$, respectively. Based on Table 4, the desired pineapple yield was 32.5 t/ha. Thus, the NPKCaMg fertilizer formula adjusted for plant pineapple in Vi Thanh city, Hau Giang province was 488 N-359 P_2O_5-407 K_2O-1108 CaO-568 MgO kg/ha.

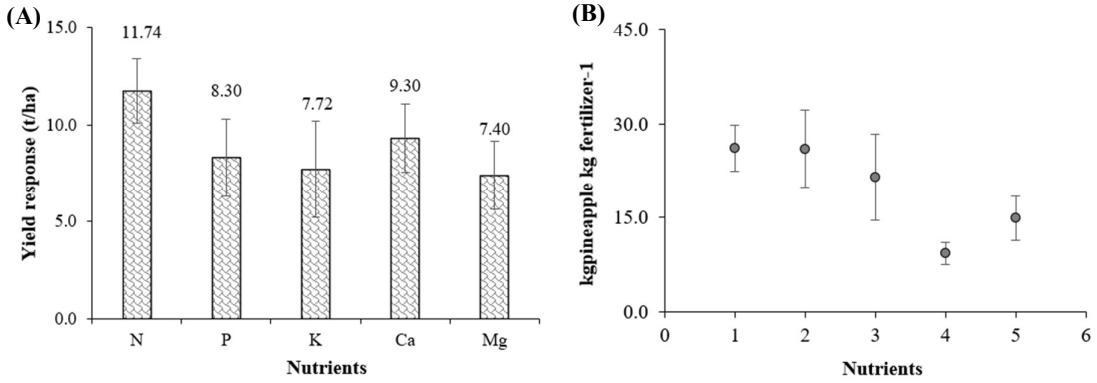

Figure 2 Effects of site-specific nutrient management on (A) yield response of plant pineapple and (B) agronomic efficiency.

Table 5 Effects of fertilizing N, P, K, Ca, and Mg on fruit quality of plant pineapple grown in acid sulfate soil.

Treatment	pH	Brix	Water content	Vitamin C	Titratable acid	Fruit color		
			mL	mg 100 g^{-1}	Mg/L	L^*	a^*	b^*
No fertilizer	3.40^{c}	10.4^{a}	197.9^{d}	104.7^{bc}	1.40	35.7	15.5^{bc}	22.9^{ab}
NPKCaMg	3.57^{a}	11.4^{a}	535.2^{a}	104.5^{bc}	1.39	36.8	14.5^{cde}	21.3^{bc}
PKCaMg	3.45^{bc}	11.3^{a}	407.8^{c}	116.6^{a}	1.35	36.3	17.4^{a}	24.4^{a}
NKCaMg	3.55^{ab}	11.1^{a}	478.3^{b}	118.2^{a}	1.22	36.4	16.7^{ab}	24.0^{a}
NPCaMg	3.53^{ab}	9.08^{b}	492.4^{b}	95.7^{cd}	1.20	36.7	13.6^{e}	20.3^{c}
NPKMg	3.52^{ab}	11.1^{a}	478.2^{b}	114.4^{ab}	1.19	35.5	15.0^{cd}	20.9^{bc}
NPKCa	3.56^{ab}	11.0^{a}	478.9^{b}	91.3^{d}	1.23	35.6	14.9^{cde}	22.8^{ab}
FFP	3.56^{ab}	10.9^{a}	536.4^{a}	116.0^{a}	1.19	36.8	13.9^{de}	19.9^{c}
Significance level	*	*	*	*	ns	ns	*	*
CV (%)	2.01	6.99	3.15	6.53	15.4	4.27	5.74	6.23

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan's post-test. *: different at significance level 5% (p <0.05); ns: different insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

3.6 Effects of site-specific nutrient management on fruit quality of plant pineapple

Table 6 reveals that pH in pineapple juice in the treatment omitting N fertilization was 3.4, which was lower than that in the treatment with full NPKCaMg fertilization, with 3.57. Furthermore, Brix index in the treatment omitting K fertilization (9.08%) was lower than that in the treatments with full NPKCaMg fertilization or omitting each of N, P, Ca, and Mg fertilization (10.4-11.4%). Water content in the treatment with full NPKCaMg fertilization was 535.2 mL, which was higher than that in the treatments omitting each of N, P, K, Ca, and Mg fertilization, ranging from 407.8 to 492.4 mL. Meanwhile, vitamin C content and TA content fluctuated within the range of approximately 91.3-118.2 mg 100 g^{-1} and 1.19-1.40 mg/L, respectively. The values of L^*, a^*, and b^* in pineapple fruit colors among treatments were in the ranges of 35.5-36.8, 13.6-17.4, and 19.9-24.4, respectively.

Table 6 Agronomic efficiency (AE_x) of N, P, K, Ca, and Mg in acid sulfate soil for plant pineapple.

Nutrient	GY	$GY_{(0N.\ 0P.\ 0K.\ 0Ca.\ 0Mg)}$	F	AE
	t/ha	t/ha	kg/ha	$kg_{pineapple}/kg_{fertilizer}$ [1]
N	31.5	19.8	450	26.1
P		23.2	320	25.9
K		23.8	360	21.4
Ca		22.2	1000	9.30
Mg		24.1	500	14.8

Note: GY: pineapple yield in the NPKCaMg fertilized plot; GY_{0N}: pineapple yield in the N omitting plot; GY_{0P}: pineapple yield in the P omitting plot; GY_{0K}: pineapple yield in the K omitting plot; GY_{0Ca}: pineapple yield in the Ca omitting plot; GY_{0Mg}: pineapple yield in the Mg omitting plot; F: applied amount of fertilizer; AE: agronomic efficiency.

4. Discussion

4.1 Properties of soil for plant pineapple cultivation

Table S2 illustrates that soil for pineapple in Hau Giang possessed an average pH_{KCl} at 2.25, evaluated to be low by Horneck et al. [17], due to the value <5.1. Low pH results in high content of toxins, including ferrous (Fe^{2+}), aluminum (Al^{3+}), sulfate (SO_4^{2-}), and restricting uptakes of N, P, K, Ca, and Mg nutrients into plants [18]. Additionally, the content of N, P, K, and Ca in the treatments omitting a nutrient of correspondence was lower by 50.2, 37.8, 16.4, and 82.8% compared to that in the treatment with full NPKCaMg fertilization. Since the treatment with P fertilization resulted in reduced contents of Al^{3+} and Fe^{2+} toxins in the soil, the treatment omitting P fertilization had increased contents of Al^{3+} and Fe^{2+} by 26.3 and 41.2%, respectively, as against the treatment with full NPKCaMg fertilization. This can be interpreted that P can bind soil toxins and form insoluble compounds, that is, Al-P and Fe-P, which plants cannot use [19].

4.2 Dry biomass and total nutrient uptakes in plant pineapple

Omitting fertilization of each of N, P, K, Ca, and Mg resulted in reduced dry biomass in crown, pulp, core, shell, slips, peduncle, stem, and leaves by 17.4-42.9, 15.7-36.3, 18.2-23.6, 13.8-41.4, 17.6-72.5, 22.0-33.2, 5.53-26.7, and 5.88-35.9%, respectively, as against the treatment with full NPKCaMg fertilization (Table 1). Therefore, total N, P, K, Ca, and Mg uptakes in the treatments omitting each of N, P, K, Ca, and Mg correspondingly decreased by 12.6-52.9, 7.60-40.4, 23.3-50.4, 22.9-53.2, and 21.7-45.7%, as against the treatment with full NPKCaMg fertilization (Table 2). Pegoraro et al. [20] claimed that in order to reach a yield of 72 t/ha, macronutrients uptake in the "Vitória" pineapple is ranked as the following decreasing order: K> N> S> Ca> Mg> P, corresponding to 898, 452, 134, 129, 126, and 107 kg/ha. On the contrary, according to the result of Souza et al. [21], K, N, Ca, P, Mg, and S content in pineapple stem reduced gradually as 1,311 (12%), 150 (9%), 144 (11%), 52 (11%), 46 (12%), and 36 (12%) kg/ha, respectively. According to the result of Cruz et al. [22], in pineapple in Costa Rica, with a plant density of 65,000 plants ha^{-1}, nutrient uptakes are 98 N, 1 P, 16.5 K, 2.2 Ca, and 1.9 Mg (g $plant^{-1}$), while nutrient contents, including N, P, K, Ca, and Mg in D-leaf at 10 months after planting, decreased by 61.6, 68.9, 94.5, 83.9, and 83.3%, respectively, as against the treatment with full NPKCaMg fertilization. Therefore, although nutrient uptakes in pineapple differed due to soil characteristics in each region, providing NPKCaMg for pineapple can help it reach its potent yield, leading to increased dry biomass.

4.3 Growth of plant pineapple

The treatment with full NPKCaMg fertilization had plant height, leaf length, peduncle length, and peduncle diameter peaking at 77.1, 63.8, 21.9, and 2.32 cm, respectively (Table S14). The result of Ramos and Pinho [23] supported that the treatment with full NPKCaMg has peduncle length increased by 0.78-21.3%, as against the treatments omitting each of N, P, K, Ca, and Mg fertilization. On the other hand, in the study by Maneesha et al. [24], fertilizing 15: 5: 15 g NPK/plant/crop results in the tallest plant and the highest D-leaf length and weight, with 58.2, 63.4 cm, and 42.3 g, as against other treatments. In the study of Cunha et al. [25], fertilizing without K reduced D-leaf length by 7.90 cm, as against the treatment with full NPKCaMg fertilization. This can be seen as a K deficiency symptom, which remarkably influences the appearance of the leaves [6]. Thus, the combination of NPKCaMg fertilization helps pineapple to grow and develop better than supplying without each of the nutrients.

4.4 Yield components and yield of plant pineapple

The treatment with SSNM-following fertilization resulted in increasing fruit length and fruit diameter by 11.9 and 3.39%, respectively, as against the treatment with FFP-following fertilization. Consequently, pineapple fruit yield in the treatment with SSNM-following fertilization increased by 30.2%, as against the treatment with FFP-following fertilization (Table 4). As reported by Mahmud et al. [26], fertilization of N, P, K, Ca, and Mg needed to be combined together, due to the importance of these nutrients for fine plant growth and development, contributing to enhancing crop yield. The results of Ramos and Pinho [23] also indicated that the treatment with full NPKCaMg fertilization resulted in higher fruit weight, fruit length, and fruit diameter (1.452 kg, 18.1, and 11.8 cm, respectively) compared to the treatments omitting each of N, P, K, Ca, and Mg fertilization (0.532-1.404 kg, 11.1-14.3, and 9.20-10.8 cm, respectively). In addition, Cunha et al. [25] believed that sufficient NPKCaMg fertilization gives out a raise in pineapple fruit yield of 26.9% as against the treatment with no fertilization.

4.5 Quality of plant pineapple

Table 6 reveals that pH in pineapple juice in the treatment omitting N fertilization was 3.45, which was lower than that in the treatment with full NPKCaMg fertilization. In addition, Brix index in the treatment with K fertilization increased from 20.9 to 25.3%, as against the treatment omitting K fertilization. This was because the K nutrient affects the sugar content in pineapple [6]. On the other hand, water content in the treatment with full NPKCaMg fertilization was the highest, with 535.2 mL, as against the treatments omitting each of N, P, K, Ca, and Mg fertilization. According to the result of Ramos and Pinho [23], Brix index in the treatment omitting K fertilization was 10.7%, which was lower than that in the treatment with full NPKCaMg fertilization with 11.2%. However, pH in pineapple juice among treatments fluctuated within the range of approximately 3.60-4.58. Therefore, the effects of K on fruit development were insignificant, as against N, P, Ca, and Mg [27]. However, nutrients affected fruit quality the most (hardness and fine colors in pulp, carbohydrate content, and TA content) [28]. Furthermore, full NPKCaMg fertilization resulted in increased water content in pineapple juice by 8.74-31.1% because fruit weight under this condition was higher than that in the treatments omitting each of N, P, K, Ca, and Mg fertilization (Table 6). Valleser [29] also demonstrated that MD2 pineapple with full NPKCaMg fertilization had heavier fruit weight (1.42 kg) than that with no fertilization.

5. Conclusion

The fertilizer formula for plant pineapple in acid sulfate soil in Hau Giang was 488 N-359 P_2O_5-407 K_2O-1108 CaO-568 MgO kg/ha. The soil capability of providing N, P, K, Ca, and Mg for plant pineapples was 44.4, 11.9, 42.3, 10.2, and 13.1 kg/ha, respectively, which was insufficient for the maximal growth and yield of pineapples. Meanwhile, the treatment with SSNM-following fertilization helped in increasing pineapple growth which resulted in enhancing its yield by more than 30.2% as against the treatment with FFP-following fertilization. Based on this study, a new recommended fertilizer formula can be applied to pineapple farms in the Tan Tien commune, Vi Thanh city, in order to not only obtain a steady high yield of pineapples but also ensure the farmers' livelihood there.

6. Acknowledgements

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7. References

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Appendix

Table S1 Pineapple-cultivating soil properties at the beginning of the crop.

Features	Unit	Depth 0-20 cm	Depth 20-40 cm
pH_{H2O}	-	2.67	1.95
EC	mS/cm	0.671	4.73
Organic matter	%C	2.13	3.34
CEC	meq 100 g^{-1}	16.6	12.5
Na^{+}	meq 100 g^{-1}	0.112	0.063
K^{+}	meq 100 g^{-1}	0.179	0.062
Mg^{2+}	meq 100 g^{-1}	0.749	1.97
Ca^{2+}	meq 100 g^{-1}	0.273	0.218
N total	%N	0.175	0.154
NH_4^{+}	mg/kg	27.9	7.72
P total	%P	0.048	0.039
P soluble	mg/kg	22.8	29.5
Al-P	mg/kg	54.0	67.7
Fe-P	mg/kg	341.3	274.3
Ca-P	mg/kg	34.1	16.3
pH_{KCl}	-	2.18	1.68
Titratable acidity	meq 100 g^{-1}	13.5	29.8
Al^{3+} exchangeable	meq 100 g^{-1}	4.17	10.2
Al/CEC	-	25.1	81.6
$Fe_{dissolved}$	mg/kg	132.5	725.9
Fe_2O_3	%	1.62	1.28
Fe^{2+}	mg/kg	119.74	634.8
Mn	%	2.43	3.00

Table S2 Effects of site-specific nutrient management on chemical features of soil for plant pineapple at the depth 0-20 cm.

Treatment	pH_{H2O}	EC	CHC	CEC	Na^+	K^+	Mg^{2+}	Ca^{2+}	pH_{KCl}	Titratable acidity	Al^{3+}	$Fe_{dissolved}$	Fe_2O_3	Fe^{2+}	Mn^{2+}	N_{total}	NH_4^+	P_{total}	$P_{soluble}$	Al-P	Fe-P	Ca-P
		mS/cm	%C	meq100 g^{-1}						meq 100 g^{-1}		mg/kg	%	mg/kg	%	%N	mg/kg	%P	mg/kg			
No fertilizer	2.83	0.528	2.09	14.9	0.098^{c}	0.140^{cd}	0.458^{a}	0.47^{d}	2.25	16.3^{a}	5.44^{a}	86.6^{e}	1.35^{bc}	113.0^{cd}	2.15^{a}	0.170	16.8^{c}	0.048	17.1^{c}	42.5^{e}	275.0^{c}	10.5^{de}
NPKCaMg	2.87	0.538	2.35	15.5	0.135^{ab}	0.183^{abc}	0.563^{a}	3.49^{a}	2.33	14.3^{abc}	3.50^{d}	70.1^{f}	1.38^{abc}	95.8^{d}	2.02^{abc}	0.200	40.2^{a}	0.047	38.1^{a}	61.9^{cd}	364.7^{ab}	20.9^{a}
PKCaMg	3.03	0.520	2.35	14.7	0.095^{c}	0.213^{a}	0.428^{a}	2.29^{b}	2.33	14.8^{ab}	3.70^{cd}	95.8^{de}	1.52^{ab}	98.1^{d}	2.20^{a}	0.215	20.0^{c}	0.058	28.6^{b}	75.6^{ab}	381.6^{ab}	23.0^{a}
NKCaMg	2.84	0.558	2.16	15.0	0.130^{ab}	0.210^{a}	0.508^{a}	1.05^{c}	2.27	14.5^{ab}	4.42^{b}	98.5^{cde}	1.60^{a}	162.9^{b}	2.13^{a}	0.188	33.4^{b}	0.056	23.7^{b}	41.3^{e}	329.8^{bc}	8.43^{e}
NPCaMg	2.83	0.540	2.25	15.5	0.143^{a}	0.153^{bcd}	0.510^{a}	2.51^{b}	2.27	13.3^{bc}	3.53^{d}	109.3^{cd}	1.51^{ab}	101.2^{cd}	1.91^{bc}	0.183	40.3^{a}	0.053	26.8^{b}	86.4^{a}	317.3^{bc}	13.8^{bc}
NPKMg	2.74	0.573	2.34	14.2	0.145^{a}	0.125^{d}	0.495^{a}	0.60^{d}	2.20	13.4^{bc}	3.66^{cd}	144.6^{a}	1.49^{ab}	187.4^{a}	2.08^{ab}	0.203	28.8^{b}	0.054	26.7^{b}	70.9^{bc}	425.7^{a}	16.3^{b}
NPKCa	2.80	0.585	2.04	15.0	0.110^{bc}	0.198^{ab}	0.418^{a}	1.35^{c}	2.22	12.4^{c}	4.19^{bc}	129.2^{b}	1.37^{bc}	157.0^{b}	2.16^{a}	0.173	31.2^{b}	0.054	26.7^{b}	77.1^{ab}	403.5^{ab}	10.5^{de}
FFP	2.80	0.428	1.97	13.8	0.120^{abc}	0.123^{d}	0.208^{b}	0.35^{d}	2.16	12.3^{c}	3.99^{bcd}	114.3^{bc}	1.26^{c}	121.3^{c}	1.85^{c}	0.178	40.4^{a}	0.052	25.2^{b}	59.4^{d}	336.0^{bc}	11.6^{cd}
Significance level	ns	ns	ns	ns	*	*	*	*	ns	*	*	*	*	*	*	ns	*	ns	*	*	*	*
CV (%)	4.63	17.9	17.0	11.2	13.2	19.4	20.3	15.3	3.64	9.22	8.71	9.73	9.78	10.7	5.87	15.2	11.9	14.8	14.3	11.0	15.5	12.7

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan post-test.*: different at significance level 5% (p <0.05); ns: diffferent insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

Table S3 Effects of site-specific nutrient management on chemical features of soil for plant pineapple at the depth 20-40 cm.

Treatment	pH_{H2O}	EC	CHC	CEC	Na^+	K^+	Mg^{2+}	Ca^{2+}	H_{KCl}	Titratable acidity	Al^{3+}	$Fe_{dissolved}$	Fe_2O_3	Fe^{2+}	Mn^{2+}	N_{total}	NH_4^+	P_{total}	$P_{soluble}$	Al-P	Fe-P	Ca-P
		mS/cm	%C	meq 100 g^{-1}						meq 100 g^{-1}		mg/kg	%	mg/kg	%	%N	mg/kg	%P	mg/kg			
KBP	2.81	0.470	1.98	16.2	0.155^{abc}	0.188^{abc}	0.510^{b}	0.358^{b}	.25	15.8	4.99	101.6	1.36^{b}	77.9	2.06^{c}	0.178	21.1^{b}	0.047	13.9	53.6	380.1	32.7
NPKCaMg	2.74	0.490	1.72	17.5	0.135^{b-e}	0.225^{a}	0.638^{b}	0.773^{a}	.20	14.8	4.98	95.1	1.57^{ab}	89.4	3.31^{a}	0.145	27.3^{a}	0.047	17.9	57.6	430.5	27.2
PKCaMg	2.85	0.550	1.59	15.3	0.110^{e}	0.218^{ab}	0.593^{b}	0.720^{a}	.25	14.8	6.05	95.8	1.60^{ab}	85.3	3.15^{a}	0.140	15.8^{b}	0.051	15.7	56.9	442.4	28.8
NKCaMg	2.89	0.543	1.75	17.7	0.175^{a}	0.215^{ab}	0.933^{a}	0.770^{a}	.32	14.5	6.36	98.5	1.67^{a}	83.9	2.03^{c}	0.153	27.0^{a}	0.049	14.5	56.9	413.1	34.7
NPCaMg	2.81	0.543	1.76	17.0	0.163^{ab}	0.173^{bc}	0.578^{b}	0.673^{a}	.25	14.7	5.45	109.3	1.56^{ab}	72.4	3.19^{a}	0.153	31.0^{a}	0.051	17.6	54.7	423.0	27.6
NPKMg	2.80	0.558	1.69	16.6	0.148^{a-d}	0.213^{ab}	0.805^{a}	0.590^{a}	.20	15.9	6.67	117.1	1.75^{a}	58.4	2.74^{b}	0.155	29.0^{a}	0.052	15.9	58.7	424.1	31.1
NPKCa	2.82	0.510	1.78	16.8	0.130^{cde}	0.203^{ab}	0.563^{b}	0.708^{a}	.25	15.5	6.99	121.7	1.59^{ab}	86.6	3.11^{a}	0.160	30.2^{a}	0.051	17.7	59.1	446.4	34.5
FFP	2.83	0.393	1.69	15.2	0.120^{de}	0.143^{c}	0.345^{c}	0.335^{b}	.22	14.4	5.96	114.3	1.37^{b}	71.3	1.65^{d}	0.148	29.0^{a}	0.045	17.2	51.1	420.1	24.1
Significance level	ns	ns	ns	ns	*	*		*	s	ns	ns	ns	*	ns	*	ns	*	ns	ns	ns	ns	ns
CV (%)	5.05	21.9	12.2	7.6	13.0	15.9	5.1	24.0	.46	5.73	21.3	20.7	10.2	18.5	6.62	14.0	14.3	9.39	20.7	16.0	15.1	22.1

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan post-test.*: different at significance level 5% (p<0.05); ns: diffferent insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

Table S4 Effects of fertilizing N, P, K, Ca and Mg on N content in stovers of plant pineapple grown in acid sulfate soil.

Treatment	N concentration (%)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	2.36^{ab}	0.700^{c}	0.642^{c}	1.24^{ab}	1.90^{bc}	0.828^{b}	1.12^{c}	0.099^{de}
NPKCaMg	2.11^{bcd}	1.138^{ab}	0.638^{c}	1.16^{abc}	2.06^{ab}	1.211^{a}	1.65^{b}	0.151^{ab}
PKCaMg	1.71^{e}	0.723^{c}	0.537^{d}	1.00^{bc}	1.69^{c}	0.654^{cd}	1.28^{c}	0.087^{e}
NKCaMg	2.28^{abc}	0.933^{b}	0.607^{cd}	0.98^{c}	2.11^{ab}	0.770^{bc}	1.66^{b}	0.096^{de}
NPCaMg	2.02^{cd}	1.004^{ab}	0.875^{a}	1.10^{abc}	2.16^{ab}	0.735^{bcd}	1.73^{b}	0.168^{a}
NPKMg	2.01^{cde}	1.190^{a}	0.758^{b}	1.31^{a}	2.28^{a}	0.817^{b}	1.88^{ab}	0.113^{cde}
NPKCa	1.88^{de}	1.178^{a}	0.778^{b}	1.03^{bc}	1.96^{bc}	0.735^{bc}	1.60^{b}	0.124^{bcd}
FFP	2.46^{a}	1.027^{ab}	0.583^{cd}	1.01^{bc}	2.30^{a}	0.591^{d}	2.16^{a}	0.132^{bc}
Significance level	*	*	*	*	*	*	*	*
CV (%)	9.13	13.6	9.06	13.6	9.45	11.6	13.1	16.4

Table S5 Effects of fertilizing N, P, K, Ca and Mg on P content in stovers of plant pineapple grown in acid sulfate soil.

Treatment	P concentration (%)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	0.144	0.053^{b}	0.047	0.105^{c}	0.075^{abc}	0.064^{bc}	0.055^{d}	0.115^{e}
NPKCaMg	0.219	0.108^{a}	0.056	0.135^{b}	0.069^{bc}	0.082^{a}	0.136^{a}	0.136^{bc}
PKCaMg	0.206	0.096^{a}	0.048	0.153^{ab}	0.070^{bc}	0.064^{bc}	0.139^{a}	0.120^{de}
NKCaMg	0.207	0.066^{b}	0.040	0.114^{c}	0.064^{c}	0.062^{c}	0.082^{c}	0.133^{c}
NPCaMg	0.205	0.104^{a}	0.047	0.158^{a}	0.079^{ab}	0.074^{ab}	0.084^{c}	0.127^{cd}
NPKMg	0.225	0.115^{a}	0.049	0.151^{ab}	0.080^{ab}	0.069^{bc}	0.124^{ab}	0.152^{a}
NPKCa	0.213	0.097^{a}	0.054	0.137^{ab}	0.078^{ab}	0.068^{bc}	0.117^{b}	0.145^{ab}
FFP	0.243	0.097^{a}	0.056	0.156^{ab}	0.081^{a}	0.061^{c}	0.130^{ab}	0.126^{cd}
Significance level	ns	*	ns	*	*	*	*	*
CV (%)	22.6	20.3	15.3	10.1	9.00	9.30	10.5	4.71

Table S6 Effects of fertilizing N, P, K, Ca and Mg on K content in stovers of plant pineapple grown in acid sulfate soil.

Treatment	K concentration (%)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	1.54^{e}	0.403^{e}	0.275^{e}	0.783^{b}	1.53^{d}	0.823^{de}	0.753^{c}	0.066^{de}
NPKCaMg	1.86^{bc}	1.143^{b}	0.793^{b}	1.005^{a}	1.83^{bc}	1.295^{a}	0.978^{a}	0.128^{a}
PKCaMg	2.20^{a}	1.105^{b}	1.043^{a}	0.960^{a}	1.91^{b}	1.063^{b}	0.768^{c}	0.103^{c}
NKCaMg	1.91^{b}	0.845^{c}	0.783^{b}	0.773^{b}	1.83^{bc}	1.010^{bc}	0.920^{ab}	0.114^{b}
NPCaMg	1.68^{d}	0.708^{d}	0.470^{d}	0.680^{c}	1.32^{e}	1.033^{bc}	0.375^{d}	0.069^{d}
NPKMg	1.91^{b}	1.295^{a}	0.618^{c}	0.530^{d}	2.19^{a}	0.890^{cd}	0.923^{ab}	0.128^{a}
NPKCa	1.78^{cd}	1.300^{a}	0.623^{c}	0.575^{cd}	1.73^{c}	0.690^{e}	0.780^{c}	0.123^{ab}
FFP	1.91^{b}	1.150^{b}	0.588^{cd}	0.550^{d}	1.51^{d}	0.990^{bc}	0.823^{bc}	0.058^{e}
Significance level	*	*	*	*	*	*	*	*
CV (%)	3.86	6.20	13.3	9.13	5.32	9.63	9.78	6.17

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan post-test. *: different at significance level 5% (p <0.05); ns: diffferent insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

Table S7 Effects of fertilizing N, P, K, Ca and Mg on Ca content in stovers of plant pineapple grown in acid sulfate soil.

Treatment	Ca concentration (%)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	0.076^{c}	0.053^{ab}	0.046^{c}	0.054^{c}	0.068^{b}	0.087^{b}	0.307^{d}	0.075^{f}
NPKCaMg	0.102^{a}	0.045^{bcd}	0.068^{a}	0.103^{a}	0.074^{b}	0.103^{a}	0.649^{a}	0.169^{a}
PKCaMg	0.089^{abc}	0.058^{a}	0.057^{b}	0.087^{b}	0.080^{b}	0.081^{bc}	0.506^{c}	0.149^{b}
NKCaMg	0.097^{ab}	0.061^{a}	0.056^{b}	0.076^{b}	0.073^{b}	0.087^{b}	0.539^{bc}	0.134^{c}
NPCaMg	0.091^{abc}	0.042^{cd}	0.070^{a}	0.077^{b}	0.098^{a}	0.074^{c}	0.542^{bc}	0.150^{b}
NPKMg	0.047^{d}	0.052^{abc}	0.032^{d}	0.051^{c}	0.053^{c}	0.081^{bc}	0.292^{d}	0.095^{e}
NPKCa	0.084^{bc}	0.026^{e}	0.063^{ab}	0.076^{b}	0.079^{b}	0.077^{c}	0.566^{b}	0.153^{b}
FFP	0.080^{c}	0.040^{d}	0.040^{cd}	0.054^{c}	0.066^{b}	0.051^{d}	0.515^{c}	0.118^{d}
Significance level	*	*	*	*	*	*	*	*
CV (%)	12.2	14.8	12.3	13.3	12.1	7.57	5.34	7.81

Table S8 Effects of fertilizing N, P, K, Ca and Mg on Mg content in stovers of plant pineapple grown in acid sulfate soil.

Treatment	Mg concentration (%)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	0.128^{c}	0.105^{c}	0.121^{de}	0.070^{b}	0.094^{d}	0.101^{e}	0.101^{d}	0.122^{c}
NPKCaMg	0.205^{a}	0.126^{a}	0.178^{a}	0.092^{a}	0.114^{bc}	0.157^{a}	0.157^{b}	0.143^{a}
PKCaMg	0.207^{a}	0.118^{ab}	0.159^{b}	0.054^{c}	0.108^{c}	0.111^{d}	0.160^{b}	0.119^{c}
NKCaMg	0.166^{b}	0.124^{a}	0.142^{c}	0.060^{bc}	0.122^{b}	0.123^{c}	0.160^{b}	0.106^{d}
NPCaMg	0.211^{a}	0.120^{ab}	0.143^{c}	0.061^{bc}	0.133^{a}	0.149^{b}	0.169^{a}	0.136^{ab}
NPKMg	0.167^{b}	0.120^{ab}	0.142^{c}	0.060^{bc}	0.113^{bc}	0.118^{cd}	0.159^{b}	0.122^{c}
NPKCa	0.107^{d}	0.111^{bc}	0.117^{e}	0.055^{c}	0.091^{d}	0.088^{f}	0.132^{c}	0.125^{c}
FFP	0.137^{c}	0.123^{a}	0.133^{cd}	0.063^{bc}	0.107^{c}	0.120^{c}	0.124^{c}	0.127^{bc}
Significance level	*	*	*	*	*	*	*	*
CV (%)	5.06	6.08	5.83	10.8	6.52	3.88	3.71	5.18

Table S9 Effects of fertilizing N, P, K, Ca and Mg on N uptake in stovers of plant pineapple grown in acid sulfate soil.

Treatment	N uptake (kg/ha)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	4.46^{e}	4.89^{e}	1.10^{e}	9.33^{d}	2.78^{d}	1.15^{e}	4.66^{e}	1.85^{d}
NPKCaMg	10.8^{a}	22.0^{a}	2.70^{a}	20.9^{a}	11.8^{a}	3.80^{a}	14.9^{a}	7.50^{a}
PKCaMg	4.99^{e}	8.88^{d}	1.73^{cd}	10.6^{d}	2.66^{d}	1.37^{de}	9.88^{d}	4.25^{c}
NKCaMg	8.99^{b}	15.1^{c}	1.97^{bc}	14.1^{c}	7.58^{c}	1.72^{bcd}	11.0^{cd}	3.64^{c}
NPCaMg	6.36^{d}	13.4^{c}	2.26^{b}	17.1^{bc}	9.51^{b}	1.69^{bcd}	14.7^{a}	6.46^{ab}
NPKMg	8.47^{bc}	19.4^{ab}	2.63^{a}	18.7^{ab}	10.2^{b}	2.00^{b}	14.0^{ab}	6.99^{a}
NPKCa	7.64^{c}	18.7^{b}	2.61^{a}	14.2^{c}	9.28^{b}	1.77^{bc}	12.2^{bc}	6.29^{ab}
FFP	10.9^{a}	13.3^{c}	1.48^{d}	14.2^{c}	11.8^{a}	1.40^{cde}	12.3^{bc}	5.07^{bc}
Significance level	*	*	*	*	*	*	*	*
CV (%)	9.85	14.2	10.4	14.8	12.5	13.1	11.1	21.8

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan post-test. *: different at significance level 5% (p <0.05); ns: diffferent insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

Table S10 Effects of fertilizing N, P, K, Ca and Mg on P uptake in stovers of plant pineapple grown in acid sulfate soil.

Treatment	P uptake (kg/ha)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	0.273^{d}	0.37^{e}	0.080^{e}	0.80^{d}	0.110^{d}	0.088^{e}	0.230^{f}	4.00^{f}
NPKCaMg	1.115^{a}	2.09^{a}	0.238^{a}	2.44^{a}	0.398^{ab}	0.258^{a}	1.223^{a}	9.38^{a}
PKCaMg	0.600^{c}	1.17^{cd}	0.153^{bcd}	1.63^{c}	0.110^{d}	0.135^{d}	1.068^{b}	5.31^{e}
NKCaMg	0.818^{abc}	1.06^{d}	0.133^{d}	1.64^{c}	0.233^{c}	0.140^{cd}	0.545^{e}	7.34^{c}
NPCaMg	0.640^{bc}	1.39^{cd}	0.123^{d}	2.47^{a}	0.345^{b}	0.170^{b}	0.718^{d}	7.92^{b}
NPKMg	0.953^{ab}	1.88^{ab}	0.170^{bc}	2.16^{ab}	0.360^{ab}	0.168^{b}	0.925^{c}	9.20^{a}
NPKCa	0.868^{abc}	1.53^{bc}	0.183^{b}	1.90^{bc}	0.368^{ab}	0.163^{bc}	0.893^{c}	9.43^{a}
FFP	1.075^{a}	1.25^{cd}	0.143^{cd}	2.18^{ab}	0.415^{a}	0.143^{cd}	0.740^{d}	6.62^{d}
Significance level	*	*	*	*	*	*	*	*
CV (%)	24.8	21.1	14.2	11.7	13.3	10.6	11.2	5.33

Table S11 Effects of fertilizing N, P, K, Ca and Mg on K uptake in stovers of plant pineapple grown in acid sulfate soil.

Treatment	K uptake (kg/ha)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	2.91^{g}	2.81^{f}	0.47^{e}	5.91^{d}	2.25^{g}	1.13^{d}	3.12^{e}	2.30^{f}
NPKCaMg	9.47^{a}	22.1^{a}	3.35^{a}	18.2^{a}	10.5^{a}	4.06^{a}	8.85^{a}	8.85^{a}
PKCaMg	6.41^{e}	13.6^{d}	3.37^{a}	10.2^{b}	3.01^{f}	2.22^{b}	5.90^{c}	4.58^{d}
NKCaMg	7.57^{cd}	13.6^{d}	2.54^{b}	11.1^{b}	6.59^{d}	2.26^{b}	6.10^{bc}	6.32^{c}
NPCaMg	5.28^{f}	9.50^{e}	1.21^{d}	10.6^{b}	5.83^{e}	2.38^{b}	3.23^{e}	4.31^{d}
NPKMg	8.08^{bc}	21.2^{ab}	2.14^{c}	7.54^{c}	9.77^{b}	2.17^{b}	6.87^{b}	7.70^{b}
NPKCa	7.21^{d}	20.6^{b}	2.09^{c}	7.94^{c}	8.17^{c}	1.67^{c}	5.95^{c}	8.02^{b}
FFP	8.45^{b}	14.9^{c}	1.49^{d}	7.63^{c}	7.74^{c}	2.34^{b}	4.70^{d}	3.06^{e}
Significance level	*	*	*	*	*	*	*	*
CV (%)	5.03	5.84	13.3	10.1	7.63	10.7	11.1	7.08

Table S12 Effects of fertilizing N, P, K, Ca and Mg on Ca uptake in stovers of plant pineapple grown in acid sulfate soil.

Treatment	Ca uptake (kg/ha)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	0.143^{e}	0.368^{e}	0.080^{c}	0.410^{e}	0.095^{d}	0.120^{d}	1.28^{h}	2.60^{f}
NPKCaMg	0.518^{a}	0.865^{a}	0.288^{a}	1.860^{a}	0.428^{a}	0.320^{a}	5.86^{a}	11.7^{a}
PKCaMg	0.258^{c}	0.710^{b}	0.185^{b}	0.918^{cd}	0.125^{d}	0.170^{c}	3.89^{d}	6.61^{cd}
NKCaMg	0.383^{b}	0.980^{a}	0.180^{b}	1.090^{bc}	0.265^{c}	0.193^{bc}	3.57^{e}	7.40^{c}
NPCaMg	0.285^{c}	0.560^{c}	0.180^{b}	1.203^{b}	0.430^{a}	0.170^{c}	4.63^{b}	9.38^{b}
NPKMg	0.200^{d}	0.848^{a}	0.113^{c}	0.723^{d}	0.233^{c}	0.198^{b}	2.17^{g}	5.71^{e}
NPKCa	0.343^{b}	0.408^{de}	0.213^{b}	1.058^{bc}	0.373^{b}	0.183^{bc}	4.31^{c}	9.96^{b}
FFP	0.350^{b}	0.518^{cd}	0.100^{c}	0.758^{d}	0.338^{b}	0.118^{d}	2.93^{f}	6.19^{de}
Significance level	*	*	*	*	*	*	*	*
CV (%)	11.5	14.7	13.4	14.0	12.4	8.25	5.53	8.33

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan post-test. *: different at significance level 5% (p <0.05); ns: diffferent insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.

Table S13 Effects of fertilizing N, P, K, Ca and Mg on Mg uptake in stovers of plant pineapple grown in acid sulfate soil.

Treatment	Mg uptake (kg/ha)							
	Crown	Pulp	Core	Shell	Slips	Peduncle	Stem	Leaves
KBP	0.243^{e}	0.74^{e}	0.208^{f}	0.525^{d}	0.140^{e}	0.140^{e}	0.42^{e}	4.25^{g}
NPKCaMg	1.045^{a}	2.44^{a}	0.753^{a}	1.665^{a}	0.653^{a}	0.493^{a}	1.42^{a}	9.90^{a}
PKCaMg	0.603^{c}	1.45^{d}	0.515^{b}	0.573^{d}	0.173^{e}	0.233^{d}	1.23^{b}	5.27^{f}
NKCaMg	0.658^{bc}	2.01^{b}	0.460^{c}	0.865^{bc}	0.438^{d}	0.275^{c}	1.06^{c}	5.84^{e}
NPCaMg	0.663^{bc}	1.60^{cd}	0.370^{de}	0.953^{b}	0.588^{b}	0.345^{b}	1.44^{a}	8.45^{b}
NPKMg	0.705^{b}	1.96^{b}	0.490^{bc}	0.855^{bc}	0.503^{c}	0.290^{c}	1.19^{b}	7.37^{c}
NPKCa	0.438^{d}	1.76^{c}	0.395^{d}	0.763^{c}	0.428^{d}	0.213^{d}	1.00^{c}	8.10^{b}
FFP	0.605^{c}	1.59^{cd}	0.335^{e}	0.873^{bc}	0.548^{bc}	0.280^{c}	0.71^{d}	6.68^{d}
Significance level	*	*	*	*	*	*	*	*
CV (%)	6.61	6.85	7.03	9.12	9.41	6.44	4.42	4.88

Table S14 Effects of fertilizing N, P, K, Ca and Mg on growth of plant pineapple grown in acid sulfate soil.

Treatment	Plant height	Number of leaves per plant	Leaf length	Leaf width	Peduncle length	Peduncle diameter	Crown length	Crown diameter
	cm	leaves	cm	cm	cm	cm	cm	cm
No fertilizer	62.8^{d}	27.2^{d}	49.8^{d}	4.25^{d}	15.9^{d}	1.45^{d}	10.7^{c}	3.33^{c}
NPKCaMg	77.1^{a}	39.1^{a}	63.8^{a}	6.25^{a}	21.9^{a}	2.32^{a}	17.7^{a}	3.97^{a}
PKCaMg	69.8^{c}	33.3^{c}	57.5^{bc}	5.44^{c}	17.5^{c}	1.86^{c}	13.0^{bc}	3.60^{b}
NKCaMg	73.1^{b}	35.2^{bc}	58.2^{bc}	5.92^{ab}	19.5^{b}	2.01^{bc}	15.7^{ab}	3.95^{a}
NPCaMg	73.0^{b}	39.7^{a}	60.5^{b}	5.42^{c}	18.9^{bc}	1.90^{c}	11.7^{c}	3.49^{bc}
NPKMg	72.8^{b}	33.2^{c}	57.9^{bc}	5.38^{c}	19.2^{b}	1.96^{bc}	13.9^{bc}	3.55^{bc}
NPKCa	73.1^{b}	37.7^{ab}	56.9^{c}	5.56^{bc}	20.3^{b}	2.01^{bc}	16.5^{ab}	3.90^{a}
FFP	69.4^{c}	55.2^{bc}	58.0^{bc}	5.42^{c}	19.6^{b}	2.13^{b}	17.9^{a}	4.12^{a}
Significance level	*	*	*	*	*	*	*	*
CV (%)	2.71	4.65	3.73	4.80	5.51	6.26	16.1	4.49

Note: In the same column, numbers followed by the same letter were insignificantly different from each other via Duncan post-test.*: different at significance level 5% (p <0.05); ns: diffferent insignificantly. NPKCaMg: full fertilization; PKCaMg: omitting nitrogen fertilization; NKCaMg: omitting phosphorus fertilization; NPCaMg: omitting potassium fertilization; NPKMg: omitting calcium fertilization; NPKCa: omitting magnesium fertilization; FFP: farmers' fertilizer practice.