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Article

Gypsum Supplies Calcium to Ultisol Soil and Its Effect on Pineapple Growth, Yield and Fruit Quality in Lower Single Bed under Climate Change Issue

Supriyono Loekito[1] Afandi[2*], Auliana Afandi[3], Naomasa Nishimura[4], Hiroyuki Koyama[4], and Masateru Senge[5]

[1] Research and Development, PT Great Giant Pineapple,Jl. Raya Terbanggi Km 77,Central Lampung,Lampung Indonesia, 34163
[2] Department of Soil Science, Faculty of Agriculture, Lampung University, Jl. Sumantri Brojonegoro 1, Bandar Lampung, Lampung, Indonesia 35145
[3] Department of Plant Protection, Faculty of Agriculture, Lampung University, Jl. Sumantri Brojonegoro 1, Bandar Lampung, Lampung, Indonesia 35145
[4] Faculty of Applied Biological Science, Gifu University, 1-1 Yanagido, Gifu, Japan
[5] Gifu University Laboratory, Ltd. Union, 1-1 Yanagido, Gifu, Japan

* Corresponding author: afandi.unila@gmail.com; supriyono.loekito@ggpc.co.id

Abstract: A lower bed single row for pineapple cultivation could protect pineapple from soil erosion in rainy season and during drought, however, disease problem could arise due to water logging. Two experiments using a lower bed single row was done to understand the ability of gypsum providing soil calcium (Ca) available to pineapple plant, resistance to heart rot disease, and give better effect on crop growth and fruit quality of the pineapple in Ultisol soil. In the first trial, four level dosis of gypsum (0, 1.0, 1.5, 2.0 Mg ha^{-1}) and dolomite 2 Mg ha^{-1} were applied by spreading and incorporated into the soil which have saturated with inoculums of *Phytophthora nicotianae*. In the second trial, gypsum treatments (0, 1.0, 1.5, 2.0, 2.5 Mg ha^{-1}) were applied in the row between the single row beds as a basic fertilizer. The result showed that *P. nicotianae* attacked the pineapple plants in all treatments at 6 weeks after planting (WAP), and at 10 WAP, the mortality of dolomite treatment reached 63.8%, significantly different than that for gypsum treatments (3.3-14.3%). In the second experiment, gypsum increased plant weight significantly at 3 until 9 months after planting especially when it was applied 1.5-2.5 Mg ha^{-1}. Fruit texture, total soluble solid (TSS), titratable acidity (TA) were not significant different among the treatment but all meet the standards for grades of canned pineapple. Result showed that soil applied gypsum before planting provides soil calcium and met the plant Ca requirement during a period of early and fast growth step and safe for heart rot disease.

Keywords: Lower bed single row; plant weight; fruit texture; crop growth

1. Introduction

Pineapple is one of the economically most important tropical fruit a worldwide scale. At current time, PT Great Giant Pineapple (GGP) plantation in Lampung, Sumatera, is now the biggest single pineapple plantation in the world. The climate is humid tropical where the annual rainfall, average temperature, relative humidity, duration of sunshine and standard evaporation rate are 2,500 mm/year, 21 to 33^{o}C, 83%, 4.6 hours/day and 36 mm/day, respectively. The year-round temperatures, heavy rainfall, and high humidity are unique to the humid tropics and cause the organic material in the soil to decompose at a high rate, resulting in low chemical fertility, a high clay content, and low soil pH. The soil is generally categorized as Red-Yellow Podzolic or Ultisol soil [1]. This soil covers a large part of Indonesia's land surface, approximately 45,794,000 ha (25%) and about 21% of that land (9,469,000 ha) is on Sumatera Island [2].

During the last 10 years, the unpredictable rainfall made the pineapple cultivation had faced several problems, especially with long dry season. "Wet dry season", where the amount of rainfall occurred during dry season almost the same with rainy season occurred 5 times for the last 10 years from 2010-2020, while long dry season occurred 4 times (Fig. 1). High rainfall, soil erosion, low soil fertility, and soil borne disease are the challenges in pineapple cultivation in these conditions. Commonly pineapple was planted in a raise bed double row (Fig. 2), erosion problem usually come when the rainfall was high which caused in damaged beds shape and disturbed roots and plant during pineapple growth, while it is also susceptible to drying condition and water logging. A pineapple's cultivation in lower bed single row was used in this research so the roots were not disturbed, stronger with challenge of soil borne disease due to poorer drainage, and more resistance to drying compare to raised bed.

In addition to uncertain climate condition lately, the second biggest problem in pineapple under humid tropical climate was the availability of calcium (Ca) in the soil. To manage 32,000 ha area of GGP plantation, the field was divided into blocks, 10 to 15 ha each. When the cultivation of pineapple began in 1986, the soil Ca content in all blocks of the plantation was higher (206 to 434 mg/kg) than the standard soil Ca adequate, which is 100 mg/kg [3]. However, in 1993, the blocks with a soil Ca content greater than the standard had decreased to 90 %, and in 2004, only 60 % of the blocks met that standard. The soil pH values of the GGP plantation range from 3.7-5.9, whereas the optimum soil pH for cultivated pineapple ranges from 4.7-5.5 [4].

Calcium (Ca) is an essential crop nutrient and the primary cation used to manage soil pH. It is required for synthesis of new cell wall, especially the middle lamellae that separate the new cell during cell division, and for the normal function of the plant membranes [5]. Calcium also plays an important role in nutrient balances in plant and soil [6]. Many physiological disorders of fruits and vegetables are related to Ca [7]. In humid tropical climate which soil generally dominated by red acid soil (Ultisol), the deficiency of Ca was occurred low due to the low pH and low cation exchange capacity (CEC) of the soil [8]. However, in pineapple cultivation, increasing soil pH above 5 would promote disease in the form of heart rot and root rot disease due to *Phytophthora sp.* [9,10,11]. On the other hand, if the pH is very low, the availability of macro nutrient will be limited.

Soil with Ca content below 25 mg/kg can induce calcium deficiency symptoms in the pineapple plant and fruit [3]. The symptoms of calcium deficiency are necrosis of the edges of the rapidly growing young leaves and multiple small and sometimes deformed fruits [12]. Dolomite lime is commonly applied to the fields to raise the soil pH to at least 4.7 as well as to supply Ca and Mg. Alternative of dolomite to supplied Ca when the soil pH was quite high is gypsum. Large amounts of gypsum will not increase the soil pH [13]. Pegg and Giblin [14] reported that gypsum supplied Ca, increased the disease resistance of avocado roots and acted as a mild fungicide by suppressing the formation of *Phytophthora* spores. Messenger et al. (2000) [15] showed that zoospore production of *Phytophthora cinnamomi* in avocados was decreased by 78% in soil that had been treated with 1% gypsum and that the number of zoospores was decreased by 74% with a 5% gypsum treatment. Correia et al. (2017) [16] reported that soil management with millet coverage and gypsum let to adequate levels of nutrients in the soil at the end of the pineapple crop cycle.

The objective of the present research was to evaluate gypsum as a substitute of dolomite in supplying calcium in the pineapple plant and soil and to know the effects of soil application Ca gypsum on the root system, crop growth, fruit quality and *Phytophthora cinnamomi* disease incidence of pineapple cultivated in Ultisol soil under single lowered bed system. By this present experiment result, Ca needs to soil and plant could be supplied to meet the requirement standard without any problem of the disease, the Integrated Disease Management in humid tropical could be improved to keep the sustainable pineapple production.

2. Materials and Methods

Two field experiments were conducted at the research station in a pineapple field of GGP plantation, with latitude 04°49'13" South and longitude 105°13'13" East, during 2016 – 2018.

Experiment I: Effect of gypsum soil application on hearth rot disease (*Phytophthora nicotianae*.)

The experimental design was a randomized complete block design with five treatments and three replications. The experimental plots were prepared in an area known to be infested with *Phytophthora* spp previously before September 2016. The soil in the experimental plots was saturated with inoculums of fungi that have identified as *Phytophthora nicotianae* [17] by watering the soil with a solution prepared by soaking infected plants. Then treatments were applied and the soil was tilled to evenly incorporate the liming treatment. The gypsum (G) treatments and dolomite (D) in ton ha^{-1} of amendment and kg ha^{-1} Ca, were G0 (untreated), G1 (1.0 and 233), G2 (1.5 and 349), G3 (2.0 and 465), and D1 (2.0 and 440). The gypsum was spread and incorporated into the soil a week before planting on December, 2016. The dolomite treatment was spread and incorporated into the soil during land preparation in the plots two months before planting on October, 2016.

Each plot contained at least 200 plants in 10 single row beds spaced 55 cm apart with 27 cm between plants in the row (equivalent to 67 340 plants ha^{-1}). There were four border rows between the plots to avoid unwanted interaction and the plots were planted and maintained following conventional plantation practices. Magnesium sulfate monohydrate ($MgSO_4.H_2O$) at 100 kg ha^{-1} was applied in the soil as a basic fertilizer together with diammonium phosphate (DAP) and potassium chloride (KCl) before planting. Selected medium size crowns of 'Smooth Cayenne' clone GP3 (250 - 350 g in weight) were planted on December, 2016.

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Data on plant mortality caused by *Phytophthora nicotianae* were collected from each plot by counting the dead plants 4, 6, 8 and 10 weeks after planting (WAP). The percent of plant mortality (disease incidence) was calculated by the following formula:

$$Plant\ mortality = \frac{Numbers\ of\ died\ plants}{Total\ numbers\ of\ plants}\ x\ 100\%$$

The soil pH (H_2O) was measured by pH meter - Mettler Toledo at 0 (before the treatments were applied), 4 and 10 weeks after planting. The Ca and Mg in the soil were extracted with neutralized 1N acetic acid at pH 7 and analyzed by atomic absorption spectrophotometry (AAS).

Experiment II: Effect of gypsum soil application on soil and leaf nutrition, plant response and fruit quality

The experimental design was a randomized complete block design with six treatments and four replications. Soil gypsum treatments were applied in the row between the single bed as a basic fertilizer before planting together with KCl (200 kg ha^{-1}), DAP (250 kg ha^{-1}), $MgSO4.H_2O$ (300 kg ha^{-1}), $CuSO_4$ (10 kg ha^{-1}), Borax (10 kg ha^{-1}) and Fine Compost (4.0 ton ha^{-1}). The gypsum (G) treatment in ton ha^{-1} and kg ha^{-1} Ca were G0 (Untreated and 0), G1 (0.5 and 116), G2 (1.0 and 233), G3 (1.5 and 349), G4 (2.0 and 465), and G5 (2.5 and 440). Soil pH at the beginning was 4.2, and then 1000 kg ha^{-1} of Dolomite lime was applied on June, 2016. Soil pH increase reached to 4.4 at planting on September, 2016 (Table 1).

Soil properties (pH, P, K, Ca, Mg, Cu, total C, total N) was observed at initial and at planting. Calcium and magnesium content in the soil and leaf were observed at 2, 3, 6, 7 and 9 months after planting (MAP). The length of the longest leaf with a leaf angle of 45^{o} from the soil surface (D-leaf) and plant weight were measured destructively at 3, 7, 9 and 11 MAP. Root length, total number, fresh weight and dry weight were observed at 3 MAP obtained. Plant weight, stem weight, fruit weight, crown weight, fruit size and crown size distribution were observed at harvest. Fruit quality of total soluble solid (TSS), titratable acidity (TA), TSS/TA ratio and fruit texture were observed at harvest.

The following soil nutrients were analyzed using the following methods: (a) pH with pH meter - Mettler Toledo, (b) C organic with Walkey and Black method, (c) P with P Bray method, (d) K, Ca and Mg were analysed using extraction by acetic acid pH 7 and reading with AAS, (e) micro nutrient (Cu) was analyzed using extraction by DTPA and reading with AAS, (f) N with Kjeldahl methods. Leaf analysis was done on D-leaf. One third of the upper leaves sample were cut not used, and the leaves were cut into pieces and separated into two parts; on part which green color were used for micro nutrient analysis and other part which have white/ pale color were used for macro nutrient analysis, and then dried in oven with temperature 70 ^{o}C for 24 hours. The dry leaf samples were grinded and sieve with 0.5 mm. Extraction was done using HNO_3 and H_2O_2 and destruction was done in temperature 175^{o}C. The AAS was used for reading macro and micronutrient, except P using spectrometer.

D-leaf was collected from each treatment plot. D-leaf is easily identified on the pineapple plant because it is the longest leaf with a leaf angle of 45^{o} from the soil surface.

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The D-leaf length is measured from the bottom to the top using ruler. The root samples were taken by circling each plant with a steel ring 54.5 cm in diameter, and 25 cm in height, then watering the soil carefully to separate the soil and the rhizosphere. The length of the longest root from the stem was measured with a ruler. The number of roots from the stem was counted. To get the fresh and dry root weight the roots were cut from the basal stem, air dried at room temperature to remove excess moisture and then weighed to determine fresh weight. Roots were then oven dried to a constant weight at 105°C to obtain the dry weight data.

To determine TSS content the fruit flesh sample was cut into small pieces (not including the fruit skin, fruit core or the top and bottom 2 cm of the fruit) then the juice was extracted, filtrate was measured by a hand-held refractometer (MASTER-53 α; Atago, Japan). TA was detected by titration to pH 8.1 with 0.1 M NaOH using phenolphthalein as an indicator and revealed as a percentage of citric acid. Fruit texture was measured at three point regions of the fruit slices taken from the top, middle and bottom section using a Brookfield Ametex CT3 Texture Analyser, a compression and tension testing tool for rapid quality control analyses. The fixture used was TA5 (a cylindrical probe 12.7 mm in diameter and 35 mm in length). Fruit size distribution was made by measured the larger diameter of the pineapple fruit: (a) < 1T diameter < 9.9 cm, (b) 1 T diameter 9.9 – 10.5 cm, (c) 1 3/8 T diameter 10.6 – 11.5 cm, (d) 2 T diameter 11.6 – 12.9 cm, (e) 2 ½ T diameter > 12.9 cm. Crown size distribution was made by measured the crown weight: (a) Extra small is < 150 g, (b) Small is 150 – 200 g, (c) Medium is 201 – 350 g, (d) Big is 351 – 450 g, and (e) Extra big is > 450 g. The collected data were analysed using an analysis of variance (ANOVA), and the means were compared with the Tukey test with a difference of 95% ($P<0.05$).

3. Results

Effect of gypsum soil application on hearth rot disease (Phytophthora nicotianae) incidence

The result showed that there was higher plant mortality in the D treatment than in the G treatments (Table 2). The shortest period from planting until significant numbers of plants had disease symptoms was four weeks after planting for treatment D1 (Table 2). Treatment D1 had also the highest soil pH among the treatments (Table 3). Eight weeks after planting, the plant mortality remained 54.3 % significantly higher for treatment D1 than for all other treatments, while the plant mortality for the G treatments was variable, but the differences were not significant (Table 2).

Effect of gypsum soil application on soil and leaf nutritions, plant response and fruit quality

The soil calcium content was affected by gypsum application consistently until 6 month after planting and declined by the time (Fig. 4). As shown in Fig. 5, untreated had a lower Ca uptake to the leaves compare to all gypsum treatments.

The effect of gypsum soil application on plant growth was provided in Table 4, while for root response was presented in Table 5. The application did not give any statistical difference to untreated on the D-Leaf length at 3, 7, 9 and 11 MAP, but increased plant weight significantly at 3 until 9 map. Root length, total root number, root fresh and dry weight were not affected significantly different by gypsum application.

Fruit weight, crown weight, stem weight and plant weight at harvest showed higher in all dosage treatments of gypsum compare to untreated but did not significant different (Table 6). Fruit TSS, TA, TSS/TA ratio and fruit texture (firmness) were presented in Table 7. There were not significant different of TSS, TA and fruit texture among treatments, but all gypsum treatment showed higher firmness value than untreated both in shell colour 1 and 3. Fruit size and crown size distribution at harvest were presented in Table 8, 9. All of Ca gypsum treatments could increase the number of big fruit size 2 T and 2 ½ T.

4. Discussion

The goals of the current experiment was the evaluation of an effect of gypsum soil application on hearth rot disease (*Phytophthora nicotianae*) incidence and the effect on soil and leaf nutrition, plant response and pineapple fruit quality. The results showed that *P. nicotianae* attacked the pineapple plants in all treatments six weeks after planting when the soil pH was over 5.0 due to high rainfall from December 2016 to March 2017, namely 270, 369, 352 and 418 mm per month, respectively. The mortality rates continued to increase with the increasing soil pH. Ten weeks after planting, the mortality with treatment D1 reached 63.8% when the soil pH was 5.9. This is significantly different than that for the G treatment (3.3-14.3%) with a soil pH level of 4.5-4.7.

Increasing the amounts of gypsum did not consistently increase the soil pH (Table 2). Ten weeks after planting, the plant mortality was low for treatments G0 through G3 and significantly different than treatment D1. This shows that keeping the soil pH low (treatment G0) and adding Ca using gypsum (treatment G1-G3) are more beneficial than using dolomite (treatment D1). Tsao et al. (1986) [18] reported that soil amendment with gypsum (calcium sulfate monohydrate) showed inhibition activity agains sporangium formation of *P. parasitica* that could not be done by lime, hydrate lime or dolomite lime. Calcium ion may stimulate a compound known to be implicated in the defense mechanisms of plants, called phytoalexin, as a result of fungal attacks [19].

The results also showed that the soil Ca contents in treatments G2 and G3 were significantly higher than that of the untreated soil ten weeks after planting (Table 2). Gypsum is moderately soluble in water (2.5 g/l) or approximately 200 times greater than lime [20]. This makes the Ca in gypsum more mobile than the Ca in dolomite lime and allows it to more easily move through the soil profile. When the initial soil content of Mg is less than 50 mg/kg a magnesium application is required [21]. In the present experiment the initial Mg content was 99 mg/kg and kieserite fertilizer (magnesium sulfate monohydrate: $MgSO_4.H_20$) was applied at planting time together with DAP and KCl to keep the Mg content at not less than 50 mg/kg in the soil. Nontheless the Mg content in the soil increased to 162 mg/kg in eight months and decreased to 159 mg/kg with D1 higher than all G treatments ten weeks after the pineapples were maintained with GGP's fertilizer regime. According to Nome et al. (2009) [22] magnesium can actually suppress Phytophthora by influencing how the pathogens invade and colonize plant tissue. When the

Mg nutrient is sufficient during plant growth the structural integrity of the middle lamella and the production of energy necessary for defense functions and inactivation of pathogen metabolites will increase [23]. Tsao et al. (1986) [18] reported that Mg ion induces the sporangia of *P. parasitica* to become nonfunctional or prevents the release of zoospores. Magnesium content in the soil was highest in treatment D1 but the highest mortality was seen also in the D1 treatment. It appears that higher soil pH level has a greater effect on increasing the disease than Mg ability to suppress the disease.

Calcium increases the absorption of some nutrients, such as ammonium, potassium and phosphorus, stimulates photosynthesis, and increases the size of the sellable plant parts [24]. Soil application of gypsum dosage 1.0-2.5 ton/ha could maintain the soil Ca content remain above the standard. Meanwhile, if Ca was supplied only by dolomite application at liming, it must be re-applied to meet the standard requirement not less than 100 mg/kg (Fig. 4). The higher the dose of gypsum applied to the soil, the higher Ca uptake to the leaves (Fig. 5).

Calcium is used in the synthesis of new cell walls, particularly the synthesis of the middle lamella to separate the newly divided cells [24]. The D-Leaf had 'succulent-brittle' leaf base that are commonly used to evaluate the plant nutrient status as an index of growth [25]. In this experiment, it was shown that soil applied calcium gypsum application as a basic fertilizer have no effect significantly on D-Leaf length. Calcium gypsum also increased plant weight significantly at 3 until 9 MAP when applied with high level dose 1.5-2.5 ton/ha (Table 4). Actually, the stem weight increases progressively after planting, with no unique morphological changes in the plant until the reproductive development phase begins [3]. Calcium can be supplied at high concentrations more than 10% of the dry weight in mature leaves without symptoms of toxicity or serious inhibition of plant growth [26].

The case also similar with the root system; root length, root number, root fresh and dry weight were not affected by gypsum application at 3 months after planting (Table 5). The roots of the pineapple plant may grow continuously throughout the year, but there is evidence that the root growth decreases after the flower induction and that the maximum root mass is reached at anthesis (Malezieux and Bartholomew, 2003). Actually, the availability of Ca in the rhizosphere supports the elongation of the root cells [27]. However, the proliferation depends on the availability of water and minerals in the rhizosphere. If the rhizosphere is too dry or poor in nutrients, the root growth is slow. The root growth increases when the condition of the rhizosphere improves [24]. Excess or lack of moisture, high salinity, roots disease are conditions that restrict the Ca uptake, may lead Ca deficiency symptoms in plant [28].

Fruit size, crown size and fruit quality usually depend on type, environment and cultivations. Fruit weight, crown weight, plant weight and stem weight at harvest were affected by calcium gypsum and increased compare to untreated regardless of the dose given in the treatments although did not statistically significant (Table 6). The fruit quality in the most fruit is determined by sugar content [29]. In this study, fruit quality (physio-chemical) analysis were made with following parameters of TSS, TA, TSS/TA (brix acid) ratio and fruit firmness. The result showed that TSS, TA and TSS/TA ratio were not significant different among the treatment (Table 7) but all meets standard of United States Standards for Grades of Canned Pineapple [30] and also meet requirement for fresh fruit market in Hawaii and Australia which a minimum of 12 °Brix soluble solids content in the fruit [31], while the TSS level of all treatments were in range of 12.0-13.5 °Brix. The TSS activity in all fruits increased during ripening progress.

When more soluble calcium is available in the soil, the calcium uptake into the pineapple fruit and the firmness of the flesh will increase. To evaluate the effect of calcium gypsum on the fruit firmness, the result were made in two stages of fruit ripening SC1 (shell colour 1, 10% yellow) and SC3 (shell colour 3, 20 – 30% yellow). All gypsum treatments increase the firmness both in SC1 and SC3, It showed need more energy (gram force) to pressure the pineapple flesh to changing shape or anthesis in treated soil than in untreated soil although not significantly different both in top, middle and bottom part of the fruit (Table 7). Previous research reported that a high level of calcium could prevent the deterioration of the cell wall pectate and that it was important to maintain the integrity of the cell membrane and the cell wall stabilization [26].

Conclusions

The plant mortality of dolomite treatment reached 63.8% when the soil pH was 5.9, higher than the gypsum treatments (3.3-14.3%) with a soil pH level of 4.5-4.7 at ten months after planting. Soil application of gypsum dose 1.0-2.5 ton/ha could maintain the soil Ca content remain above the standard value of 100 mg/kg for more than 7 MAP, increased Ca and K uptake to the leaves, but was not for Mg and P. Calcium gypsum also increased plant weight significantly at 3 until 9 MAP when applied with high level dose 1.5-2.5 ton/ha. Soil applied gypsum before planting met the plant Ca and Mg requirement during a period of early and fast growth step and recommended to be used as a substitute of dolomite when the soil pH must be kept at certain level safe for heart rot disease.

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Conflicts of Interest

The authors declare there are no conflicts of interest.

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Table 1. Soil analysis at planting

Properties	Unit	Experiment 1	Experiment 2		Fine compost
		At planting (Dec, 2016)	Initial soil (May, 2017)	At planting (Sep, 2017)	
pH	-	4.6	4.2	4.4	7.2
P	mg/kg	17.7	21.2	22.9	2.6
K	mg/kg	86.4	68.5	75.0	18.13

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Ca	mg/kg	314.4	60.3	127.8	21.50
Mg	mg/kg	98.6	49.1	60.8	5.26
Cu	mg/kg	Not analysed	0.6	0.6	Not analysed
Total C	Wt %	1.2	1.4	1.3	21.6
Total N	Wt %	Not analysed	Not analysed	Not analysed	1.68
C/N ratio	-	Not analysed	Not analysed	Not analysed	12.86

Note: Liming dolomite 1 ton ha^{-1} was done at June 2017 (Exp. 2)

Table 2. Mortality of pineapple due to *Phytophthora nicotianae* disease at 4, 6, 8 and 10 weeks after planting (WAP).

Treatment	Plant mortality (%)			
	4 WAP	6 WAP	8 WAP	10 WAP
G0 (Untreated)	0.0 a	1.3 a	2.7 a	3.3 a
G1 (Gypsum 1000 kg/ha)	0.0 a	4.7 a	9.3 a	10.3 a
G2 (Gypsum 1500 kg/ha)	0.0 a	4.3 a	7.0 a	8.7 a
G3 (Gypsum 2000 kg/ha)	0.3 a	7.3 ab	12.0 a	14.3 a
D1 (Dolomite 2000 kg/ha)	0.7 a	24.3 b	54.3 b	63.8 b
P – value	0.12	0.01	0.00	0.00

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 3. Soil pH, Ca and Mg contents in soil at 0, 4 and 10 weeks after planting (WAP).

Treatment	Soil pH			Ca (mg/kg)			Mg (mg/kg)		
	0 WAP	4 WAP	10 WAP	0 WAP	4 WAP	10 WAP	0 WAP	4 WAP	10 WAP
G0	4.6	5.1 a	4.5 a	314	430 a	311 a	99	137 ab	75 ab
G1	4.6	5.3 ab	4.6 a	314	493 a	379 ab	99	156 ab	77 ac
G2	4.6	5.3 ab	4.7 a	314	489 a	400 b	99	146 a	98 ac
G3	4.6	5.0 a	4.7 a	314	448 a	389 b	99	120 b	62 b
D1	4.6	5.5 b	5.9 b	314	467 a	369 ab	99	162 c	159 c
P-value	-	0.00	0.00	-	0.61	0.02	-	0.00	0.00

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 4. D-Leaf length and plant weight at 3, 7, 9 and 11 months after planting (MAP)

Treatment	D-Leaf length (cm)				Plant weight (g)			
	3 MAP	7 MAP	9 MAP	11 MAP	3 MAP	7 MAP	9 MAP	11 MAP
G0 (Untreated)	51.2 a	75.9 a	87.2 a	95.1 a	201.3 a	842.5 a	1336.3 a	2546.3 a
G1 (0.5 ton/ha)	51.0 a	75.8 a	88.1 a	97.4 a	215.0 ab	1032.5 a	1606.3 ab	2592.5 a

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G1 (1.0 ton/ha)	53.1 a	77.4 a	89.4 a	96.5 a	222.5 ab	901.3 ab	1450.0 ab	2772.5 a
G1 (1.5 ton/ha)	51.9 a	76.4 a	89.0 a	97.2 a	207.5 ab	1021.3 b	1736.3 b	2598.8 a
G1 (2.0 ton/ha)	53.6 a	78.1 a	90.2 a	104.7 a	210.0 ab	1002.5 ab	1698.8 ab	2722.5 a
G5 (2.5 ton/ha)	54.1 a	76.6 a	88.7 a	96.2 a	225.0 b	1037.5 b	1725.0 ab	2520.0 a
P-value	0.56	0.94	0.91	0.36	0.02	0.01	0.02	0.66

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 5. Root length, total root number, root fresh and root dry weight at 3 months after planting (MAP).

Treatment	Root length (cm)	Total root number	Root fresh weight (cm)	Root dry weight (cm)
G0 (Untreated)	43.1 a	38.9 a	5.3 a	2.5 a
G1 (0.5 ton/ha)	41.8 a	29.9 a	5.8 a	2.7 a
G1 (1.0 ton/ha)	45.1 a	35.8 a	5.3 a	2.6 a
G1 (1.5 ton/ha)	41.9 a	32.5 a	5.3 a	2.4 a
G1 (2.0 ton/ha)	46.3 a	34.7 a	4.5 a	2.1 a
G5 (2.5 ton/ha)	43.9 a	36.3 a	6.5 a	3.3 a
P-value	0.82	0.16	0.25	0.10

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 6. Plant weight, stem weight, fruit and crown weight at harvest in gram (g)

Treatment	Plant weight at harvest	Stem weight at harvest	Fruit weight	Crown weight
G0 (Untreated)	2451.3 a	520.0 a	1455.0 a	322.5 a
G1 (0.5 ton/ha)	2908.3 a	607.5 a	1497.5 a	402.5 a
G1 (1.0 ton/ha)	2730.0 a	590.0 a	1731.3 a	365.0 a
G1 (1.5 ton/ha)	2645.0 a	580.0 a	1467.5 a	330.0 a
G1 (2.0 ton/ha)	2647.5 a	532.5 a	1677.5 a	335.0 a
G5 (2.5 ton/ha)	2527.3 a	537.5 a	1632.5 a	345.0 a
P-value	0.41	0.59	0.13	0.51

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 7. Pineapple fruits quality at harvest

Treatment	Fruit TSS (°Brix)	Fruit TA (%)	TSS/ TA ratio	Fruit texture (firmness)					
				Shell colour 1 (10% yellow)			Shell colour 3 (20 – 30% yellow)		
				Top	Middle	Bottom	Top	Middle	Bottom

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				(g)	(g)	(g)	(g)	(g)	(g)
G0 (Untreated)	13.5 a	0.55 a	24.5	282.8 a	282.2 a	278.3 a	230.6 a	261.7 a	230.6 a
G1 (0.5 ton/ha)	12.6 a	0.49 a	25.6	296.7 a	298.3 a	282.2 a	267.2 a	267.2 a	267.2 a
G1 (1.0 ton/ha)	12.1 ab	0.46 a	26.2	283.3 a	289.4 a	281.7 a	257.8 a	277.2 a	257.8 a
G1 (1.5 ton/ha)	12.7 a	0.53 a	23.9	326.1 a	312.8 a	282.2 a	262.8 a	279.4 a	262.8 a
G1 (2.0 ton/ha)	12.0 ab	0.50 a	23.9	281.1 a	289.4 a	299.4 a	254.4 a	267.8 a	254.4 a
G5 (2.5 ton/ha)	13.3 a	0.52 a	25.6	285.6 a	292.2 a	303.3 a	293.9 a	275.6 a	293.9 a
P-value	0.045	0.140	-	0.916	0.720	0.844	0.431	0.977	0.121

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 8. Fruit size distribution at harvest

Treatment	Fruit size distribution (%)					
	< 1T	1 T	1 3/8 T	2 T	2 1/2 T	(2 T + 2 1/2 T)
G0 (Untreated)	3.7 a	12.0 a	15.4 a	26.0 a	43.0 a	68.9
G1 (0.5 ton/ha)	3.0 a	8.2 a	10.7 a	31.2 a	46.8 a	78.0
G1 (1.0 ton/ha)	2.8 a	8.0 a	15.6 a	33.1 a	40.5 a	73.6
G1 (1.5 ton/ha)	2.2 a	8.2 a	15.1 a	28.5 a	46.1 a	74.5
G1 (2.0 ton/ha)	4.5 a	8.4 a	13.1 a	30.8 a	43.1 a	73.9
G5 (2.5 ton/ha)	1.7 a	11.4 a	14.8 a	30.7 a	41.4 a	72.1
P-value	0.601	0.771	0.707	0.863	0.588	-

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

Table 9. Crown size distribution at harvest

Treatment	Crown size distribution (%)					
	Extra small	Small	Medium	Big	Extra big	(Big + Extra big)
G0 (Untreated)	0.3 a	3.2 a	60.1 a	33.2 a	3.2 a	36.4
G1 (0.5 ton/ha)	0.0 a	0.0 a	40.1 a	54.2 a	5.7 a	59.9
G1 (1.0 ton/ha)	0.0 a	3.0 a	39.3 a	54.0 a	3.7 a	57.7
G1 (1.5 ton/ha)	0.0 a	1.7 a	43.9 a	52.6 a	1.8 a	54.4
G1 (2.0 ton/ha)	0.0 a	3.3 a	40.8 a	54.4 a	1.5 a	56.9

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G5 (2.5 ton/ha)	0.0 a	3.7 a	35.0 a	56.0 a	5.7 a	61.7
P-value	0.458	0.895	0.433	0.346	0.691	-

Means within a column followed by a common letter are not significantly different (P<0.05) according to Tuckey test of difference.

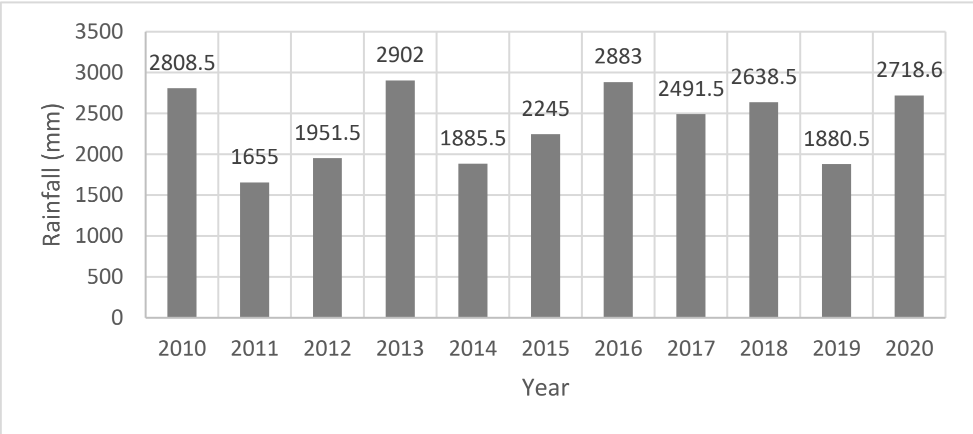

Figure 1. Yearly rainfall with several "wet dry season" and "long dry season" normal rainfall was around 2500 mm/year

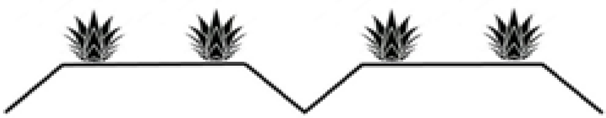

Figure 2. Raised bed double row

Figure 3. Lower bed single row

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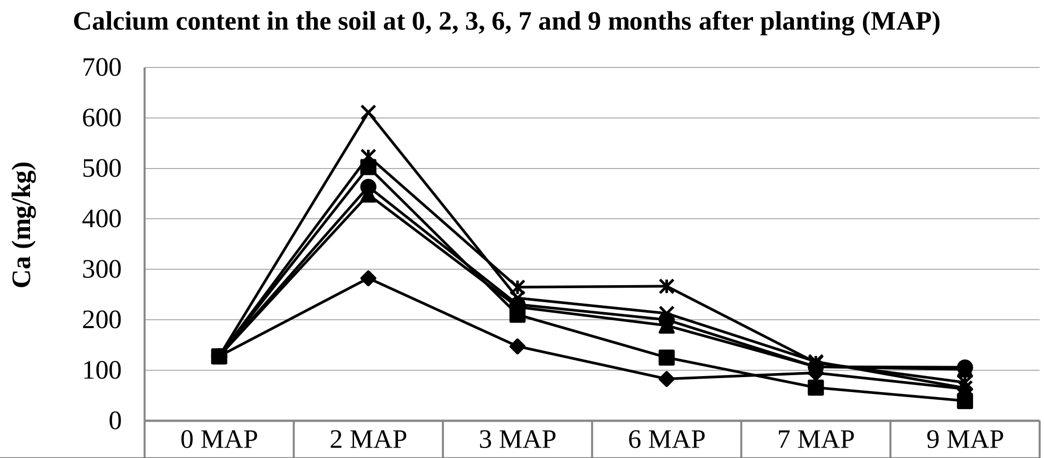
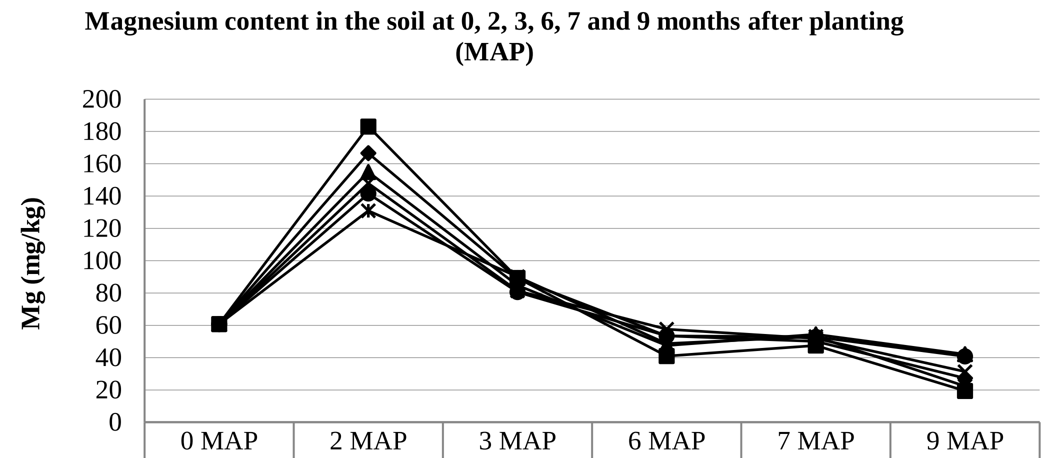


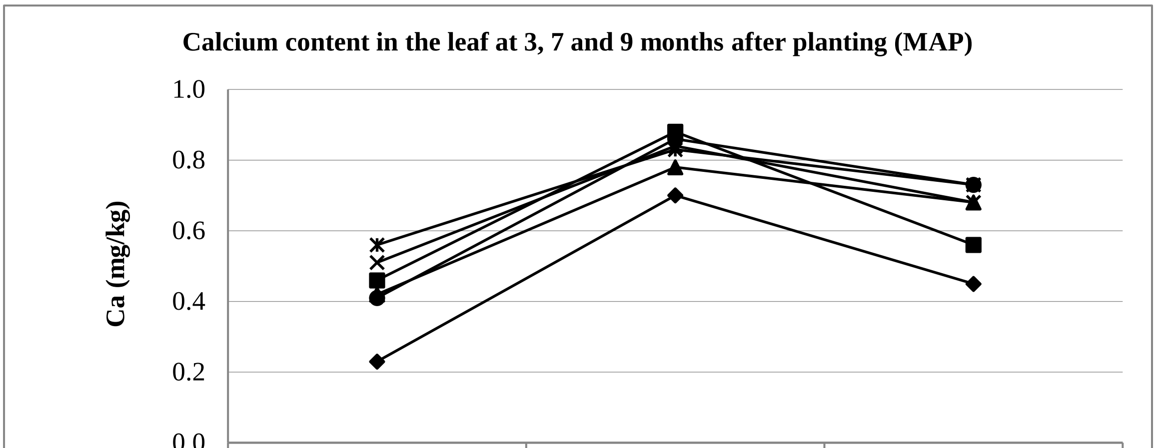
	0 MAP	2 MAP	3 MAP	6 MAP	7 MAP	9 MAP
0.0 ton/ha	127.8	282.5	147.7	83.2	94.9	63.0
0.5 ton/ha	127.8	502.7	210.1	125.3	65.7	39.5
1.0 ton/ha	127.8	448.2	225.6	188.5	106.7	101.8
1.5 ton/ha	127.8	611.2	243.0	212.5	117.0	64.9
2.0 ton/ha	127.8	524.1	264.9	266.8	115.4	75.9
2.5 ton/ha	127.8	463.9	230.8	200.4	107.1	106.0

Figure 4. Calcium content in the soil at 0, 2, 3, 6, 7 and 9 months after planting (map).



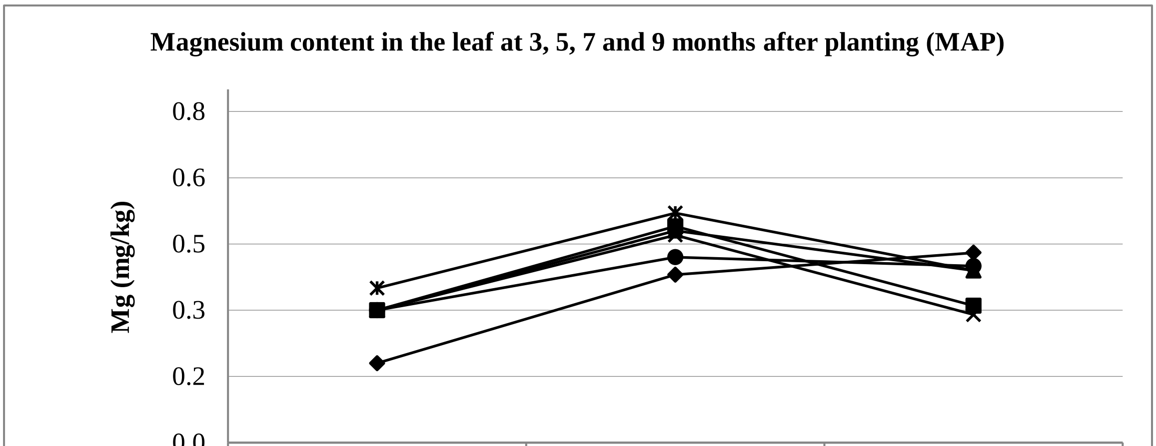
	0 MAP	2 MAP	3 MAP	6 MAP	7 MAP	9 MAP
0.0 ton/ha	60.8	166.5	88.8	53.4	50.1	27.2
0.5 ton/ha	60.8	183.1	89.2	40.9	47.5	19.4
1.0 ton/ha	60.8	154.9	84.8	47.5	54.4	42.0
1.5 ton/ha	60.8	147.9	81.3	57.6	51.8	31.3
2.0 ton/ha	60.8	130.9	90.0	48.6	53.0	22.3
2.5 ton/ha	60.8	141.5	80.6	53.4	52.8	40.8

Figure 5. Magnesium content in the soil at 0, 2, 3, 6, 7 and 9 months after planting



	3 MAP	7 MAP	9 MAP
0.0 ton/ha	0.2	0.7	0.5
0.5 ton/ha	0.5	0.9	0.6
1.0 ton/ha	0.4	0.8	0.7
1.5 ton/ha	0.5	0.8	0.7
2.0 ton/ha	0.6	0.8	0.7
2.5 ton/ha	0.4	0.9	0.7

Figure 6. Calsium content in the leaf at 3, 7 and 9 months after planting.



	3 MAP	7 MAP	9 MAP
0.0 ton/ha	0.2	0.4	0.4
0.5 ton/ha	0.3	0.5	0.3
1.0 ton/ha	0.3	0.5	0.4
1.5 ton/ha	0.3	0.5	0.3
2.0 ton/ha	0.4	0.5	0.4
2.5 ton/ha	0.3	0.4	0.4

Figure 7. Magnesium content in the leaf at 3, 7 and 9 months after planting.