agronomy

MDPI

Article

Phosphogypsum Organic, a Byproduct from Rare-Earth Metals Processing, Improves Plant and Soil

Mohamed Musa Hanafi [1,*], Parisa Azizi [1] and Jeyanny Vijayanathan [2]

[1] Institute of Tropical Agriculture and Food Security, Universiti Putra Malaysia, Serdang 43400, Selangor, Malaysia; bahar3236@yahoo.com
[2] Soil Management Branch, Forest Plantation Program, Forest Research Institute of Malaysia, Kepong 52109, Selangor, Malaysia; jeyanny@frim.gov.my
* Correspondence: mmhanafi@upm.edu.my; Tel.: +60-13-356-5900

Abstract: Phosphogypsum organic (PG organic) is a soil conditioner, derived from residues, water leach purification (WLP) and neutralisation underflow (NUF) from rare-earth metals processing in combination with composted organic material. There was no report available with regards to the effectiveness of this byproduct for crops improvement in a sandy soil texture. Therefore, a field trial involving a multi-crop was conducted by the addition of PG organic on a sandy texture soil for 23-month period. Guinea grass or guinea grass intercropping with teak wood trees, corn and kenaf showed an improvement in cumulative fresh yield in plot treated with PG organic either with a half- or full-fertilizer recommended rate for the respective crop as compared to control. The same trend was also observed in teak wood trees in hole planting systems and pandan coconut seedlings in the polybags. Application of PG organic in each season showed a consistently higher cumulative fresh yield or yield for certain crop types due to soil ability to maintain the soil pH buffering capacity (pH 5.8–6.0). Therefore, the application of PG organic as soil conditioner promotes plant growth and development due to the improvement of soil condition by creating suitable ecosystem for nutrients absorption by roots.

Keywords: water leach purification (WLP); neutralisation underflow (NUF); sandy soil texture; phosphogypsum organic; soil conditioner; rare-earth metals; organic material

Citation: Hanafi, M.M.; Azizi, P.; Vijayanathan, J. Phosphogypsum Organic, a Byproduct from Rare-Earth Metals Processing, Improves Plant and Soil. *Agronomy* **2021**, *11*, 2561. https://doi.org/10.3390/agronomy11122561

Academic Editors: Othmane Merah, Purushothaman Chirakkuzhyil Abhilash, Magdi T. Abdelhamid, Hailin Zhang and Bachar Zebib

Received: 24 November 2021
Accepted: 29 November 2021
Published: 16 December 2021

Highlights

- Addition of PG organic improves soil pH buffering capacity by creating efficient soil ecosystem for nutrient absorption by roots.
- Most crops tested showed an improvement in cumulative fresh yield during the period of this trial.
- Utilisation of PG organic had improved the physico-chemical characteristics of a problematic sandy soil.

1. Introduction

Two types of residues, mainly water leach purification (WLP) and neutralisation underflow (NUF) are produced from the processing of rare-earth metals. The WLP contains iron phosphate ($FePO_4{\cdot}(H_2O)_2$), gypsum ($Ca_2SO_4{\cdot}(H_2O)_2$), silicon (amorphous and crystalline), silicon dioxide (SiO_2), magnesium hydroxide ($Mg(OH)_2$), aluminium hydroxide ($Al(OH)_2$), uranium phosphate (O_8P_2U) and thorium pyrophosphate (ThP_2O_7). The NUF is highly rich in gypsum, it supplies great amounts of needed nutrients to the soil, including magnesium (Mg^{2+}), sulphide ($S_2{}^{-}$), calcium (Ca^{2+}) and phosphorus ($PO_4{}^{-3}$) [1]. Furthermore, the residues have the property of a liming agent. Therefore, a combination of WLP and NUF has the potential to improve soil nutrients by supplying nutrients (Ca^{2+}, $SO_4{}^{2-}$, Mg^{2+}, PO_4, $PO_4{}^{2-}$ and $SO_4{}^{2-}$), reducing soil toxicity ($SO_4{}^{2-}$ reduces Al toxicity), changing soil mechanics (Ca^{2+} promotes flocculation in soil hardening process) and acting as a liming agent to increase pH of acidic soil for nutrient uptake. Our initial research has produced the best ratio of 2:1:7 of WLP, NUF and BRIS soil and/or composted oil palm empty fruit bunch (COPEFB) for agricultural purposes [2].

Since, a major proportion of the constituents is gypsum ($CaSO_4 \cdot 2H_2O$), subsequently, the product is called 'phosphogypsum organic' (PG organic) [3]. This PG organic contains no significant amounts of radionuclides other than naturally occurring radionuclides (each radionuclide in the U or Th decay chain is <1 Bq/g or K40 < 10 Bq/g) [1]. Therefore, this formulation is not a radioactive material as reported by Malaysia Nuclear Agency (MNA) and approved by the Atomic Energy Licensing Board (AELB) to conduct this study. Our previous study in the laboratory and under field conditions showed there was no leaching of natural occurring radionuclides and metal ions to the groundwater. Therefore, the application of PG organic to the studied soil had no impact on the soil, plants and water [3].

In order, to develop specific soil quality remediation and have soil with a great preference, which will be important requisites in the development of the agricultural product, PG organic has been applied to improve problematic sandy soils. Since, the organic material used as filler is derived from COPEFB, a by-product from palm oil processing mill. This soil contains more than 80% of sand fraction, which is a problematical soil in Southeastern Asia, including Malaysia and Indonesia [4]. It is unsuitable for agricultural purposes because of its weak structure, deficient of nutrients, low capacity of water retention, high soil temperature and ultimately inadequate supports of plants to grow [5]. However, it is assumed that the application of fertilizer in combination with PG organic may improve sandy soil structure and quality. The organic fraction may play an important role to hold nutrients and in the formation of soil structure. Successful utilisation of this PG organic in this soil might be used for other problematic soils worldwide.

Previous study, mainly concerned on the effect of the rare earth elements (REEs) on seed germination, root development, increment plant biomass and fruit quality improvement [6,7], the dosage of REEs on plant growth inhibition and plant death [6,8,9] and reduction of heavy metals uptake by plants [10]. Furthermore, several plant mechanisms were suggested to be involved in REEs, when added in sufficient quantity, including (i) improving nutrient uptake of nitrogen (N), potassium (K) and phosphorus (P) [11], (ii) activating enzymes involved in the processes of plant and/or soil microbe's nutrients [11,12], (iii) improving chlorophyll production [13] and (iv) improving plant tolerance to drought or cold stress [14]. To the best knowledge of the authors, there was no such study related to the usage of PG organic for improvement of soil and its effect on multiple crops growth in sandy texture soils. Therefore, the objectives of the study were (i) to evaluate the use of PG organic as a soil conditioner on multiple crops performance grown on a sandy soil texture and (ii) to measure the soil physico-chemical characteristics changes following the addition of PG organic to the soil.

2. Materials and Methods

2.1. Experimental Research Site, Design and Treatments

The field trial was conducted on 1.62 ha at Kampung Darat Sungai Ular (3°50′51″ N, 103°21′46″ E), located about 4 km from the Lynas Advance Material Plant (LAMP), Gebeng, Kuantan, Pahang (Figure 1). The experiment was performed with randomised complete block design (RCBD) with three replications for each in three planting seasons (23-month) beginning in 2015 with 4-month cycles for each season. There are seven treatments applied as shown in Figure 2. The PG organic (Table 1) and fertilizer were added to the top of the soil under the plant canopy, when permissible based on soil and foliar analyses. The residual effect of the PG organic was measured for five test crops, including sweet corn (*Zea mays* L.), kenaf (*Hibiscus cannabinus* L.), guinea grass (*Panixum maximum* Jacq), pandan coconut, also known as green dwarf coconut (*Cocos nucifera* L.) seedlings and 'Jati Unggul Nusantara' teak wood (*Tectona grandis*) tree from Indonesia. A drip irrigation water system was applied to each plot using black plastic tape tubing. The water was supplied when necessary to achieve the target moisture content of soil field capacity (FC).

Figure 1. Kampung Darat Sungai Ular map located about 4 km from the LAMP complex in Gebeng, Kuantan, Pahang (Courtesy of Google Inc., Mountain View, CA, USA).

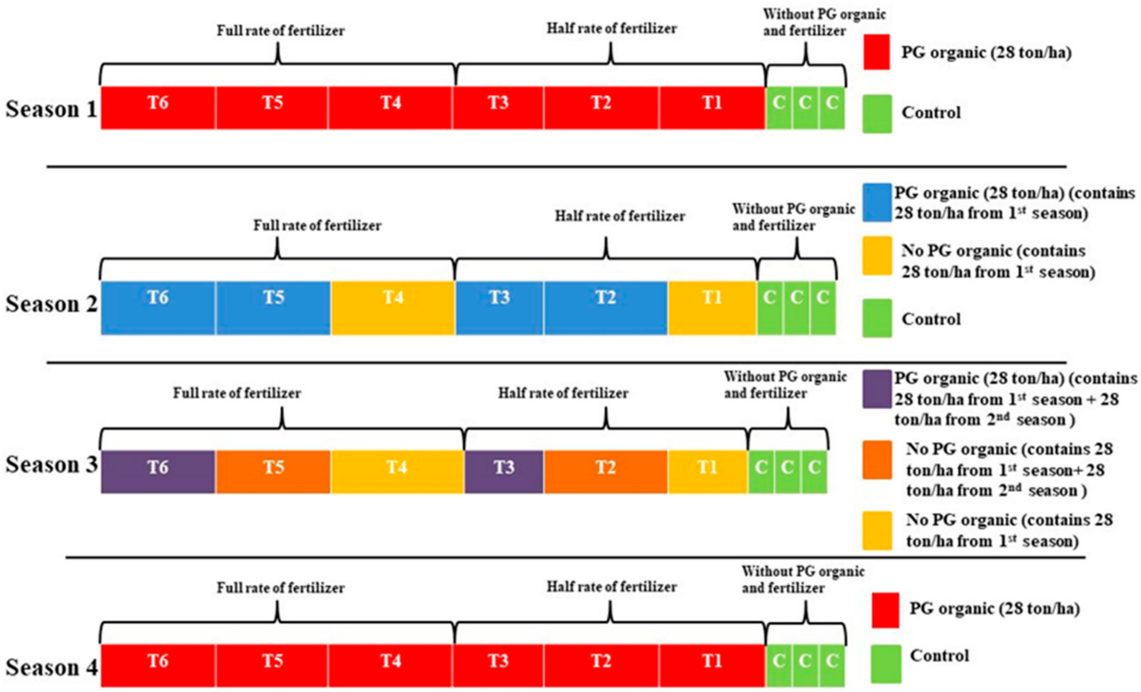


Figure 2. The sub-plots receiving the PG organic treatment for three cropping seasons for corn, kenaf, guinea grass, pandan coconut and teak wood tree. *Note: Blue colour represents the sub-plot receiving the PG organic for each cropping season, and yellow colour represents the sub-plot receiving residual treatment. After three seasons, total PG organic received by plot, T1 and T4 = 28 ton/ha, T2 and T5 = 56 ton/ha and T3 and T6 = 84 ton/ha.*

Table 1. Physico-chemical characteristics of PG organic [3].

Parameter	Value
Moisture (%)	13.79 ± 0.052
pH_{water} (1:2.5)	7.16 ± 0.012
Conductivity (mS/cm)	4.96 ± 0.058
Cation exchange capacity (CEC) ($cmol_+$/kg)	24.31 ± 2.325
Exchangeable Ca	65.60 ±5.205
Exchangeable K	14.82 ± 1.209
Exchangeable Mg	51.04 ± 5.074
Exchangeable Na	1.85 ± 0.010
Nitrogen (%)	1.29 ± 0.027
Phosphorus (%)	2.62 ± 0.143
Potassium (%)	2.24 ± 0.030
Calcium (%)	9.56 ± 0.598
Magnesium (%)	2.99 ± 0.022
Water soluble P (mg/kg)	154.67 ± 12.837
Aluminium (%)	0.74 ± 0.056
Boron (%)	0.02 ± 0.003
Copper (%)	0/01 ± 0.001
Iron (%)	5.93 ± 0.345
Manganese (%)	0.17 ± 0.007
Zinc (%)	0.04 ± 0.003

Note: MS ISO/IEC 1702.

2.2. Planting of the Test Crops

Corn and kenaf were planted using the seeds. They were seeded manually and maintained throughout the study period according to the standard practices of respective crops. Guinea grass was planted using grass cuttings with similar vigour, about 15 cm in length with 3 nodes. One node was placed in the soil to facilitate roots growth and two nodes were exposed for leaf development and growth. Pandan coconut was planted in black polybags (38 cm × 45 cm) containing about ¾ full of the top 15 cm of soil from this site. The teak wood tree seedlings with three fully developed leaves were transplanted in the field. The teak wood seedling was purchased from a local supplier.

For teak wood trees and green dwarf coconut, the addition of the PG organic to the sandy soil was done in a similar manner to other crops. The hole planting system was used for planting of teak wood tree and pandan coconut seedlings (Supplementary data—S1). Eighty-four superior clonal teak Jati Unggul Nusantara seedlings were planted using a 3 × 3 m spacing on 17 November 2015 within the guinea grass crop, which was planted using 0.5 × 0.5 m spacing (Figure 3). The PG organic and fertilizer were added to guinea grass as mentioned above and broadcasted on top of the soil under the plant canopy, when permissible based on soil and foliar analyses.

The quantity of fertilizer used for pandan coconut was based on the age (Table 2). Recommended fertilizer, 'refers to full-fertilizer' rates were used for guinea grass, sweet corn and kenaf in every season of cropping. For guinea grass, the fertilizer rates were 100 kg N/ha (urea, 45% N), 115 kg P_2O_5/ha (triple superphosphate (TSP), 45% P_2O_5) and 60 kg K_2O/ha (muriate of potash (MoP), 60% K_2O). For sweet corn, the rates were 120 kg N/ha (urea), 60 kg P_2O_5/ha (TSP) and 90 kg K_2O/ha (MoP). The fertilizers were applied as the basal dressing during the planting time except for N, which was half applied at the planting time and the remaining half 30 days after sowing (DAS) to reduce leaching and volatilisation losses. For kenaf, the fertilizer Nitrophoska Green (15:15:15) was applied at a rate of 200 kg/ha as the basal dressing, and nitrogen (N) was later applied as top dressing at the rate of 300 kg/ha in three splits at intervals of 20 days using urea (46% N) fertilizer. When necessary, chlorpyrifos insecticide was applied at 2 L/ha to control insects.

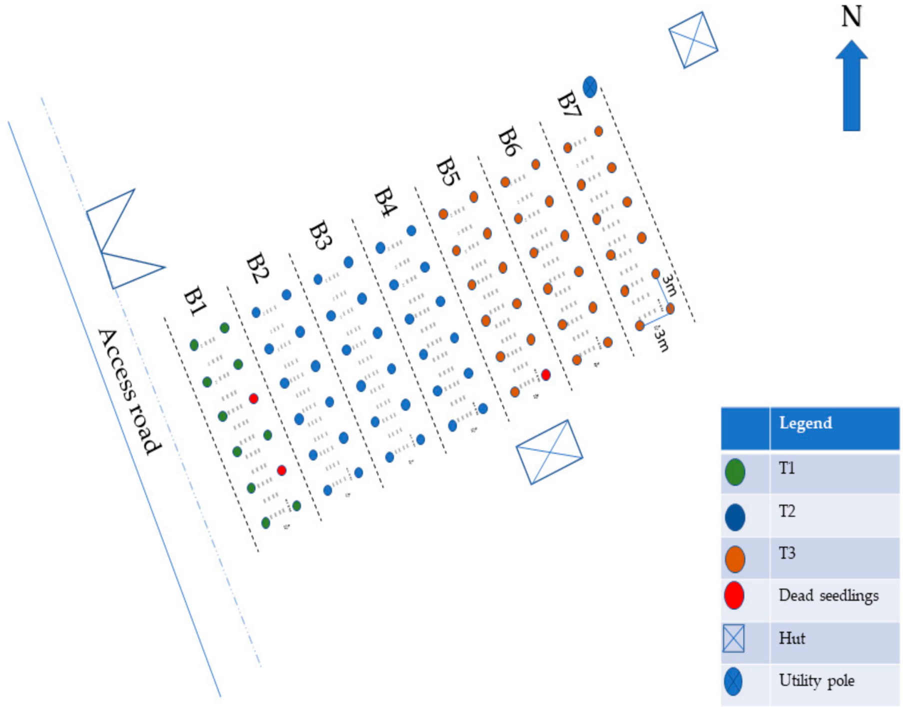


Figure 3. The layout of the planted teak wood seedlings intercropped with guinea grass. *Note: B represents block, numbers 1 to 7.*

Table 2. The quantity of straight fertilizer used for pandan coconut during this experiment.

Month	N	P_2O_5	K_2O	MgO	Urea	TSP	MoP	GML
				——g/palm——				
1 to 2	1.5	1.5	0.6	0.4	3.3	3.3	1.0	3.3
3	2.25	2.25	0.9	0.6	4.9	4.9	1.5	5.0
4 to 5	3	3	1.2	0.8	6.5	6.5	2.0	6.7
6 to 10	4.5	4.5	1.8	1.2	9.8	9.8	3.0	10.0
>12	6.75	6.75	2.7	1.8	14.7	14.7	4.5	15.0

Note: Urea (46% N),triple superphosphate (TSP, 46% P_2O_5), muriate of Potash (MoP, 60% K_2O) and ground magnesium limestone (GML, 12% MgO; 30% CaO).

2.3. Plant Sampling, Sample Preparation and Methods of Analysis

The crops in this study were harvested or observed and recorded at different times depending on the length of the cropping season. Guinea grass was harvested by cutting at 10 cm from the soil surface for every month, and a three-month period is considered one season. Corn and kenaf were harvested between 3 and 4 months for one season. There were 3 seasons for kenaf and 4 seasons for corn. Pandan coconut was destructively harvested at the end of the experimental period after approximately one and a half years. The teak tree was intercropped with the grass, where the treatment was only applied to the grass. Therefore, the teak tree was indirectly derived nutrients from the surrounding areas. The data for teak were measured two times during the growing period. The dates of harvest or data measurement that were taken for each crop used in this study are provided in Table 3.

2.3.1. Corn

The whole plot for each treatment was harvested and the fresh cob yield was measured. A sub-sample of 3 plants was randomly selected and carefully uprooted. They were separated into stem, leaves, husk, cob and grain, and then the fresh weight was measured. They were oven dried for 48 h at 65 °C in the laboratory and the dry weight was measured before the samples were ground and kept in plastics bags for further analysis.

Table 3. The Harvesting date or vegetative data measurements for each crop used in this study.

Crop Type	Harvesting or Sampling Date	Season	Remarks
Guinea grass	03-01-2016, 03-02-2016, and 08-03-2016	1	Three grass cuttings
	19-04-2016, 04-06-2016, and 03-07-2016	2	Three grass cuttings
	20-08-2016, 25-09-2016, and 04-11-2016	3	Three grass cuttings
Kenaf	18-02-2016	1	
	29-11-2016	2	
	21-06-2017	3	
Corn	12-01-2016	1	
	30-03-2016	2	
	28-08-2016	3	
	22-04-2017	4	
Pandan coconut	11-05-2017	-	Destructive sampling
Teak wood tree	12-01-2016	Soil profile sampling, field observations on nutrient deficiency symptoms	
	24-05-2016	Height and basal diameter measurements, plant tissue sampling for nutrient deficiency	
	09-08-2016	Height and basal diameter measurements, chlorophyll content measurement	
	11-11-2016	Height and basal diameter measurements, pest incidence consultation	
	07-02-2017	Height and DBH measurements, pest incidence consultation	
	09-08-2016	Height and DBH measurements	
	23-05-2017	Height and DBH measurements, soil and foliar sampling for analysis	

Note: DBH, diameter at breast height.

2.3.2. Kenaf

The same procedure as for the grass was followed. The total fresh weight and plant height were measured. A sub-sample of three kenaf plants was carefully uprooted to prevent the loss of root biomass during this process. They were separated into roots, stems, and leaves. The fresh weight and oven-dried (for 48 h at 65 °C) weight of each section were measured in the laboratory. They were ground and the sample was kept for further analysis.

2.3.3. Guinea Grass

Three samplings' areas represented by one square meter quadrants were selected randomly in each plot. The grass was cut at 10 cm from the soil surface, and the fresh weight was measured. A sub-sample was put in the oven and dried for 48 h at 65 °C in the laboratory. The sample was ground to pass through a 0.5-mm sieve using a universal grinder (MF10 basic IKA® WERKE, Staufen, Germany). The sample was placed in a labelled self-adhesive plastic bag for further analysis.

2.3.4. Pandan Coconut

The following vegetative growth parameters were measured: (i) fresh and dry weight of upper and lower parts; (ii) height of the seedlings from the soil level to the tip of the leaves in the third frond; (iii) number of fronds based on the total number of leaves; (iv) length of the from the first torn to the tip of the rachis of the third frond; (v) number of leaflets; (vi) girth of seedlings at the bole of stem from one cm above the ground using absolute digimatic calipers (Mitutoyo, Tokyo, Japan); (vii) chlorophyll content on the third frond using SPAD-502Plus (Konica Minolta, Tokyo, Japan) according to the method described by Hardon et al. [15] and the reading were taken three times; (viii) root lengths; and (iv) total number of primary roots.

The leaf area index (LAI) was measured by conventional methods, in which the LAI is the product of three variables. The three variables were frond area (a), number of green fronds (N) and planting density (D). The relative leaf area was converted to the true area by multiplying by a correction factor of 0.55. The leaf chosen was frond number three, near the middle of the crown, which was assumed to be representative of the crown. Therefore, frond number three was selected from each palm. The total number of healthy fronds was calculated for each palm. Then, the rachis length was measured from the first torn to the tip of the rachis. The number of leaflets for each frond was recorded. Leaflets from one-side of the frond were cut. The one-sided leaflet area was multiplied by two to obtain the total leaflet area of the frond. The length and width of the petioles were measured. Finally, the LAI was then calculated using the following formula by Hardon et al. [15]:

$$LAI = a \times N \times D \times 0.55$$

where, a = frond area, N = number of green fronds and D = planting density.

2.3.5. Teak Wood Tree

Only the plant height and diameter of the trunk were measured, and the results were compared to existing data in Indonesia, which was from teak trees planted on volcanic and fertile soil.

The following parameters were measured two times on 7 February and 23 May 2017: (i) the seedling height and (ii) and the diameter at breast height (DBH) or the mean basal diameter (BD) were recorded (cm). The initial data measurements at 6 months after planting (MAP) and at 12 MAP were also summarised using the relative growth rate (RGR) equation below for the mean basal diameter and seedling height. The formula to calculate the RGR is given below:

RGR = [ln(Mo − Mt)]/t, where Mo = Data at initial, 6 MAP, Mt = Data at final, 12 MAP, and t = time (months).

The stand volume was calculated using a common formula for the basal area (g) and volume (v) at 15 and 18 MAP. The formula to calculate 'g' and 'v' is given below:

$$g = 3/4(\pi \times DBH2)/10{,}000$$

v (cm^3) = g × height (m) × 0.2¥, where DBH is the diameter at breast height (cm), v is the stem height (m), g is the basal area (cm^2) and ¥ is the stem taper for small-sized teak seedlings.

2.4. Statistical Analysis

All the data were analysed using the Statistical Analysis System (SAS) version 9.4 software [16]. All data were subjected to an analysis of variance (ANOVA) statistical analysis to detect the variation of plant response at different sampling times, which coincided with the PG organic application. A comparison of means was performed using the least significant difference (LSD) test for other crops and the Student Newman Keuls (SNK) test for teak wood trees. The seedling growth model using linear regression was tested for significance in the software.

3. Results

3.1. Fresh Weight Yield of Crops at Harvest

3.1.1. Guinea Grass

In the first harvest, no fresh weight of grass was measured. However, the fresh weight was estimated using a linear regression equation between the concentration of N and the fresh weight of grass harvested. The fresh weight of grass harvested varied greatly between each harvest (Supplementary data—S2). For the control plot (without fertilizer and PG organic), the fresh weight yield decreased gradually from cutting 1 to cutting 9 by approximately 5000 kg/ha. However, the plots treated with PG organic and with the half and full recommended rates of fertilizer showed some variation (Supplementary data—S2). To observe the effect of continuously added or residual PG organic, the data were averaged from three cuttings to represent each season (3-month period) and presented into half and full recommended rates of fertilizer for grass and the season of harvest with cumulative fresh yield (Table 4). Since the control plot did not receive any fertilizer and PG organic, the fresh weight yield of the grass decreased to 8777.8 kg/ha (63% of the first season) and a cumulative fresh yield of 42,324.4 kg/ha. The cumulative fresh yields from the plot treated with a full- and half-fertilizer rates were 40.3 and 19.4% higher than in the control plot, respectively. Among the plot receiving full-fertilizer rates, the cumulative fresh yield was always higher in the plot receiving a full dosage of PG organic for every season (84 ton/ha) as compared to the plot receiving only at 28 and 56 kg/ha. The trend showed that the plot receiving once 28 ton/ha PG organic was less than 5% lower as compared to the plot receiving 56 kg/ha. In contrast the same trend was not observed among the plots receiving a half-fertilizer rate. The plot receiving PG organic either as freshly added for every season or as residual showed some consistency in the fresh yield of grass production as compared to the control plot.

Table 4. The fresh weight of guinea grass in the plot with the addition of PG organic and/or the residual plot with the half and full recommended rates of fertilizer.

Season	Treatment Plot						
	Control	A Half Fertilizer			Full Fertilizer		
		T1	T2	T3	T4	T5	T6
	kg/ha						
1	23,880.0	21,658.3	21,091.7	19,200.0	18,208.3	23,100.0	24,316.7
2	9666.7	10,222.2	11,000.0	10,000.0	13,416.7	12,694.4	16,155.6
3	8777.8	21,166.7	18,111.1	19,166.7	24,638.9	22,222.2	23,333.3
Cumulative	42,324.4	53,047.2	50,202.8	48,366.7	56,263.9	58,016.7	63,805.6

Note: The shaded parts represent the residual plot (without PG organic addition. After three seasons, total PG organic received by plot, T1 and T4 = 28 ton/ha, T2 and T5 = 56 ton/ha and T3 and T6 = 84 ton/ha.

3.1.2. Corn

The total fresh weight excluding roots of corn for the control plot increased with each season of corn planted in this study (Supplementary data—S3). It reached the highest total fresh weight in the 3rd season (1692 kg/ha). The increase was approximately 20-fold compared to the 1st season. However, a reduction of approximately 48% in the total fresh weight of corn was observed in the 4th season compared to the 3rd season. For the plots receiving a half and full-recommended rates of fertilizer, the cumulative fresh weights of corn were 535.2 and 631.2%, respectively higher compared to control (Table 5). However, among the treatment receiving PG organic, plot receiving a fresh application for every season provided a greater cumulative fresh yield of corn as compared to residual PG organic for three seasons (28 ton/ha) in either a half- or full- fertilizer recommended rate for corn, while the highest total fresh weight of corn was observed in the 3rd season of planting (Supplementary data—S3). The experiment was repeated in the 4th season due to changes in the variety of corn planted in the second season. The supplier of corn seeds was unable to deliver for the same variety of corn seeds at the time of planting date.

Table 5. Total fresh weight of corn in the plot with the addition of PG organic and/or the residual plot with the half and full recommended rates of fertilizer.

Season	Control	A Half Fertilizer			Full Fertilizer		
		T1	T2	T3	T4	T5	T6
	kg/ha						
1	81.0	962.9	3910.0	5480.3	6782.9	5142.9	6261.0
2	636.7	2398.2	2938.1	2938.1	2794.15	3716.5	4085.5
3	1691.9	7084.2	7995.0	10,194.4	7267.82	8614.1	10,496.8
4	1137.5	7066.2	8664.5	7955.4	5579.55	7991.36	9074.9
Cumulative	3547.0	17,511.5	23,507.6	26,568.2	22,424.4	25,464.9	29,918.1

(Treatment Plot spans Control through T6.)

Note: The shaded parts represent residual plot (without PG organic addition). After three seasons, total PG organic received by plot, T1 and T4 = 28 ton/ha, T2 and T5 = 84 ton/ha and T3 and T6 = 112 ton/ha.

The fresh weight of corn cobs for the control plot showed the lowest value (31 kg/ha) in the first season and increased for the next season, with the highest fresh weight of corn ears at 283.5 kg/ha in season 3 (Table 6). However, the cumulative fresh weight of corn cobs showed an increase of approximately 37.1 and 39.1% as compared to the control treatment plot for a half- and full-fertilizer recommended rate of corn, respectively (Table 6). However, some inconsistency was observed on the plot that received residual (at 28 or 84 ton/ha) of PG organic, where the plot receiving PG organic at 84 ton/ha showed about 4% higher than in plot that receiving 28 ton/ha for a full fertilizer recommended rate. The same trend was also observed for the fresh weight of corn ears with respect to the continuous application or residue of PG organic (Supplementary data—S4). For the same amount of PG organic, the contrast results were observed for a half-fertilizer recommended rate.

Table 6. Total fresh weight of corn cobs in the plot with the addition of PG organic and/or the residual plot with the half and full recommended rates of fertilizer.

Season	Control	A Half Fertilizer			Full Fertilizer		
		T1	T2	T3	T4	T5	T6
	kg/ha						
1	25.9	46.0	88.7	107.3	105.7	121.3	90.0
2 #	30.3	47.7	100.7	102.3	89.0	92.0	102.3
3	187.3	283.5	112.8	174.3	154.0	169.3	146.2
4	92.8	120.3	86.2	114.0	110.8	105.5	117.7
Cumulative	336.4	497.5	388.3	497.9	459.4	488.2	456.2

(Treatment Plot spans Control through T6.)

Note: Theshaded parts represent residual plots (without PG organic addition). After three seasons, total PG organic received by plot, T1 and T4 = 28 ton/ha, T2 and T5 = 84 ton/ha and T3 and T6 = 112 ton/ha. # Change in corn variety in season 2.

3.1.3. Kenaf

The fresh weight of kenaf had the lowest value in the control plot for every season (Supplementary data—S5). However, season 2 provided the highest fresh weight of approximately 31,016 kg/ha for the plot receiving PG organic at half the recommended fertilization rate. The higher fresh weight of kenaf in the 2nd season observed was attributed to an increased planting density adopted after the recommendation of National Kenaf and Tobacco Authority 'Lembaga Kenaf dan Tembakau Negara' (LKTN) for kenaf planting to farmers. However, in the 3rd season, there was a reduction across the treatments. This was due to the insufficient supply of water during the growing period. It seems that the piping system was clogged with the sand, hence retarding the growth of kenaf.

All treatment and control plots showed some fluctuation in the fresh weight of kenaf with respect to the season. Cumulative fresh weight of kenaf after 3rd season in the control plot was 22,680.1 kg/ha. The plots receiving a half- or full-fertilizer recommended rate had increased in the cumulative yield of kenaf by 118.1 and 86.3%, respectively (Table 7). The plot receiving PG organic for every season (84 ton/ha) showed the highest fresh weight of kenaf as compared to 28 or 56 ton/ha PG organic throughout the kenaf planting period. The cumulative yield of kenaf was higher in the plot receiving treatment of 56 ton/ha as compared to 28 ton/ha of PG organic in the plot receiving of a half-fertilizer recommend rate for kenaf (Table 7). While, in contrast was observed in the plot receiving a full fertilizer recommended rate of kenaf.

Table 7. Fresh weight of kenaf in the plot with the addition of PG organic and/or the residual plot with half and full recommend rates of fertilizer.

Season	Treatment Plot						
	Control	A Half Fertilizer			Full Fertilizer		
		T1	T2	T3	T4	T5	T6
	kg/ha						
1	1430.1	6834.6	7082.0	5539.8	3128.1	2838.4	3063.9
2	12,492.7	17,558.5	29,349.4	31,016.1	21,801.9	18,651.3	22,748.5
3	8757.3	15,244.9	15,361.8	20,391.1	18,011.7	17,485.4	19,038.7
Cumulative	22,680.1	39,637.9	51,793.3	56,947.0	42,941.7	38,975.1	44,851.1

Note: The shaded parts represent the residual plot (without PG organic addition). After three seasons, total PG organic received by plot, T1 and T4 = 28 ton/ha, T2 and T5 = 56 ton/ha and T3 and T6 = 84 ton/ha.

3.1.4. Teak Wood Seedlings Growth

The relative growth rate (RGR), which was computed from 6 to 12 MAP (period of 6 months), showed that the RGR of the mean basal diameter for T2 and T3 were 2- and 2.5-fold higher, respectively, compared to the control (Table 8). In the context of seedling height, T2 and T3 were 1- and 1.5-fold higher, respectively, compared to the control. This study showed that seedlings reached 5 m in height within 18 months after planting with the utilisation of PG organic (Figure 4). The differences in seedling height between treatments were significant ($p < 0.05$) at 6, 9, 12, 15 and 18 MAP (Figure 4). The effects of PG organic were apparent and continuous from 6 MAP to 15 MAP. At 18 MAP, the seedling growth for T2 and T3 reached a plateau.

The seedling growth from 6 to 18 MAP can be explained using a linear regression model (Figure 5). The ANOVA model shows that there were positive significant relationships ($p < 0.01$) between the height and the time of sampling (month). The adjusted R2 shows that the regression line can explain 95% of the relationship. Based on the growth model, the projected height for T2 and T3 in 2 years (24 MAP) ranged from 6.8 to 7.3 m, compared to 4 m for T1.

Table 8. Relative growth rate of mean basal diameter and seedling height of teak at 12 MAP compared to 6 MAP.

Treatments	Mean Basal Diameter (mm)	Seedling Height (cm)
T1	0.033	0.110
T2	0.061	0.122
T3	0.082	0.161

Note: Control (T1) = 0, T2 = 28 and T3—56 ton/ha of PG organic. Fertilizer was only supplied to the guinea grass intercropping with teak wood tree.

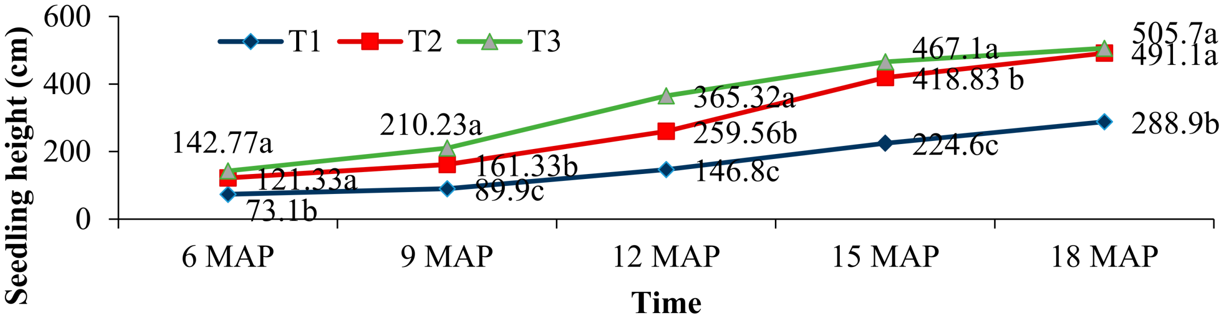


Figure 4. Overview of teak mean seedling height growth from 6 to 18 MAP across treatments. *Note: means followed by the same letters are not significantly different using Student's Newman Keul's test at the 5% level of significance across treatments at the stipulated time.*

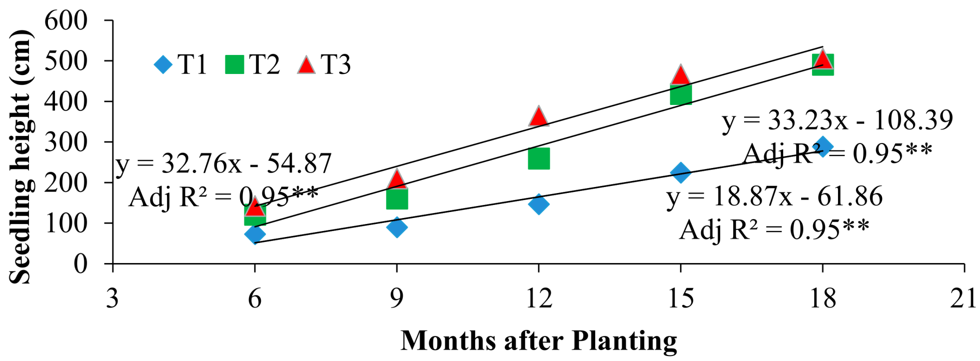


Figure 5. The seedling growth model for all treatments. *Note: the linear regression line was limited to the period of sampling;* ** *indicates significant at 0.01 level of significance.*

The mean basal diameter (MBD) also showed a growth trend line from 6 to 12 MAP; however, the relationships were not tested for significance due to the minimal number of observations (Figure 6). Earlier measurements taken in December 2016 showed that the values for T2 and T3 were significantly higher. At 9 MAP and 12 MAP, both T2 and T3 were 1.5 and 2-fold higher compared to the control plot, which was significant.

The observed values for T2 and T3 for the mean DBH were 59 and 69% higher, respectively, compared to T1 (Figure 7) at 15 MAP. Similarly, values were 2 and 1.8-fold higher in T2 and T3 compared to the control plots at 18 MAP. The continuous measurement of DBH will give a better estimate for DBH increment projections. The stand volume, which was computed for 15 and 18 MAP, also showed that the effects of PG organic were able to increase the tree volume compared to the control (Figure 8). Values of volume for half and full rates of PG organic were 21–30-fold higher compared to the control. Similarly, at 18 MAP, the PG organic was 15–20-fold higher compared to the control.

3.1.5. Guinea Grass Intercropping with Teak Wood Trees

In the first cutting, the estimated fresh weight yield of guinea grass was about 25,000 kg/ha in the control plot. However, the fresh yield in this plot decreased gradually and reached approximately 7666 kg/ha at cutting 9 (Supplementary data—S6). The fresh weight of grass intercropping with teak wood trees fluctuated between each harvest as observed in the other crops. Cumulative fresh weight of guinea grass for the control plot after the 3rd season was 39,577.8 kg/ha (Table 9). Overall, the plot receiving a half- and full-fertilizer recommended rate for grass showed an 81.1 and 105.8% increase as compared to the control plot, respectively. Except for the plot receiving a full-fertilizer recommended rate for guinea grass, the plot receiving continuous (84 ton/ha) addition of PG organic provided a higher value than that of 48 and 28 ton/ha of PG organic after the 3rd season of growing. These represent about 58.2 and 90.1% increase over control for 28 and 48 ton/ha of PG organic compared to control.

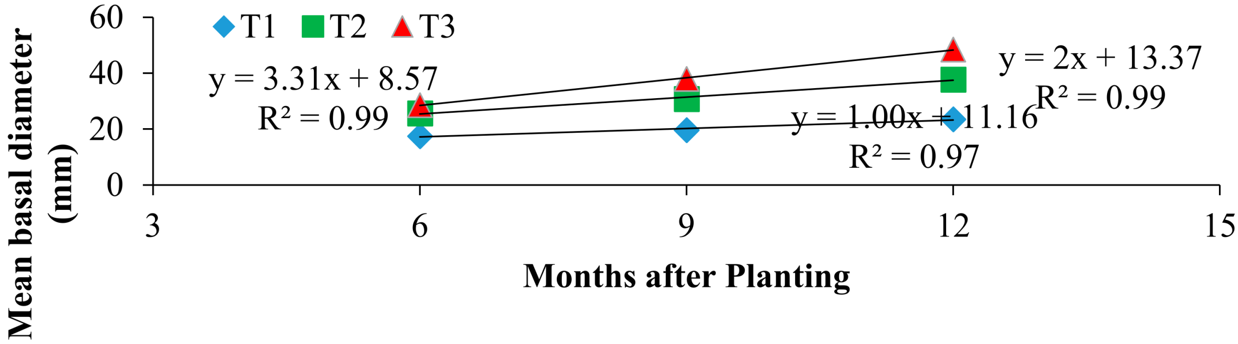


Figure 6. The mean basal diameter growth trend line for all treatments. *Note: the linear regression line was limited to the period of sampling.*

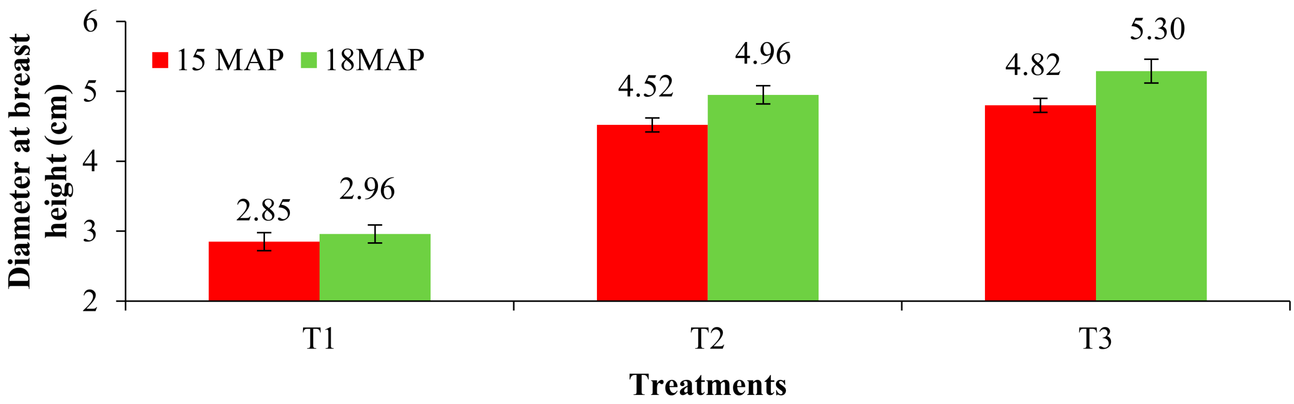


Figure 7. The diameter at breast height at 15 and 18 MAPs.

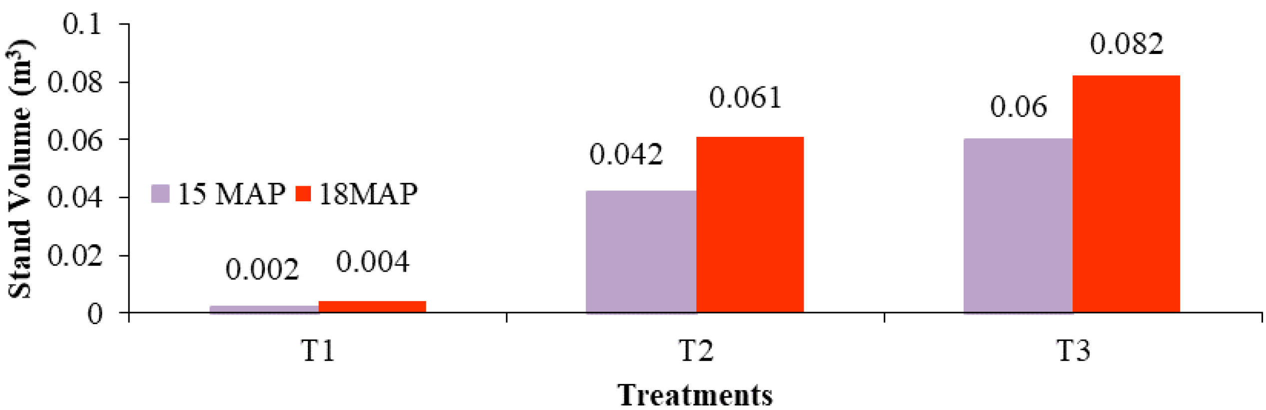


Figure 8. The stand volume at 15 and 18 MAPs.

Table 9. Fresh weight of guinea grass intercropping with teak wood trees in the plot with the addition of PG organic and/or residual plot with a half- and full-fertilizer recommended rates.

Season	Control	Treatment Plot					
		A Half Fertilizer			Full Fertilizer		
		T1	T2	T3	T4	T5	T6
	kg/ha						
1	15,966.7	23,233.3	26,608.3	28,883.3	39,500.0	23,733.3	27,658.3
2	12,944.4	18,388.9	21,494.4	23,055.6	23,888.9	22,083.3	22,833.3
3	10,666.7	21,000.0	27,166.7	25,222.2	24,055.6	27,777.8	32,833.3
Cumulative	39,577.8	62,622.2	75,269.4	77,161.1	87,444.4	73,594.4	83,325.0

Note: the shaded parts represent the residual plot (without PG organic addition; afterthree seasons, total PG organic received by plot, T1 and T4 = 28 ton/ha, T2 and T5 = 56 ton/ha and T3 and T6 = 84 ton/ha.

3.1.6. Pandan Coconut

The fresh weight of the upper and lower parts showed a significant difference ($p < 0.0001$) between means of treatments (Figure 9). The highest average total fresh weight was observed in soil treated with PG organic and the full fertilizer rate (2.87 kg) and the lowest was observed in the control (Sandy soil only; 0.75 kg; Scheme 1), with an increment of about 282.3%. Soil treated with PG organic with either a full- or half-fertilizer recommended rates showed higher biomass accumulation in the upper part, whereas all other treatments showed a higher proportion in the lower part. This indicates that when there are insufficient nutrients in the soil, more energy is required for the formation of roots. These roots are developed to a large extent for the absorption of nutrients.

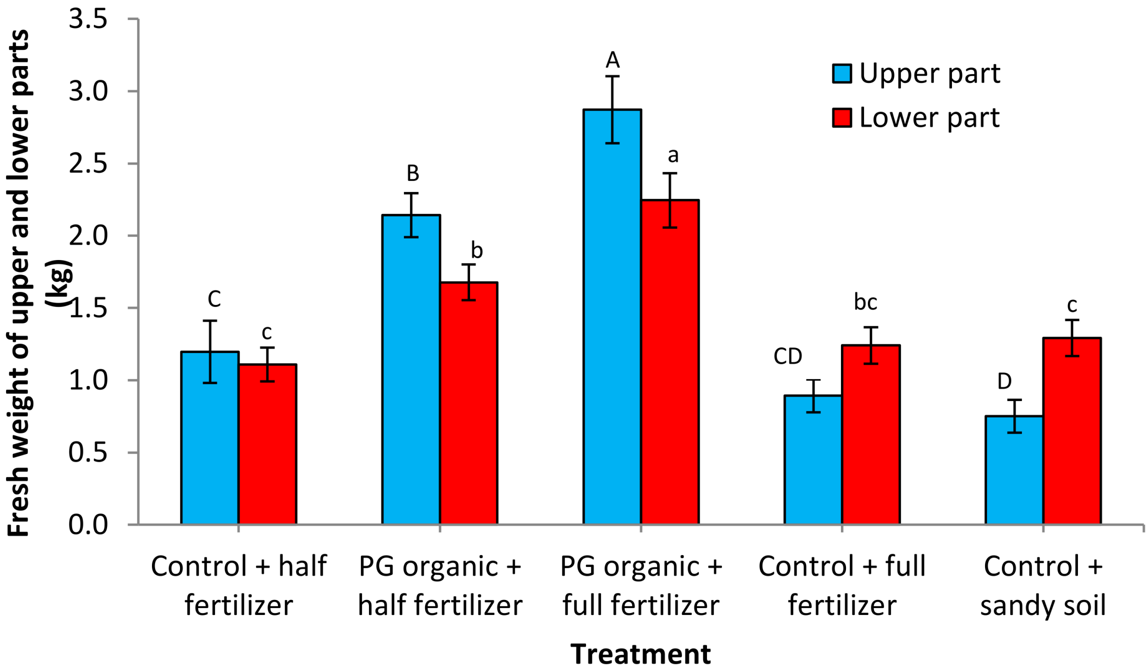


Figure 9. Fresh weights of the lower and upper parts of pandan coconut at harvest following the addition of PG organic or without (control) in combination with a half- and full-fertilizer recommended rates for pandan coconut. *Note: The difference in a small- and capital-letter show a significant difference at 5% level of significance by DMRT test for the lower- and upper-part of pandan coconut, respectively.*

Scheme 1. PThe picture shows the appearance of pandan coconut seedlings at harvest following the addition of PG organic or without (control) in combination with fertilizer (**a**) and in sandy soil only (**b**).

Vigorous growth of pandan coconut when treated with PG organic in combination with recommended fertilization compared to the control treatment was supported by the other measured parameters, as indicated by the significant difference of the ANOVA value (Table 10), namely, plant height ($p < 0.015$), the total number of fronds ($p < 0.0126$), rachis length ($p < 0.0209$) and SPAD value ($p < 0.029$).

Table 10. The probability that the parameters of pandan coconut measured at harvest were greater than the F-value from ANOVA.

Parameter	p > F Value
Plant height	0.015
Total frond number	0.013
Rachis length	0.021
Number of leaflets	0.067
LAI	0.054
SPAD	0.029

4. Discussion

The dissolution of PG organic releases ions into the soil solution. The dissolution of PG organic depends on the characteristics of PG organic, the soil properties and characteristics of solvent. The ions released may be adsorbed to the soil particles or organic materials, such as humic acid components and/or absorb by plants through the root systems and transported to the organs, such as leaf and fruit. Any ions that are not adsorbed and absorbed are subjected to leaching losses through the soil profile to the underground water, river and finally to the sea. Therefore, the mode(s) of ions released and their movements in the soil, water and plant ecosystems are a very important aspect in the assessment of PG organic for agricultural usage.

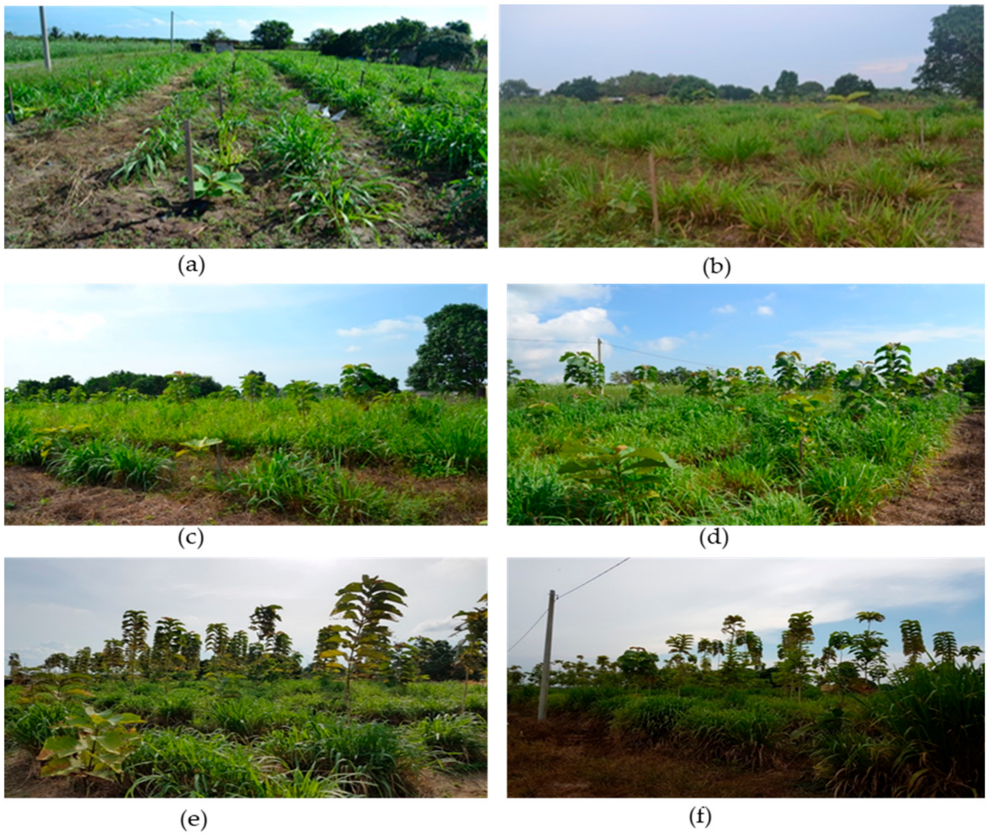
Since PG organic comprises mainly gypsum (Calcium sulphate hydrate) (PDF 00-033-0311) [3]. Chemically, PG organic is a natural compound with a pH of about 7 and electrical conductivity (5.0 mS/cm) of about 10-fold lower than the seawater. The macro-nutrients, such as P, Ca and micro-nutrients Zn, Cu, B, Co, Mn and Mo are important for plant growth and development; and other metal ions that contributed to soil and water contamination and plant and human toxicity are detected at very low levels (Table 1). For crop growth and development, the quantity of macro-nutrients is low and insufficient to support low or high demand of nutrient crop requirements. Hence, an additional fertilizer either singly or in combination with several elements is still needed.

The results from several seasons of field trial using guinea grass, corn, kenaf, pandan coconut and teak wood trees showed an improvement in the growth response, such as a cumulative fresh yield (in guinea grass alone, guinea grass intercropping with teak, corn, and pandan coconut) and girth/stem diameter and height for teak wood trees) in PG organic treated plot as compared to control. The degree of improvement, however, depends on crop types. In the case of guinea grass either planted alone or guinea grass intercropping with teak wood trees, the control treatment plot can sustainably produce a substantial quantity of the fresh weight even after three seasons (9 cuttings) without any input due to the extensive root proliferation to a deeper soil depth to acquire nutrients and moisture. The same trend was also observed in kenaf. In contrast, the same observation did not occur in corn, where there was no crop growth/fresh yield was recorded in the control plot due to its high requirement for nutrients. Most treatment plots receiving continuous addition of PG organic for every season, such as in plot treated at 84- or 112-ton PG organic/ha showed the best performance of any crops as compared to residual, such as using once (28 ton/ha) or twice (56 ton/ha) addition of PG organic. At 28 ton/ha of PG organic added to a sandy soil used in the present study, the initial pH of 6.5 decreases drastically to about pH 6.0 and stabilised at this value for quite some time and dropped to pH 5.8 (unpublished data). The pH 5.8 to 6.0 represents a soil buffering capacity of a sandy soil treated with PG organic. In this pH range, most likely the roots of plant can absorb most of the nutrients very efficiently. Consequently, if the pH drops lower than this lower limit the addition of PG organic is necessary for the maintenance of the soil buffering capacity. This could be the reason why the crop response is much better in every season added of PG organic as compared to residual PG organic treated plots. The presence of radioactivity elements, such as Th in the form of ThO_2 in the PG organic did not dissolve is in the pH < 5.6 [3].

A different scenario was observed for teak wood trees and pandan coconut, since these crops only received the same total dosage of PG organic (0, 28 and 56 ton/ha) in a split application during the trial. In the case of teak wood trees, this study showed that the effects of PG organic (T2 and T3) were relatively better for the initial mean basal diameter and seedling height relative growth rates, respectively (Table 8). Similarly, growth was recorded for height and mean basal growth trends (Figure 5, Figure 6, Figure 7). The mean DBH and stand volume for seedlings (Figure 8 and Figure 9) treated with PG organic were superior compared to the control. The results for T3 were the best compared to all three treatments. The overall visual observations of teak seedlings can be found in Scheme 2. The same trend was also observed for pandan coconut in the upper- and lower-part of plant (Figure 9). These two measured parameters at harvest were positively correlated with the other parameters, such as plant height, the total number of fronds, rachis length, number of leaflets, LAI and total chlorophyll contents as measured by SPAD value (Table 10).

The growth in teak wood trees and pandan coconut with the addition of 56 ton/ha of PG organic (T3) could possibly related to the combined effects of the full rate of fertilization and the supplementation of P, Ca and Mg and other nutrients from PG organic (Table 2). The growth of T2 and T3 teak clonal materials had higher values for stand height and DBH compared to values reported for the mean of 1 to 5-year-old teak seedlings, which had an average height of 3.03 m and DBH of 2.74 cm [17]. Based on our projections, the teak seedlings can surpass 6.8 m (Figures 6 and 7) at 24 months compared to a similar study by Nugraha [18], which cites 5 m in the same period. This teak wood trees var. Jati Unggul clones are reported to have multiple roots to enhance nutrient absorption, providing rapid growth and better wood quality [18]. The residual effect of PG organic was prominent, as it helped speed up growth of treated seedlings at the initial stage compared to routine fertilization with MOP and urea. The selected clonal teak was reported to reach a stand volume of 0.2 m^3 in a span of 5 years for logging [19]. We assume that the teak seedlings in our site may reach approximately 0.26 m^3 (T3) in the duration of 5 years and will be fit for timber extraction in that timeline. Another assumption is that the mean DBH will soar up to

17.6 cm (T3) in 5 years. Due to the increment of teak price indices (Supplementary data—S7) in the world market, the production of teak for timber will be a lucrative business [20]. The teak harvested at 5 years will be viable for furniture, parquet flooring, frames, boat parts and gift items. The current price for superior clonal material logs harvested at 5 years (±16–19 cm diameter) is USD 148/unit in Indonesia [21]. Assuming the net present value (NPV) is USD 2055, the internal rate of return (IRR) is close to 40%.



Scheme 2. Progressive growth of teak wood seedlings intercropped with guinea grass from 2 to 18 MAPs showing Teak wood tree seedlings at (**a**) 2 MAP (January 2016), (**b**) 6 MAP (May 2016), (**c**) 9 MAP (August 2016), (**d**) 12 MAP (November 2016), (**e**) 15 MAP (February 2017) and (**f**) 18 MAP (May 2017).

The growth performance of multi-crops with the addition of PG organic in a sandy soil texture in this trial is due to its ability to nourish soil by the presence of Ca^{2+}, $SO_4{}^{2-}$, Mg^{2+}, PO_4, $PO_4{}^{2-}$, $FePO_4{\cdot}(H_2O)_2$, gypsum ($Ca_2SO_4{\cdot}(H_2O)_2$, silicon (amorphous and crystalline) and $SO_4{}^2$ contents). Either directly or indirectly, it reduces soil toxicity (*via* replacing Al toxicity with $SO_4{}^{2-}$), transforms soil mechanics (by supporting flocculation in soil hardening process using Ca^{2+}), performs as a liming agent, improves soil pH and nutrients uptake. Additionally, physico-chemical characteristics of the sandy soil texture had improved substantially in pH, EC, organic C, CEC, macro- and micro-nutrients in soil when measured at different times as compared to the control (Supplementary data—T1). Though it is not the subject of this study, we may speculate that the presence of a trace amount of REE's (if any) in the PG organic may potentially contribute to a better crop growth performance [11–14].

The role of Mg in teak and other plants is mainly linked to its function as the central atom for the chlorophyll molecule [22]. Magnesium is needed for chlorophyll and protein synthesis, photosynthesis, enzyme activation and the partitioning of carbohydrates. Calcium is an important constituent for strengthening the cell walls of plant tissues. It also protects from microbial infections and facilitates root extensions [22]. Thus, it may have enhanced the fibrous root system, which is common with clonal materials, allowing more nutrients and water mobilisation and providing increased growth with additional fertilization. A more conclusive report will be presented once the soil and plant analysis is completed at the end of the study period.

5. Conclusions

The dissolution of PG organic in soil releases congruent ions in soil solution. Besides supplying the nutrients to the plant, PG organic also provides conditions to stabilise the soil pH buffering capacity for optimum absorption of nutrients. More improvement to the crops was achieved by the addition of necessary nutrients for the test crops either at a half- or full-fertilizer recommended rate. Continuously adding PG organic every season improved the consistent and sustainable yield of many crops as compared to the control. These were observed for both application of fertilizer recommended rates for different crops in cumulative fresh yield as compared to control, for guinea grass, corn, corn cob, kenaf and guinea grass intercropping with teak wood trees. Pandan coconut and teak wood trees on hole planting using 56 ton/ha PG organic during the period of this study showed an improvement compared to control by more than three-fold in fresh weight of the upper part and more than 20-fold of stand volume at 18 MAP, respectively. Therefore, the application of PG organic as soil a conditioner in combination with the recommended nutrients rate for respective crops improved the growth and yield through improving the soil phyco-chemical characteristics.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agronomy11122561/s1. Figure S1: The method used in the planting of teak wood and coconut seedlings in planting holes in the field and in black plastic bags, respectively. S2, Figure S2: Fresh weight yield of guinea grass grown on a sandy soil with the addition of PG organic or without PG organic (residual) at every season in combination with half- and full-recommended rates of fertilizer. S3, Figure S3: Total fresh weight of corn grown on a sandy soil with the addition of PG organic or without PG organic (residual) at every season in combination with the half and full recommended rates of fertilizer. S4, Figure S4: Fresh weight of corn ears grown on a sandy soil with the addition of PG organic or without PG organic (residual) in every season in combination with the half and full recommended rates of fertilizer. S5, Figure S5: Fresh weight yield of kenaf grown on a sandy soil with the addition of PG organic or without PG organic (residual) at every season in combination with half and full recommended rates of fertilizer. S6, Figure S6: Fresh weight yield of guinea grass intercropping with teak wood tree grown on a sandy soil with the addition of PG organic or without PG organic (residual) at every season in combination with half and full recommended rates of fertilizer. S7, Figure S7: Development of teak and mixed species price indices from 1998–2016 (Kollert and Kleine, 2017). T1, Table S1: Soil properties before and after PG organic application in the experimental plot.

Author Contributions: Conceptual, design, data collection and analysis, project management, funding, draft and finalised the manuscript, M.M.H.; data analysis, visualisation and preparation of draft, P.A., J.V. and M.M.H.; data collection and analysis, draft preparation of manuscript for teak wood tress field trial, J.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We wish to express want to express our gratitude to Ahmad Rusydi (MITRON Group) for initiating this project, Ahmad Husni Mohd Haniff, Aizul Azfar Zulkefli and Nurul Mayzaitul bt Jamaludin; Universiti Putra Malaysia (UPM) and Jeyanny Vijanathan of the Forest Research Institute of Malaysia (FRIM) for providing the facilities and support for this project. We are fully acknowledged the staff members of the Institute of Tropical Agriculture and Food Security (ITAFoS), UPM, the Department of Land Management, Faculty of Agriculture, UPM, Serdang, Selangor and the Soil Management Branch, Forest Plantation Programme, Forest Biotechnology Division, FRIM, Kepong, Selangor for supporting in the field, laboratory data collection and technical services during this study.

Conflicts of Interest: The authors declare no conflict of interest and agreed for publication of this manuscript.

References

1. Brown, S.; Collier, D.; Emett, M.; Prince, K. *A Report to Lynas Corporation on Characterization of Solid Samples from the LAMP Site*; Kirrawee: New South Wales, Australia, 2013.
2. Husni, A.M.H.; Hanafi, M.M. Effect of Different Ratios of WLP, NUF and BRIS Soil Mixture on Nutrients Released Characteristics. Unpublished Report Submitted to Lynas Malaysia Sdn Bhd.
3. Hanafi, M.M.; Azizi, P.; Akinbola, S.T.; Ismail, R.; Sahibin, A.R.; Wan Mohd Razi, I.; Ismail, A.F. Valorization of Rare Earth Processing Byproducts for Agriculture Usage. *Sci. Rep.* **2021**, *11*, 15234. [CrossRef]
4. Toriman, M.E.; Mokhtar, M.; Aziz, N.A.A. Analysis of the Physical Characteristics of Bris Soil in Coastal Kuala Kemaman, Terengganu. *Res. J. Earth Sci.* **2009**, *1*, 1–6.
5. Roslan, I.; Shamshuddin, J.; Fauziah, C.I.; Anuar, A.R. Occurrence and Properties of Soils on Sandy Beach Ridges in the Kelantan–Terengganu Plains, Peninsular Malaysia. *Catena* **2010**, *83*, 55–63. [CrossRef]
6. He, Y.; Xue, L. Biological Effects of Rare Earth Elements and Their Action Mechanisms. *J. Appl. Ecol.* **2005**, *16*, 1983–1989.
7. Xiangsheng, L.; Jiachen, W.; Jun, Y.; Yubin, F.; Yanping, W.; He, Z. Application of Rare Earth Phosphate Fertilizer in Western Area of China. *J. Rare Earths* **2006**, *24*, 423–426. [CrossRef]
8. Xie, Z.; Zhu, J.; Chu, H.; Zhang, Y.; Zeng, Q.; Ma, H.; Cao, Z. Effect of Lanthanum on Rice Production Nutrient Uptake, and Distribution. *J. Plant Nutr.* **2002**, *25*, 2315–2331. [CrossRef]
9. Xu, X.; Wang, Z. Phosphorus Uptake and Translocation in Field-Grown Maize after Application of Rare Earth-Containing Fertilizer. *J. Plant Nutr.* **2007**, *30*, 558–568. [CrossRef]
10. Wang, J.; Liu, X.; Yang, J.; Zhang, H.; Liu, Y.; Fan, Y.; Wu, Y.; Han, X. Development and Prospect of Rare Earth Functional Biomaterials for Agriculture in China. *J. Rare Earth* **2006**, *24*, 427–431.
11. Liu, H.; Wen, L.; Li, Y.; Hao, R. Effects of Rare Earth on the Growth, Fruiting and Absorption of N, P, K on Blackcurrant. *J. Fruit Sci.* **1997**, *14*, 32–35.
12. Zhu, J.; Chu, H.; Xie, Z.; Yagi, K. Effects of Lanthanum on Nitrification and Ammonification in Three Chinese Soils. *Nutr. Cycl. Agroecosyst.* **2002**, *63*, 309–314. [CrossRef]
13. Guo, B. The Application of Rare Earth Elements on Agriculture and Breeding. *J. Rare Earth Soc.* **1993**, *15*, 37–43.
14. Guo, B.; Zhu, W.; Xiong, B.; Ji, Y.; Liu, Z.; Wu, Z. *Rare Earths in Agriculture*; Agricultural Scientific Technological Press: Beijing, China, 1988. (In Chinese)
15. Hardon, J.J.; Williams, C.N.; Watson, I.A. Leaf Area and Yield in the Oil Palm in Malaya. *Exp. Agric.* **1969**, *5*, 25–32. [CrossRef]
16. SAS. *SAS/STAT User's Guide, Version 9.0*; SAS Institute Inc.: Carey, NC, USA, 2002.
17. Haninec, P.; Madera, P.; Smola, H.; Habrová, H.; Šenfeld, M.; Úradnícek, L.; Rajnoch, M.; Pavliš, J.; Šmudla, R. Assessment of Teak Production Characteristics Using 1 m Spacing in a Plantation in Nicaragua. *Bois Et For. Des Trop.* **2016**, *330*, 37–47. [CrossRef]
18. Nugraha, A.A.C. Growth Performance of Jati Unggul Nusantara (JUN) Clonal Trials at 15 Months in Purwakarta Regency, West Java. Master's, Thesis, Bogor Agricultural University (IPB), Faculty Forestry, Bogor, Indonesia, 2012. Available online: https://123dok.com/document/7qv4m41q-growth-performance-unggul-nusantara-clonal-trials-purwakarta-regency.html (accessed on 12 October 2020).
19. Yunus, E.P. Early Performance of Jati Unggul Nusantara (JUN) Clones in Purwakarta, West Java. Bachelor's Thesis, Bogor Agricultural University (IPB), Bogor, Indonesia, 2011. Available online: https://repository.ipb.ac.id/handle/123456789/54282 (accessed on 12 October 2020).
20. Kollert, W.; Kleine, M. *The Global Teak Study—Analysis, Evaluation and Future Potential of Teak Resources*; IUFO World Series Volume 36; International Union of Forestry Organization (IUFO): Vienna, Austria, 2017.
21. Kurniawan, D. Analisis Kelayakan Finansial Jati Unggul Nusantara (JUN) Di Desa Ciampea, Bogor. Bachelor's Thesis, Bogor Agricultural University (IPB), Bogor, Indonesia, 2014. Available online: https://repository.ipb.ac.id/handle/123456789/67937 (accessed on 12 October 2020).
22. Marschner, H. *Mineral Nutrition of Higher Plants*, 2nd ed.; Elsevier Science: Cambridge, MA, USA, 1995.