

Cassava Response to Phosphorus Fertilizer in Warin Soil Series Amended with Cassava Tails and Stalk-Bentonite Mixture

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Abstract

A field experiment was conducted in a farmer field in Nakhon Ratchasima province, northeast, Thailand objectively to investigate the response of cassava, Huay Bong 80 variety to phosphorus (P) fertilizer in Warin soil series (classified as Grossarenic Paleustults) amended with cassava tails and stalk (CTS) mixed with bentonite (BTN). The experiment was arranged in split plot with four replications. Main plot consisted of four rates of CTS +BTN: 0+0, 6.25+1.25, 12.5+2.5 and 25+5 t/ha while subplot comprising four rates of P fertilizer: 0, 25, 50 and 100 kg P₂O₅/ha. Cassava was harvested at 12-month of age and plant samples were collected at the harvesting time to study the effects of soil amendment on the uptake of primary plant nutrients in different plant parts of cassava. The results showed that the CTS+BN mixture at the rate of 25+5 t/ha highly significantly promoted the highest fresh tuber yield (FTY) and starch yield (SY) of 31.79 and 8.97 t/ha, respectively, which were 21.2 and 20.7 % greater than that of the control with no soil amendment addition. Increasing rate of P fertilization highly significantly induced greater FTY, SY and aboveground biomass (ABG) than did the zero-P fertilization. Amending the soil with 25+5 t/ha of CTS+BN along with the addition of 100 kg P₂O₅/ha interactively gave the significantly highest respective FTY, SY and ABG of 39.76, 11.48 and 17.35 t/ha whereas the plot amended with 12.5+2.5 kg CTS+BN/ha plus 50 kg P₂O₅/ha fertilization gave slightly lower STY and SY of 36.11 and 10.30 t/ha, respectively. The former combined rate of soil amendment and P fertilizer also had the interaction that highly significantly induced the highest uptake of all primary plant nutrients in the whole plant, accounting for 131.66, 14.23 and 124.13 kg/ha of respective nitrogen, phosphorus, and potassium. The result reaffirmed that amending the soil with proper rate of CTS+BTN mixture enhanced the efficiency of P fertilizer and subsequently improved yield of cassava.

Keywords: Cassava tails and stalk, Bentonite, Phosphorus, Sandy soil, Cassava

Introduction

Cassava is one of the most economic crops in Thailand and the world. In 2019, Nigeria was the world's biggest producer, with 19.5% of all outputs globally, followed by the DR Congo (13.2 %) and Thailand (10.2 %). In 2020, Cassava cultivation is clustered most heavily in Nakhon Ratchasima (16.0 % of all Thai cassava farms by area), followed by Kamphaeng Phet (7.8 %), Chaiyaphum (6.4 %) and Kanchanaburi province (5.7 %) [1]. In 2020/21 growing season, the national average yield of cassava fresh tuber was 20.79 t/ha with 21.06 and 19.83 t/ha for the northeast and Nakhon Ratchasima, respectively [2]. The lower yield of cassava planted in Nakhon Ratchasima was due mainly to the soils being generally poor as they are characterized by medium to coarse texture [3]. This contributed the soils to have low fertility status. Recent study showed that most soils in this province had lower potential for cassava production than that in easterly area of the region because of less pronounced rainfall [4]. Continued cultivation and soil loss cause by water erosion together with improper soil management practices have led to soil degradation. These extend the difficulty in terms of trying to increase yield of cassava in the area. The application of chemical fertilizers alone is unlikely to fulfil that because most soils have low organic matter content and low cation exchange capacity (CEC) in addition with the sandy nature of the topsoil that accelerates the loss of plant nutrients through leaching [5]. Numerous studies showed that cassava responded more positively to chemical fertilizers when the soil was amended with soil organic amendments coupled with proper soil management practices [6].

In Thailand, there are 1,210 cassava processing facilities with Nakhon Ratchasima, 161 plants, having the most of all of Thailand's provinces [1]. These plants generate large amounts of organic waste,

particularly cassava tails and stalk (CTS), which is accounted for 100 - 200 kg per 1 tonne of fresh tuber processed [7]. However, this organic waste can be used as soil amendment as it contains some plant nutrients and organic carbon to some extent. A single year trial conducted by Jenwitheesuk *et al.* [8] showed that the addition of CTS at the rate of 25 t/ha gave the highest fresh tuber yield of cassava planted in a sandy soil while Jitkhamen *et al.* [9] found that the addition of CTS at the rate of 12.5 and 25 t/ha promoted the highest fresh tuber yield and starch yield in the 1st crop and tended to induce the highest ones in the 2nd crop.

Bentonite (BTN) is originally from volcanic materials, consisting essentially of smectite minerals. It has high surface area and cation exchange capacity which reduced the loss of nutrients from the rooting zone in a loamy sandy soil, particularly NH_4^+ and K, and increased fertilizer use efficiency [10]. It can improve soil water retainability of sandy soils [11], soil water holding capacity [12,13], and be a source of micronutrients. The use of BTN at the rate of 0.625 - 1.25 t/ha clearly increased cassava yield more than the rate of 1.875 t/ha but all rates of BTN improved the starch content of cassava [14].

The CTS, an organic waste, can be used together with some inorganic amendments such as gypsum, ground limestone, dolomite, perlite etc., and was observed to be more effective. A previous field trial revealed that CTS+BTN at the rate of 6.25+1.25 t/ha relatively increased cassava fresh tuber yield to almost 70 % over the control with no soil amendment addition and gave better yield than did sole application at the same rate of either CTS or BTN [15]. Expectedly, CTS would give more organic carbon to the soil, subsequently contributing soil aggregation in addition with supplementary of some plant nutrients while BTN would help retain nutrients, especially cations, against the loss through leaching which is such normal and rather extreme in sandy soils and increase water holding capacity favourably during the growth cycle of cassava.

Phosphorus (P) is one of the most important soil nutrients next to nitrogen required by plants in certain amounts. It is an important element in providing cellular energy for biochemical synthesis in plants [16]. Phosphorus encourages formation of roots and the duration of cassava's growth; thus, the amount of P required for maximum root yield was crucial [17]. With a decline in soil fertility and increasingly low soil pH in fragile soils of tropical savanna, P has gradually become unavailable to plants [18], usually due to fixation by the oxides of Fe and Al and their hydroxides [19]. Through these processes, an adequate P supply is essential for the synthesis of starch and thus for normal root production. Cassava planted in Ultisols in Brazil and Colombia were reported to have a severe P deficiency because these soils are highly P-fixing and have available (Bray II or Mehlich I) P of only 1 - 2 mg/kg [20]. During the first year(s) of cropping, cassava responds markedly to P application; but, with continuous cropping on the same land, responses to P become less significant as soil P builds up from previous applications [21-23]. In low-P soils in Kerala, India, significant initial responses to 100 kg P_2O_5 /ha were reported, but these declined over time. Thus, the addition of 45 kg P_2O_5 /ha was determined as an optimum economic rate in Asia [21]. The most marked responses to P application in Asia were observed in the Plain of Jars in Xieng Khouang province of northeast Laos in soils with only 0.9 mg/kg Bray II-extractable P [24]. Responses to P application depend on the available-P level of the soil, the mycorrhizal population and the variety used [25]. Additionally, it was showed that the application of P at the rate of 50 kg/ha also significantly promoted the highest cassava root yield [26]. In Thailand, a large number of fertilizer trials were conducted, and the rate of 50 kg P_2O_5 /ha was recommended for cassava planted in upland light-textured Ultisols with available P of lower than 5 mg/kg [27].

Since most upland soils for cassava production in northeast Thailand are infertile with several soil constraints that limit cassava yield, soil improvement using soil amendments along with effective fertilization should be considered. Therefore, this study was undertaken to follow-up the study of Intawichai *et al.* [15], objectively to investigate the response of cassava, Huay Bong 80 variety to different rates of P fertilizer in a sandy soil amended with different rates of the mixture between CTS and BTN. The outcome would be beneficial to cassava production in low fertile coarse-textured soils in the region.

Materials and methods

The field experiment was conducted in a farmer field at Ban Supplu Noi, Huay Bong subdistrict, Dan Khun Thot district, Nakhon Ratchasima province, northeast, Thailand (15°11'5.46" N, 101°27'19.93" E) in the growing season 2017 - 2018. The area is under tropical savanna climate with respective mean annual rainfall and temperature of 1,137.4 mm/yr and 26.7 °C. Soil representing the experimental area was Warin soil series classified as Grossarenic Paleustults which has commonly been used for cassava cultivation. The soil was developed on wash over residuum derived from conglomeratic sandstone, having well-drained

feature with rapid permeability and moderate runoff. Properties of the soil prior to conducting the experiment are presented in **Table 1**.

Table 1 Soil properties prior to conducting the experiment.

Property	0 - 25 cm	25 - 45 cm	45 - 60 cm
Texture ^a	Loamy sand	Loamy sand	Loamy sand
pH (1:1 H ₂ O)	5.4	4.9	5.0
Organic matter, OM ^b (g/kg)	2.75	3.61	2.02
Total N ^c (g/kg)	0.05	0.04	0.05
Available P ^d (mg/kg)	4.83	4.76	3.67
Available K ^e (mg/kg)	15.6	15.6	7.6
Available Ca ^e (mg/kg)	170	180	116
Available Mg ^e (mg/kg)	26.4	22.8	18.0
Available Fe ^f (mg/kg)	2.67	4.02	3.90
Available Mn ^f (mg/kg)	8.06	14.45	7.61
Available Zn ^f (mg/kg)	0.54	0.90	0.47
Available Cu ^f (mg/kg)	0.02	0.01	0.04
Cation exchange capacity ^g (cmol _c /kg)	7.5	1.2	4.5

^apipette method; ^bWalkley and Black titration; ^cKjeldahl method; ^dBray II extraction; ^eneutral 1 M NH₄OAc extraction; ^fDTPA extraction; ^g1 M NH₄OAc method.

Table 2 Properties of cassava tails and stalk and bentonite used in the experiment.

Property	Cassava tails and stalk	Bentonite
pH (1:5 H ₂ O)	4.60	4.40
Cation exchange capacity ^a (cmol _c /kg)	1.50	25.3
Organic carbon ^b (g/kg)	156	1.1
Total N ^c (g/kg)	3.90	0.70
Total P ^d (g/kg)	0.30	0.10
Total K ^d (g/kg)	6.20	19.6
Total Ca ^d (g/kg)	9.70	49.5
Total S ^d (g/kg)	1.97	1.20
Total Mg ^d (g/kg)	1.90	12.2
Total Na ^d (g/kg)	0.50	1.88
Total Fe ^d (mg/kg)	51	10,726
Total Mn ^d (mg/kg)	290	85.1
Total Zn ^d (mg/kg)	77	15.5
Total Cu ^d (mg/kg)	42	23.2

^aWalkley and Black titration; ^b1 M NH₄OAc method; ^cH₂SO₄-Na₂SO₄-Se digestion mixture; ^dHNO₃:HClO₄ digestion mixtures.

The experiment was arranged in split plot with 4 replications. Main plot consisted of 4 rates of CTS+BTN mixture: T1 = 0+0 t/ha of CTS+BTN; T2 = 6.25+1.25 t/ha of CTS+BTN; T3 = 12.5+2.5 t/ha of CTS+BTN; T4 = 25+5 t/ha of CTS+BTN with subplot comprising 4 rates of P fertilizer: 0, 25, 50 and 100 kg P₂O₅/ha of which the 50 kg P₂O₅/ha was the recommended rate for tropical upland light-textured Ultisols in the northeast that had available P content of lower than 5 mg/kg [27]. Nitrogen and potassium were applied to all subplots at the rate of 120:120 kg N:K₂O/ha which was 1.2 time of the recommended rate. Chemical fertilizer used in this study was in the form of urea (46-0-0), diammonium phosphate (18-46-0) and potassium chloride (0-0-60).

Soil amendments with their properties being presented in **Table 2** were broadcasted onto designed plot and then incorporated into the soil by the first plough using 3-disc plough with 28-inch diameter (deep tillage). The experimental area was left for 2 weeks before loosening the soil using 7-disc plough. Ridges was made right afterword with 1.2 m space between ridges. Cassava cutting material of Huay Bong 80 variety was staked into the soil on the top of ridges with a space of 0.80 m between plants. Fertilization was performed when the plant was 2-month-old by applying into a hole dug on the top of ridges in the middle between 2 plants and then buried with soil by hand hoe. Weed controls were performed as necessary using hand hoe, small tractor, and herbicides. Cassava was harvested at 12-month of age.

During the harvesting period, 4 different plant parts: Tuber, stem base, stem, and leaf and branch were separately sampled for primary nutrient concentration analysis and subsequent calculation of nutrient

uptake which was done by multiplying nutrient concentration of each nutrient with dry weight/ha of each plant part mentioned above. Yield factors and other plant parameters were recorded at the time with starch content being determined in the field using Riemann scale balance. The analyses of soil samples prior to conducting the field trial, soil amendments and plant samples were undertaken basing on standard methods as shown in footnotes of **Tables 1** and **2**.

Statistical analysis of all data retrieved in this study was performed basing on standard analysis of variance. Analysis of variance (ANOVA) using F-tests to statistically assess the difference of means was carried out. Duncan multiple range test was undertaken at the 0.05 probability level ($p \leq 0.05$) for significant means difference among treatments.

Results and discussion

Effect of soil amendment and P fertilizer on yield and plant components of cassava

Soil amendment and P fertilizer had clear effect on cassava performance. Amending the soil with the mixture of CTS and BTN at the rate of 25+5 t/ha highly significantly promoted the highest fresh tuber yield, starch yield, leaf and branch fresh weight and aboveground biomass of 31.79, 8.97, 5.46 and 12.25 t/ha, respectively (**Figure 1A** and **Table 3**). With no statistical difference to the highest one, the addition of this mixture at the rate of 12.5+5 t/ha also stimulated rather high fresh tuber yield of 24.49 t/ha and starch yield of 8.44 t/ha. Without the use of soil amendment at the time of land preparation before planting, cassava performed poorly, producing the lowest fresh tuber yield and starch yield of only 26.22 and 7.43 t/ha, respectively. The soil amendment, however, had no clear effect on starch content, stem base fresh weight and stem fresh weight (**Table 3**).

All plots fertilized with P fertilizer significantly gave better fresh tuber, leaf and branch fresh weight, and aboveground biomass than did zero-P fertilized plot. The highest fresh tuber yield of 33.84 t/ha and starch yield of 9.63 t/ha (**Figure 1B**), including all aboveground plant parts (**Table 2**) were obtained from the plot applied with 100 kg P₂O₅/ha. Without P fertilizer addition, cassava produced only 23.31 t/ha of fresh tuber yield, 6.55 t/ha of starch yield and 7.97 t/ha of aboveground biomass. Nonetheless, P fertilizer showed no clear influence on starch content.

Soil amendment and P fertilizer significantly had an interactive effect on cassava's yield factor and plant parameters with the exception of starch content. The addition of 25+5 t CS+BTN/ha and 100 kg P₂O₅/ha fertilization interactively stimulated the highest fresh tuber yield, starch yield, leaf and branch fresh weight, stem fresh weight and aboveground biomass of 39.76, 11.48, 7.81, 5.56 and 17.5 t/ha, respectively (**Figure 1C, D** and **Table 2**). In addition, with no statistical difference to that of the plot which gave the highest ones the plot treated with 12.5+2.5 t/ha of CTS+BTN together with the application of 50 kg P₂O₅/ha also gave quite satisfactory fresh tuber yield of 36.11 t/ha and starch yield of 10.30 t/ha.

Considering the interactive effect of soil amendment and P fertilizer application, it was clear that without P fertilization, soil amendment stimulated the fresh tuber yield in the range of only 20.83-26.85 t/ha. Likewise, without using the mixture of CTS+BTN to amend the soil, P fertilizer gave the yield of cassava, Huay Bong 80 variety when planted in this sandy soil with the fresh tuber yield being in the range of 23.18-28.82 t/ha despite the recommended rate of 50 kg P₂O₅/ha [16] also being tested in the study. This demonstrated that in this coarse-textured soil which, based on data of soil analysis prior to conducting this experiment (**Table 1**), had very low amount of organic matter and other available plant nutrients in addition with very low cation exchange capacity, P fertilization was rather ineffective, or it can be more effective with the contribution of soil amendments. This was in agreement with Parr and Hornick [28] who quoted that the use of a sole chemical fertilizer has not been helpful under intensive agriculture because it is often associated with reduced crop yield, soil acidity and nutrient imbalance, particularly in this Grossarenic Paleustult that had coarse texture to great depth and was repeatedly used for growing cassava for a long time.

With the used of CTS+BTN in combination with P fertilizer, especially at the rate of 25+5 t/ha plus 100 kg P₂O₅/ha gave the highest fresh tuber yield and starch yield of 39.76 and 11.48 t/ha which were relatively 48.1 % and 51.9 % higher than that of the plot without the use of soil amendment and P fertilizer. This was because: 1) CTS and BTN provided some nutrients, especially micronutrients (**Table 2**) to the plant, CTS alone contained quite considerable amount of organic carbon that in turn was likely to be beneficial to vesicular arbuscular mycorrhizae (VAM) which cassava, through this highly effective symbiosis, was able to absorb P from the soil with low available P as of the soil in this study that initially contained only 4.83 mg/kg of available P (**Table 1**), mainly by extending the soil volume from which P can be absorbed through the associated mycorrhizal hyphae [29] as it has been clearly shown [30, 31] that cassava is extremely dependent on an effective VAM association for absorption of P from the soil, 2) CTS could slowly release primary plant nutrients for cassava during its early growth stage as shown by the

incubation study on CTS-amended soils [32], and 3) BTN was likely to play a part in increasing fertilizer use efficiency [10,33], holding plant nutrients against leaching [34] and retaining soil moisture [11-13] which should benefit the plant to some degree.

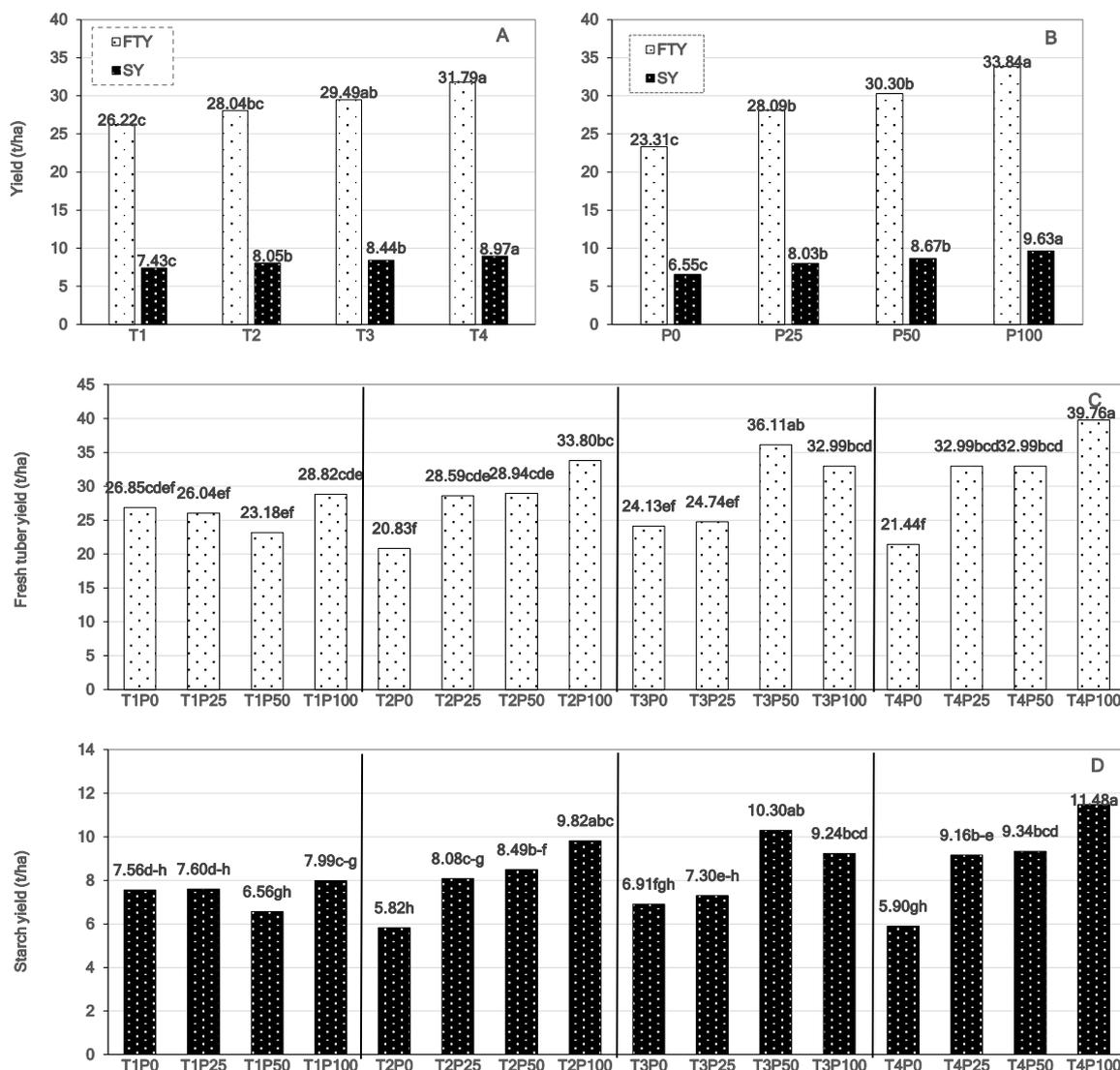
In comparison with sole application of either CTS or BTN, in a coarse-textured soil the application of CTS at the rate of 25 t/ha increased fresh tuber yield of only 19.1 % over the control without CTS application [8] while amending a loamy sand soil with 5 t/ha of BTN cassava produced 31.6% greater fresh tuber yield than without the use of BTN [35]. Therefore, it was clear that the effectiveness of this organic waste when used as soil amendment can be enhanced by mixing with the inorganic one. However, it has to note that the use of 12.5+2.5 t/ha of CTS+BTN with 50 kg P₂O₅/ha fertilization gave just slightly lower fresh tuber yield and starch yield than did the highest ones; thus, basing on a 1-year field experiment or a short-term perspective, this combination surely has better economical return, regarding the cost of the mixture and P fertilizer, and their implementation.

Table 3 Effects of soil amendment and P fertilizer on starch content and aboveground plant parts of cassava.

CTS+BN	P fertilizer (kg/ha of P ₂ O ₅)				Mean
	0	25	50	100	
Starch content (%)					
0+0	28.13	29.20	28.25	27.78	28.34
6.25+1.25	27.73	28.30	29.25	29.10	28.59
12.5+2.5	28.58	29.43	28.55	28.03	28.64
25+5	27.63	27.78	28.30	28.85	28.14
Mean	28.02	28.68	28.59	28.44	
C.V. (%)	5.0				
Stem base fresh weight (t/ha)					
0+0	2.55d	2.89cd	3.21bcd	3.82abc	3.12B
6.25+1.25	3.17bcd	4.57a	3.24bcd	3.74a-d	3.68A
12.5+2.5	2.95bcd	2.52d	3.36bcd	2.95bcd	2.95B
25+5	2.61cd	2.60cd	3.30bcd	4.17ab	3.17AB
Mean	2.82B	3.15AB	3.28AB	3.67A	
C.V. (%)	22.8				
Stem fresh weight (t/ha)					
0+0	2.95cd	2.55cd	3.04bcd	3.73bc	3.07
6.25+1.25	2.30d	3.24bcd	2.95cd	3.34bcd	2.96
12.5+2.5	2.60cd	2.26d	4.22b	2.78cd	2.96
25+5	2.17d	3.65bc	3.11bcd	5.56a	3.62
Mean	2.51C	2.92BC	3.33AB	3.85A	
C.V. (%)	24.1				
Leaf and branch fresh weight (t/ha)					
0+0	2.72bc	2.49c	2.56c	4.08bc	2.96B
6.25+1.25	2.30c	3.01bc	3.30bc	3.91bc	3.13B
12.5+2.5	2.69bc	2.47c	3.65bc	3.99bc	3.20B
25+5	2.87bc	6.77a	4.41b	7.81a	5.46A
Mean	2.64C	3.69B	3.48B	4.95A	
C.V. (%)	29.3				
Aboveground biomass (t/ha)					
0+0	8.22ef	7.93f	8.81def	11.63bc	9.15B
6.25+1.25	7.77f	10.82b-e	9.49c-f	10.98bcd	9.77B
12.5+2.5	8.25ef	7.25f	11.23bcd	9.72c-f	9.11B
25+5	7.64f	13.02b	10.81b-e	17.53a	12.25A
Mean	7.97C	9.76B	10.08AB	12.47A	
C.V. (%)	16.3				

Means with different capital letters indicate a significant difference of the main effect and different lowercase letters indicate a significant difference of interactive effect according to Duncan's multiple range test at $p \leq 0.05$.

CTS = cassava tails and stalk; BTN = bentonite.



T1 = 0+0 t/ha of CTS+BTN; T2 = 6.25+1.25 t/ha of CTS+BTN; T3 = 12.5+2.5 t/ha of CTS+BTN; T4 = 25+5 t/ha of CTS+BTN.

P0 = 0 kg/ha of P₂O₅; P25 = 25 kg/ha of P₂O₅; P50 = 50 kg/ha of P₂O₅; P100 = 100 kg/ha of P₂O₅.

CTS = cassava tails and stalk; BTN = bentonite; P = phosphorus fertilizer; FTY = fresh tuber yield; SY = starch yield.

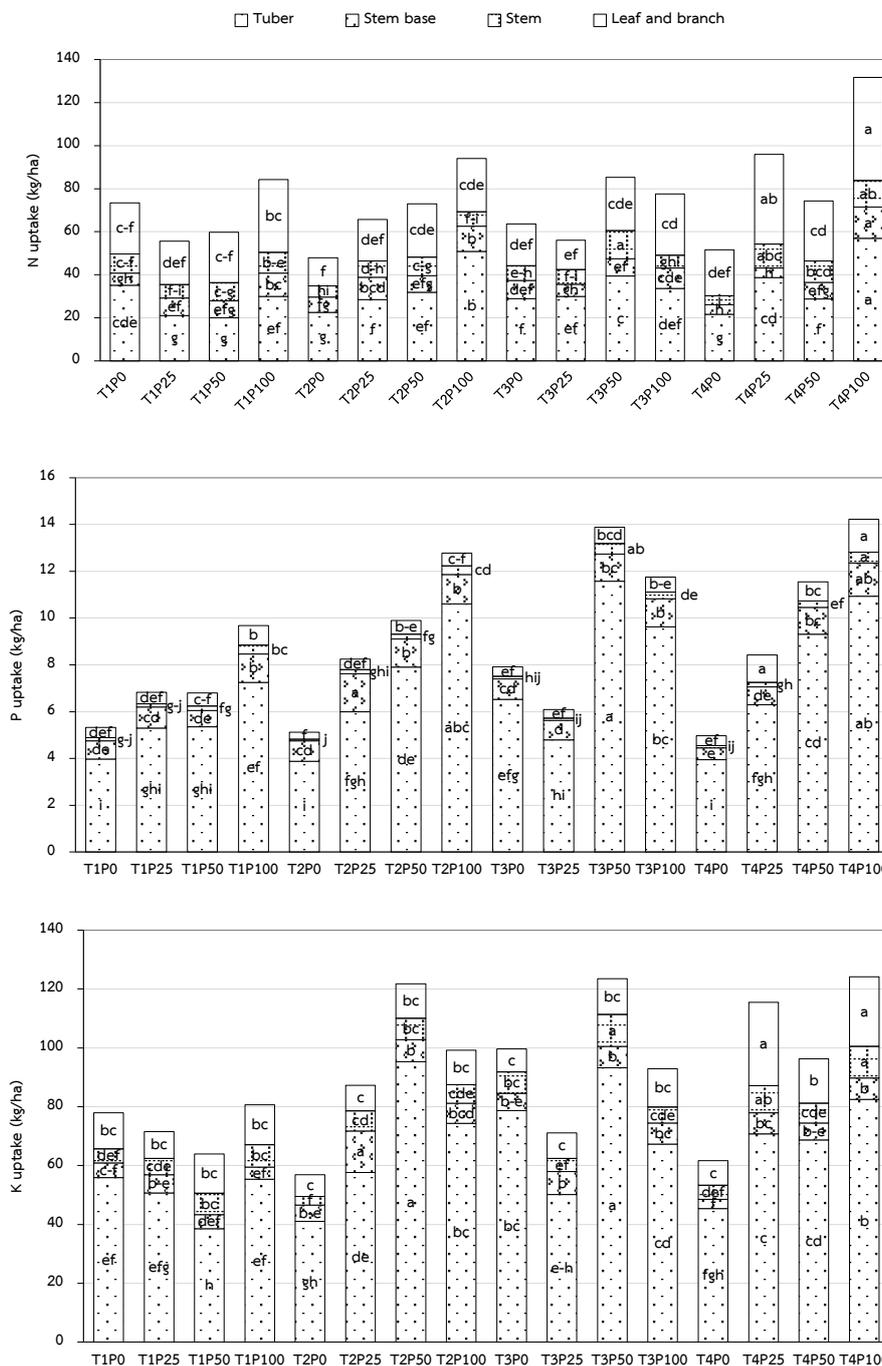
Figure 1 A) Effects of soil amendment and B) P fertilizer on fresh tuber yield and starch yield, and C) interactive effect of soil amendment and P fertilizer on fresh tuber yield and D) starch yield. Different lowercase letters on bars grouped within the same yield factor are significantly different ($p \leq 0.05$).

Effect of soil amendment and P fertilizer on the uptake of primary plant nutrient

Four different plant parts, tuber, stem base, stem, and leaf and branch, of cassava were sampled for the investigation of N, P and K uptake as affected by CTS+BTN and P fertilizer. In whole plant, cassava took up K in the highest amount followed closely by N whereas P uptake was far lower with the average amount across all treatments of 90.25, 74.34 and 8.97 kg/ha, respectively. Nitrogen was taken up in tuber and in leaf and branch in quite identical amount which was 3-to-4 fold of that taken up in stem and stem base. Phosphorus was taken up mostly in tuber, proportionally accounting for 78.94 % of the total uptake of this nutrient. Likewise, K was taken up in the highest amount in tuber with the average quantity across all treatments of 64.12 kg/ha while the amount of 12.80, 6.75 and 6.58 kg/ha were observed in leaf and branch, stem, and stem base, respectively.

The CTS+BTN evidently affected the uptake of N, P and K in cassava with the rate of 25+5 t/ha highly significantly inducing the highest uptake of all N, P, and K in leaf and branch, and stem, and N and K in tuber. Phosphorus fertilizer also had great effect on primary plant nutrient uptake in cassava.

Fertilizing with 100 kg P₂O₅/ha highly significantly stimulated the highest uptake of all N, P and K in leaf and branch, tuber, and P in stem, and N and P in stem base.



T1 = 0+0 t/ha of CTS+BTN; T2 = 6.25+1.25 t/ha of CTS+BTN; T3 = 12.5+2.5 t/ha of CTS+BTN; T4 = 25+5 t/ha of CTS+BTN.

P0 = 0 kg/ha of P₂O₅; P25 = 25 kg/ha of P₂O₅; P50 = 50 kg/ha of P₂O₅; P100 = 100 kg/ha of P₂O₅.

CTS = cassava tails and stalk; BTN = bentonite; P = phosphorus fertilizer.

Figure 2 Interactive effect of soil amendment and P fertilizer on the uptake of primary plant nutrient in different plant parts of cassava. Different lowercase letters grouped within the same plant part are significantly different ($p \leq 0.05$).

Soil amendment and P fertilizer also interactively had a significant impact on the uptake of N, P, and K in all plant parts of cassava as shown in **Figure 2**. This was due mainly to CTS containing some essential plant nutrients (**Table 2**) which became available to cassava during its growth period and BTN having the ability to increase fertilizer use efficiency [10], improve soil water retainability [11], and soil water holding capacity [12,13], and be a source of micronutrients. Amending the soil with 25+5 t/ha of CTS+BTN with 100 kg P₂O₅/ha fertilization induced the highest N uptake of 47.87, 14.52 and 59.93 kg/ha in respective leaf and branch, stem base, and tuber. This combination also boosted the highest P uptake in leaf and branch, and stem of 1.41 and 0.46 kg/ha, respectively. Similarly, K uptake as influenced by this combined use was the highest in leaf and branch (23.64 kg/ha), and stem (10.68 kg/ha). Overall, cassava significantly responded to P fertilizer at the rate of 100 P₂O₅/ha when planted in the soil amended with CTS+BTN at the rate of 25+5 t/ha, taking up the highest N, P and K of 131.66, 14.23 and 124.13 kg/ha, respectively, in the whole plant.

It was widely reported that cassava takes up substantial amounts of nutrients, mainly K and requires large amounts of N and P [36]. In this study, it was true in the case of K and N but the amount of P uptake in this study was very low even though there was a treatment with 100 kg P₂O₅/ha. Based on the report of IFA [37] of which to obtain a fresh tuber yield of 45 t/ha cassava needed to take up 62 kg/ha of N, 23 kg/ha of P₂O₅ and 197 kg/ha of K₂O in tuber and 202 kg/ha of N, 73 kg/ha of P₂O₅ and 343 kg/ha of K₂O in whole plant but in this study, considering the highest yield obtained of 39.76 t/ha in the plot received 25+5 t/ha of CTS+BTN and 100 kg P₂O₅/ha as an instance, N, P and K uptakes in tuber and whole plant were far lower than the quantities reported. Besides, the NPK ratio in tuber observed from this study was around 5:1:8 which was slightly different from 5:1:10 [38] and a study in Satuk soil series with higher K [39].

Conclusions

Growing cassava, Huay Bong 80 variety in Warin soil series with loamy sand texture extending to 100 cm depth from the mineral soil surface, and low fertility status without CTS+BTN amendment nor P fertilization, the yields obtained was inferior to that added with the soil amendment and P fertilizer. The use of 25+5 t/ha of CTS+BTN combined with 100 kg P₂O₅/ha gave the highest fresh tuber yield, starch yield and aboveground biomass. Also, the combination induced the highest N, P and K uptake in almost all plant parts of cassava. Half of this rate for both soil amendment and P fertilizer produced just slightly lower fresh tuber yield and starch yield, signifying a better economical return based on this 1-year trial. Longer term field trial should be conducted further to obtain a repeated result and to examine a cumulative effect of the soil amendment and P fertilizer on cassava performance and soil properties.

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