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Original Article

Yield response of cassava Huay Bong 80 variety grown in an Oxyaquic Paleustult to cassava starch waste and nitrogen fertilizer

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ABSTRACT

A field experiment was carried out in Na Yia district, Ubon Ratchathani province, Thailand during the 2015–2016 cropping season to investigate the response of cassava to cassava starch waste (CSW) and nitrogen (N). Split plots in a randomized completed block design with four replications were established in an Oxyaquic Paleustult soil type. The main plot consisted of five rates of CSW (0 t/ha, 6.25 t/ha, 12.5 t/ha, 25 t/ha or 50 t/ha). Six rates of N (0 kg/ha, 25 kg/ha, 50 kg/ha, 75 kg/ha, 100 kg/ha or 125 kg/ha) were applied to subplots. The addition of CSW at rates of 12.5 t/ha, 25 t/ha or 50 t/ha produced significantly higher fresh tuber and starch yields and starch content. The CSW applied at the rate of 50 t/ha produced the significantly highest aboveground biomass, but with the lowest harvest index. Applying 75 kg/ha or 100 kg/ha of N produced significantly higher fresh tuber and starch yields. The respective highest fresh tuber and starch yields were obtained from the combination of 75 kg/ha of N and 12.5 t/ha of CSW as soil amendment. The concentrations of P, Ca, Mg, S and Zn in tubers significantly increased with increments of CSW. Furthermore, the CSW also significantly enhanced the nutrients stored in the topsoil after growing cassava for one crop.

Introduction

Cassava (*Manihot esculenta* (L.) Crantz) is one of the most important crops grown in northeastern Thailand as the crop is an important raw material for human food production, animal feeds, industries and alternative fuel (Balagopalan, 2002). Cassava-growing soils in this region have medium to course texture with low fertility status, having a low content of available phosphorus, potassium, micronutrients and organic matter; they also possess low water holding capacity, low activity clay, low cation exchange capacity (CEC), very low buffering capacity and poor surface charge characteristics (Imsamut and Boonsompoppan, 1996; Kheoruenromne et al., 1998; Anusontpornperm et al., 2009). Continued cultivation of these soils without soil-improving practices has induced soil degradation and decreased crop yields due to nutrient depletion and soil exhaustion (Howeler, 1991). Unfavorable inherent soil fertility as well as frequent droughts and high inter-annual rainfall variability are the main reasons for the low productivity of cassava in this region (Howeler, 2002). Consequently, chemical fertilizers have played a predominant role in cassava cropping systems. However, under such conditions, most fertilizers applied will be leached from the soil or flushed away from the rhizosphere of the crops (Nakaviroj, 1998). Thus, the results of applying chemical fertilizers would be unimpressive.

Agricultural research conducted worldwide has shown that high and sustained yields can be maintained with judicious and balanced chemical fertilizer combined with soil organic amendment to improve soil fertility (Kapkiyai et al., 1999; Maerere et al., 2001), increase soil organic matter and plant growth (Kaur et al., 2008). Sustainable cassava crop practice in marginal soil is characterized by the incorporation of chemical fertilizers and soil organic amendments. The regular and proper addition of soil organic amendments are very important for maintaining the tilth, fertility and productivity of agricultural soils, protecting them from water erosion and preventing nutrient losses through runoff and leaching (Amanullah et al., 2007). These amendment practices have

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led to a strong improvement of cassava growth and yield (Ashok et al., 2013; Chaisri et al., 2013; Manoharan and Malliga, 2013; Owoseni, 2015; Nilnoree et al., 2016).

In view of the information on the benefits of organic waste recycling on agricultural lands, the challenge of the current study was to use organic waste available locally to conserve soil resources moving offsite. Cassava starch waste is a by-product from cassava starch manufacturing plants and typically there is an average residue of 200 kg/t of fresh roots (Department of Industrial Works, 2006). This organic waste can be used as soil amendment in cassava crop practice, which is not only beneficial to the crop but also improves soil productivity, particularly with the Oxyaquic Paleustult soil type that is inherently poor (Nilnoree et al., 2016). Since nitrogen is the major constituent of plant cells and chlorophyll in the leaves of cassava and is required for the development of the foliage and the vegetative plant organs needed for photosynthesis (Howeler, 1981), organic wastes have played a part in influencing these processes. However, different types of organic amendment are composed of some N in organic forms, so the rate and extent of N mineralization can affect the amount of nitrogen required by cassava as Körner et al. (2005) reported that greater reliance on chemical fertilizers and organic residues has negative impacts on cassava growth and yield. Thus, adding a proper dose of nitrogen fertilizer together with this organic waste is essential for enhancing crop productivity. This current study will provide useful information on the impact of cassava starch waste used as soil amendment in combination with nitrogen fertilizer on cassava yield, nutrient uptake and soil properties.

Materials and methods

Site description and soil properties prior to conducting the experiment

The field trial was carried out in a farmer field at Ban Na Dee, Na Yia district, Ubon Ratchathani province, Thailand (0504445E, 1670474N) in the growing season of 2015–2016. The area is a tropical savanna with an average annual rainfall of 1500 mm/year. The experiment was set up on a slightly undulating surface with 2% slope located on the lower part of middle terrace and the elevation was 117 m above mean sea level. Parent material of the soil was local alluvium, having moderately well-drained features with rapid permeability and moderate runoff. The soil is classified as an Oxyaquic Paleustult, having sandy loam texture in the topsoil and sandy clay loam in the subsoil.

Properties of the topsoil (0–28 cm) and subsoil (28–60 cm) prior to conducting the experiment are presented in Table 1. Soil pH (1:1 soil water suspension) was moderately acid (pH 5.6) in the topsoil and very strongly acid (pH 4.6) in the subsoil. Both layers had very low organic matter content and moderately low cation exchange capacity. The topsoil contained low amounts of total nitrogen, extractable calcium and magnesium, moderately low available phosphorus and very low available potassium while all plant nutrient contents in the subsoil were very low. Overall, this soil had poor ability to retain plant nutrients and was acidic.

Experimental design

The experiment was arranged in split plots in a randomized complete block design with four replications. Individual plot size was 10 m × 12 m with a 1 m space between plots and 2 m between blocks. The main plots consisted of five rates of cassava starch waste (0 t/ha, 6.25 t/ha, 12.5 t/ha, 25 t/ha or 50 t/ha). Cassava starch waste was sourced from a cassava starch manufacturing plant located nearby. The properties of the cassava starch waste are shown in Table 2. The average nutrient contents of the cassava starch waste used in the experiment were 7.95, 2.62 and 12.85 g/kg for N, P and K, respectively. Specific rates of organic waste were uniformly spread out onto the plots, then incorporated into the soil using a 3-disc plough. Two weeks after the incorporation, the soil was ploughed using a 7-disc plough before making ridges across the slope. Cassava (Huay Bong 80 variety) was planted with 80 cm spacing between plants and 120 cm spacing between rows. Subplots comprised different rates of nitrogen application (0, 0.25, 0.5, 0.75, 1 or 1.25 times the recommended rate or equal to N applied at 0 kg/ha, 25 kg/ha, 50 kg/ha, 75 kg/ha, 100 kg/ha or 125 kg/ha of N) while P and K were applied at 1.2 times the recommended rates which were 60 kg/ha and 120 kg/ha of P_2O_5 and K_2O, respectively. The recommended rates of chemical fertilizer were based on the results of a large number of FAO-sponsored on-farm fertilizer trials in which the Department of Agriculture of Thailand participated regarding growing cassava in infertile light-textured Ultisols (Sittibusaya, 1996). According to the analytical data of soil in this study, the soil had organic matter content, available phosphorus and potassium of lower than 6.5 g/kg, 5 mg/kg and 30 mg/kg, respectively; thus, the recommended amounts of 100:50:100 kg/ha of total N:available phosphorus (P_2O_5):water soluble potassium (K_2O) were required. N, P, and K were used in the form of urea, triple superphosphate, di-ammonium phosphate, and potassium chloride. Chemical fertilizer with respect to treatments was applied when cassava was aged 3 mth.

Plant data and soil sample collection

Cassava was harvested at age 10 mth. Plant parameters recorded at the time of harvest were fresh tuber yield, aboveground biomass (stem, stem base, leaf and branch), number of tubers and stems, survival rate (calculated from the number of surviving plants when harvested at 10-mth divided by the number of cassava originally planted) and starch content (determined using 5 kg of fresh tuberous roots harvested from each plot, which were then weighed in the air before weighing in water, and the content was read from a

Table 1
Soil chemical properties prior to conducting the experiment.

Property	Topsoil (0–28 cm)	Subsoil (28–60 cm)
pH (1:1 H_2O)	5.6	4.6
Organic matter (g/kg)	4.6	1.8
Total N (g/kg)	0.19	0.1
Available P (mg/kg)	7.18	1.40
Available K (mg/kg)	17.18	9.20
Exchangeable Ca ($cmol_c$/kg)	2.090	0.295
Exchangeable Mg ($cmol_c$/kg)	0.320	0.060
Exchangeable Na ($cmol_c$/kg)	0.091	0.155
CEC ($cmol_c$/kg)	6.9	5.8

CEC = cation exchange capacity.

Table 2
Properties of cassava starch waste used in the experiment.

Property	Cassava starch waste	Property	Cassava starch waste
pH (1:5 H_2O)	6.38	Total Ca (g/kg)	5.64
EC (dS/m, 1:1 H_2O)	1.32	Total Mg (g/kg)	3.44
OM (g/kg)	733.5	Total Na (g/kg)	0.44
CEC ($cmol_c$/kg)	61.7	Total S (g/kg)	0.39
Total N (g/kg)	7.95	Total Zn (g/kg)	171.00
Total P (g/kg)	2.62	Total Fe (g/kg)	38.90
Total K (g/kg)	12.85	Total Cu (g/kg)	8.40
C:N ratio	53.52	Total Mn (g/kg)	18.30

EC = electrical conductivity; OM = organic matter.

Riemann scale balance according to Bainbridge et al. (1996)). Four different plant parts (tuber, stem base, stem, and the leaf and branch) from each plot were sampled and weighed separately, and a known amount of samples was collected from the field for dry weight measurements and plant analysis. Soil samples of each plot were collected from 0 to 30 cm depth at harvest to investigate the effect of cassava starch waste on soil property changes.

Methods of soil, plant and soil organic amendment analysis

Soil samples were air-dried, gently crushed using an agate mortar and pestle, passed through a 2 mm stainless steel sieve, homogenized prior to analysis and used for measurements of soil chemical property. However, the soil organic carbon and total nitrogen contents were crushed and passed through a 0.5 mm sieve and stored in a plastic bag. A glass electrode pH meter was used to determine the pH (National Soil Survey Center, 1996) of aqueous suspensions (1:1 soil/solution ratio). Organic carbon was measured using the wet digestion method with Walkley and Black titration (Walkley and Black, 1934; Nelson and Sommers, 1996) and the value was converted to soil organic matter content by multiplying the percentage of carbon by 1.724. Total nitrogen was determined using the Kjeldahl method (Bremner, 1996). Available phosphorus was extracted using Bray II solution (Bray and Kurtz, 1945) and determined colorimetrically using the molybdic blue method with spectrophotometry. Available potassium was analyzed using 1 M NH_4OAc at pH 7.0 extraction (Pratt, 1965) and measured using atomic absorption spectrophotometry. The CEC determination followed the procedure of Chapman (1965) with the removal of exchangeable bases with 1 M NH_4OAc at pH 7 and subsequent replacement of exchangeable NH_4^+ ions with 10% NaCl, and distillation of NH_3 into 2% H_3BO_3 followed by titration with 0.01M HCl using bromocresol green-methyl red indicator. Extractable bases (potassium, calcium, magnesium, sodium) were extracted with neutral 1 M NH_4OAc (Thomas, 1996) and measured using atomic absorption spectrophotometry and converted to available contents.

The samples of tuberous root, stem, stem base, and leaf and branch were chopped, dried in the oven at 65–70 °C until the samples had constant weight. The samples were crushed and ground until smaller than 0.5 mm in size. The ground samples were digested using nitricperchloric acid mixtures (HNO_3:$HClO_4$) (Johnson and Ulrich, 1959) with the exception of total N which was extracted using digestion mixture (H_2SO_4-Na_2SO_4-Se) and determined using the Kjeldahl method (Jackson, 1965). Phosphorus was determined colormetrically using the vanado-molybyellow method (Westerman, 1990), and then measured using spectrophotometry (Murphy and Riley, 1962). Total potassium, calcium, magnesium, iron, manganese, zinc and copper were determined using atomic absorption spectrophotometry (Westerman, 1990). Total sulfur was analyzed using turbidimetry with $BaSO_4$, and the amount was determined using spectrophotometry with a 450 nm wavelength (Bardsley and Lancuster, 1965). The nutrient contents in cassava starch waste were also analyzed according to plant analysis procedures.

Statistical analysis

Statistical analysis of data collected was carried out using standard analysis of variance. The significance of the treatment was determined using the F-test appropriate to the general linear model as described by Gomez and Gomez (1984). To determine the significance of the difference between the means of the treatments, Duncan multiple range test was computed at the 0.05 probability level ($p \leq 0.05$).

Results and discussion

Cassava yield and plant components

Significant effects of both cassava starch waste (main plot) and nitrogen fertilizer (subplot) application on cassava yield and its components were observed (Table 3). The cassava fresh tuber yield, starch content, starch yield, leaf and branch weight, stem weight, stem base weight and aboveground biomass were greater under treatments with the addition of cassava starch waste at rates of 12.5 t/ha, 25 t/ha and 50 t/ha. Only the application of this organic waste at the rate of 6.25 t/ha showed no statistical difference from

Table 3
Effect of cassava starch waste and nitrogen fertilizer on cassava yield and plant components.

Treatment	FTY (t/ha)	STC (%)	STY (t/ha)	LW (t/ha)	SW (t/ha)	BW (t/ha)	ABG (t/ha)	HI	SURV (%)
Main plot: rate of cassava starch waste									
CSW0	26.70^b	21.03^b	5.71^b	5.74^c	3.67^c	3.14^c	12.55^c	0.68^{bc}	93.7^{ab}
CSW1	28.25^b	21.92^b	6.26^b	6.63^{bc}	4.72^b	3.67^{bc}	15.01^b	0.66^c	96.5^a
CSW2	38.01^a	24.29^a	9.24^a	6.55^{bc}	5.07^{ab}	4.16^{ab}	15.78^b	0.71^a	93.0^{ab}
CSW3	37.65^a	23.59^a	8.85^a	7.36^{ab}	5.48^{ab}	3.96^{ab}	16.81^{ab}	0.69^{ab}	94.4^a
CSW4	38.65^a	24.33^a	9.41^a	7.98^a	5.66^a	4.44^a	18.08^a	0.68^{bc}	88.9^b
F-test	**	**	**	**	**	**	**	**	*
Subplot: rate of nitrogen fertilizer									
N0	27.16^c	22.7	6.28^c	5.25^c	3.53^c	2.95^c	11.73^d	0.70^{ab}	94.2
N1	34.39^b	22.4	7.82^b	6.23^b	4.50^b	3.57^{bc}	14.30^c	0.71^a	94.2
N2	32.01^b	22.4	7.35^{bc}	6.33^b	4.59^b	3.94^b	14.86^{bc}	0.68^{abc}	92.5
N3	39.81^a	23.6	9.51^a	7.82^a	5.05^b	4.05^b	16.93^b	0.69^{ab}	95.8
N4	38.43^a	23.7	9.08^a	8.10^a	6.47^a	4.88^a	19.45^a	0.67^{bc}	94.2
N5	31.34^b	23.4	7.32^{bc}	7.38^a	5.39^b	3.85^b	16.62^b	0.66^c	89.1
F-test	**	ns	**	**	**	**	**	**	ns
Interaction: rate of cassava starch waste × rate of nitrogen fertilizer									
F-test	**	**	**	ns	ns	ns	ns	**	ns
% CV	18.3	9.5	20.6	22.2	29.7	30.6	21.7	6.4	8.8

ns = not significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.
Interaction between rate cassava starch waste and rate of nitrogen fertilizer is presented in Fig. 1.
CSW = cassava starch waste; CSW0 = 0 t/ha; CSW1 = 6.25 t/ha; CSW2 = 12.5 t/ha; CSW3 = 25 t/ha; CSW4 = 50 t/ha.
N = nitrogen fertilizer; N0 = 0 kg/ha of N; N1 = 25 kg/ha of N; N2 = 50 kg/ha of N; N3 = 75 kg/ha of N; N4 = 100 kg/ha of N; N5 = 125 kg/ha of N.
FTY = fresh tuber yield; STC = starch content; STY = starch yield; LW = leaf weight; SW = stem weight; BW = stem base weight; ABG = aboveground biomass; HI = harvest index; SURV = survival rate.

that of the control (no amendment applied). Unlike the tuber yield and aboveground yield, the application of cassava starch waste at a rate of 50 t/ha resulted in the lowest survival rate (88.9%). This might have been because the heavy application of this organic waste caused N immobilization and decomposition of this waste increased the soil temperature too rapidly in the early stage of growth. However, there was no significant difference among the numbers of tubers per plant and the numbers of cassava stems per hectare (data not shown).

Data (with the exception of starch content, harvest index and survival rate) obtained from subplots with varying rates of nitrogen fertilizer were also significantly higher than for unfertilized treatment. The application of N at the rate of 75 kg/ha highly significantly resulted in the highest cassava fresh tuber and starch yields of 39.81 t/ha and 9.51 t/ha, respectively, although statistically this amount did not differ from that applied at the recommended rate (100 kg/ha of N) which yielded 38.43 t/ha, but instead the latter rate highly significantly produced the greatest aboveground biomass of 19.45 t/ha (Table 3). Moreover, an inferior yield was observed when the applied N rate was 125 kg/ha or 1.25 times the recommended rate.

As cassava starch waste contained 7.25 g/kg of organic N, when used as soil amendment for cassava crop practice, it evidently enhanced N fertilization. The interaction between the waste and N fertilizer showed that amending the soil with this organic waste at the rate of 12.5 t/ha together with the addition of 75 kg/ha of N highly significantly stimulated the highest cassava fresh tuber and starch yields of 52.35 t/ha and 12.81 t/ha, respectively (Fig. 1A and C). This reaffirmed that there was a positive impact on improving plant performance of the immediate supply of nutrients from chemical fertilizer in combination with the slow and continuous supply of N with favorable soil conditions from the addition of soil organic amendment, particularly when cassava was grown in soil with low soil organic matter and total N contents, as in such a soil, N supply was insufficient for plant growth. However, with the same amount of the waste applied, increasing N fertilization resulted in lower yields than with 75 kg/ha of N and the cassava also responded poorly to cassava starch waste at the rate of 12.5 t/ha with no N added, yielding 26.68 t/ha of fresh tuber yield, which was only half the maximum yield obtained. This result was also consistent with previous studies (Asare et al., 2009; Anneke et al., 2010; Mathias and Kabambe, 2015). With no application of this organic waste nor N fertilizer, cassava very significantly produced the lowest fresh tuber yield of 18.98 t/ha and even increasing the N rate from 25 kg/ha up to 125 kg/ha, still only produced tuber and starch yields in the ranges 25.30–30.13 t/ha and 4.24–6.54 t/ha, respectively. Growing cassava in this Oxyaquic Paleustult soil amended with cassava starch waste at the rate of 6.25 t/ha resulted in both the tuber and starch yields of cassava significantly increasing in response to the increasing rate of N, whilst amending the soil with this organic waste at any rate higher than 6.25 t/ha resulted in a particularly poorer response by the cassava to N applied at the rate of 125 kg/ha (Fig. 1A and C). This was not surprising as John (2010) reported a tuber yield reduction of 41% and top growth increase of 11% due to high N uptake when high levels of nitrogen fertilizer were applied.

The utilization of cassava starch waste at a rate of 12.5 kg/ha, 25 kg/ha or 50 kg/ha with or without nitrogen fertilizer could maintain a higher starch content percentage in the rage 22.4–25.1%. Nevertheless the percentage of starch content decreased slightly when N was applied at the rate of 125 kg/ha (Fig. 1B). In contrast, the starch content tended to increase with an increasing rate of N applied when cassava was grown with no soil amendment application and the addition of this organic waste at the rate of 6.25 t/ha. This revealed that N mineralized from the organic waste together with that from chemical fertilizer when added at the very high rate can be excessive and cause a reduction in tuberization and starch accumulation in cassava tuber as Mengel and Kirkby (2001) stressed that excess N induced an over production of leaves and stems but poor root yield and a decrease in the tuber starch content.

The high amount of cassava starch waste and nitrogen fertilizer applied resulted in lowest harvest indexes in the treatments with more intense vegetative growth but small tuber growth. It was evident that amending the soil with cassava starch waste at rates of 25 t/ha and 50 t/ha, highly significantly decreased the harvest index, the fractions of tuber weight and total biomass, when N was applied at the rates of 100 kg/ha and 125 kg/ha (Fig. 1D). This was likely due to excessive N released from the waste along with the N from the chemical fertilizer. Generally, the performance of the tuber yield followed the same pattern as the aboveground biomass. Values of the harvest index decreased when the aboveground plant parts showed superior increase to the storage root. Cassava is known to be sensitive to over fertilization, especially with N, which will result in excessive leaf formation at the expense of root growth, and this suggested that the stem and stem base reserve establishment was the priority and that they formed a preferential sink (Sagrilo et al., 2006). In contrast, the maximum harvest index was obtained from using cassava starch waste at 12.5 kg/ha together with 75 kg N/ha, and cassava starch waste at 25 kg/ha together with 25 kg N/ha. It could be inferred that these treatments supplied a good balance between the total production of carbohydrates by the plants and their distribution to the roots.

In the case of this Oxyaquic Paleustult, the efficiency of the application of varying rates of nitrogen fertilizer was low with no soil organic amendment addition because the CEC of the soil was considerably low (6.9 $cmol_c$/kg) with a very low organic matter content (4.6 g/kg), resulting in the soil more or less having no ability to retain nutrients. It would be likewise for other Paleustults used for growing cassava in the region that also had similarly poor properties (Anusontpornperm et al., 2009). Under such conditions, most fertilizers applied will be leached away from rooting zone (Nakaviroj, 1998). As a consequence, cassava tends to respond poorly to chemical fertilizers. 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 (Parr and Hornick, 1992), especially in the soil of the experimental area that had a sandy loam texture in the topsoil and had been used for growing cassava for a long time.

As shown by the results from this study involving the fresh tuber yield response to an integrated application of cassava starch waste and N, it was very clear that all the treatments that received cassava starch waste but no application of nitrogen fertilizer produced the low yields. It can be generally assumed that the prompt availability of nitrogen to plants is low since the majority of nitrogen is bound to the organic N-pool. The greatest total N content in compost is not readily available, but it can be mineralized and subsequently taken up by plants or immobilized or leached or both (Amlinger et al., 2003). Moreover, these results indicated the synergistic effect that enabled the organic waste and fertilizer to release nutrients steadily and to make it available to the plants over a longer period without much loss.

Nutrient concentration in plant parts

To some degree, cassava responded to the different rates of cassava starch waste applied in terms of nutrient concentration in different plant parts. Most levels of nutrients taken up in the plant parts of cassava tended to increase with increasing rates of the waste (Table 4). For instance, the N concentration in the stem base highly significantly increased from 9.0 g/kg up to 11.7 g/kg from the

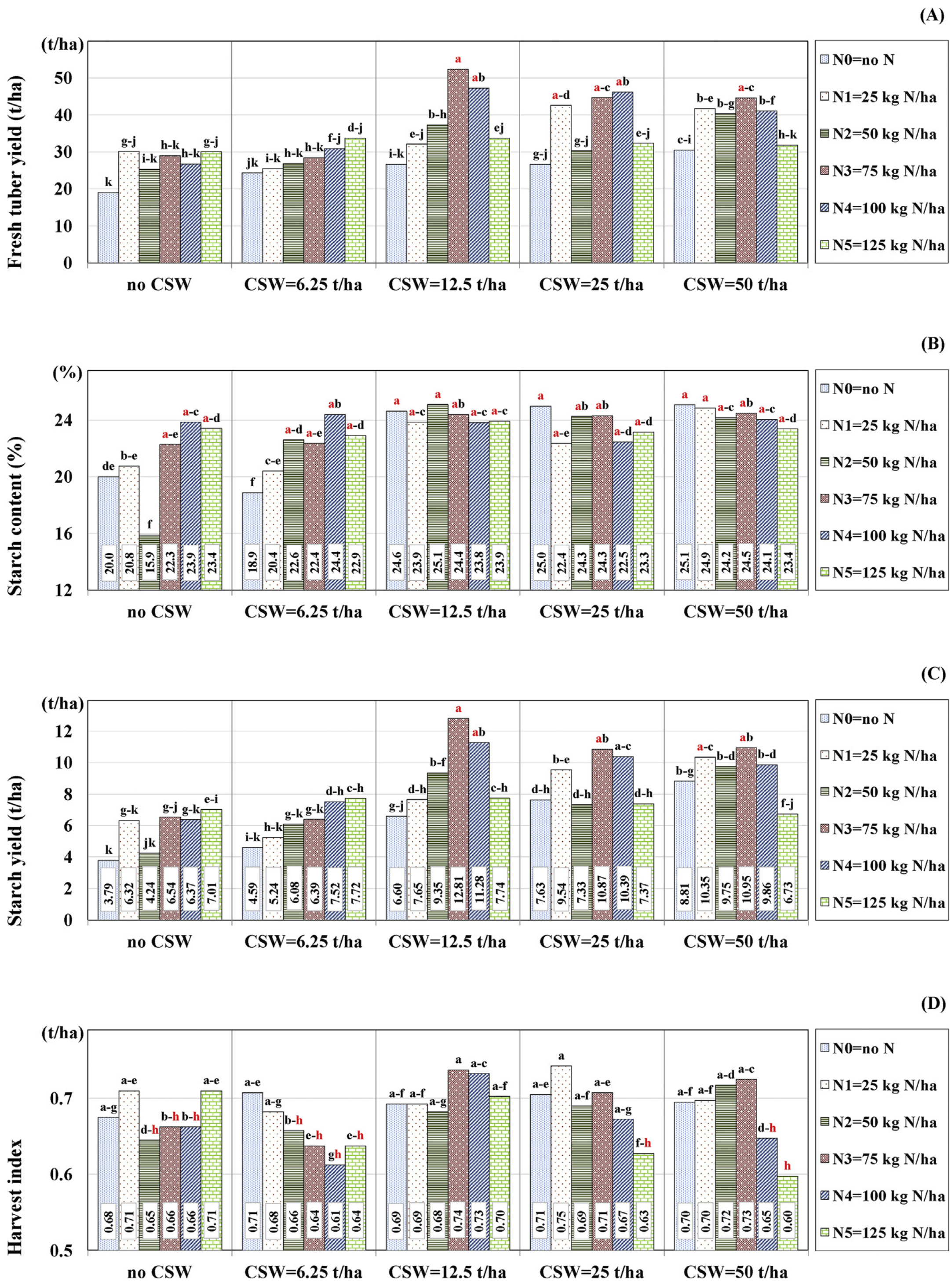

Fig. 1. Effect of cassava starch waste interaction with nitrogen fertilizer on: (A) fresh tuber yield; (B) starch content; (C) starch yield; (D) harvest index, where CSW = cassava starch waste and different lowercase letters on bars are significantly ($p \leq 0.05$) different.

no application and the addition at the highest rate of 50 t/ha, respectively. It was rather the same for the P concentration in the stem base and tuber. All rates of waste applied resulted in a statistically greater concentration of K in the range 0.23–0.24 g/kg in the stem base compared to that of the control with no application of this waste. There was a highly significant increase of the minor nutrients (Ca, Mg and S) in most plant parts which affected the increasing rate of cassava starch waste which was evidently detected with most micronutrients (Fe, Mn and Zn). With regard to cassava starch waste addition, higher nutrient concentration in aboveground plant parts was also observed with the same pattern as for tubers. Treatment with no addition of the organic waste produced the significantly lowest concentration of Ca, Mg and Mn in leaves and branches; S, Fe and Mn in stems; and N, P, K, Ca, S Mn and Zn in stem bases, which resulted in considerably lower aboveground biomass. These higher nutrient concentrations were consistent with higher cassava fresh tuber yields as mentioned earlier. This indicated that the waste that contained plant nutrients

Table 4
Effect of cassava starch waste on nutrient concentrations in cassava's plant parts.

Treatment	Nitrogen (g/kg)				Phosphorus (g/kg)				Potassium (g/kg)			
	LB	S	SB	T	LB	S	SB	T	LB	S	SB	T
CSW0	33.7^{ab}	10.8	9.0^{d}	0.07	2.0	1.2	0.80^{cd}	0.41^{c}	1.6	5.2	5.21^{b}	5.3
CSW1	33.6^{ab}	10.9	10.7^{c}	0.06	2.0	1.2	0.82^{bc}	0.46^{bc}	1.6	5.2	5.23^{a}	5.3
CSW2	33.8^{a}	10.8	10.8^{c}	0.07	2.0	1.2	0.83^{ab}	0.50^{ab}	1.6	5.2	5.24^{a}	5.3
CSW3	33.2^{ab}	11.0	11.3^{b}	0.06	2.1	1.2	0.84^{a}	0.51^{ab}	1.6	5.2	5.23^{a}	5.3
CSW4	32.5^{b}	10.8	11.7^{a}	0.06	2.0	1.2	0.79^{d}	0.54^{a}	1.6	5.2	5.23^{a}	5.3
F-test	*	ns	**	ns	ns	ns	**	**	ns	ns	*	ns
Treatment	**Calcium (g/kg)**				**Magnesium (g/kg)**				**Sulfur (g/kg)**			
	LB	S	SB	T	LB	S	SB	T	LB	S	SB	T
CSW0	7.0^{c}	11.2	8.3^{d}	10.6^{d}	0.20^{d}	0.2	0.2	0.48^{bc}	1.8	1.7^{c}	1.7^{c}	0.49^{c}
CSW1	7.3^{bc}	11.3	8.8^{cd}	11.5^{d}	0.21^{d}	0.2	0.2	0.47^{c}	1.8	1.8^{c}	1.8^{b}	0.50^{bc}
CSW2	7.3^{bc}	11.1	9.1^{c}	13.2^{b}	0.25^{c}	0.2	0.2	0.49^{ab}	1.8	1.9^{b}	1.9^{a}	0.52^{b}
CSW3	7.5^{ab}	11.2	10.6^{b}	13.5^{b}	0.28^{b}	0.2	0.2	0.50^{a}	1.7	2.0^{ab}	1.9^{a}	0.56^{a}
CSW4	7.8^{a}	11.2	12.3^{a}	15.8^{a}	0.33^{a}	0.2	0.2	0.51^{a}	1.9	2.1^{a}	1.9^{a}	0.55^{a}
F-test	**	ns	**	**	**	ns	ns	**	ns	**	**	**
Treatment	**Iron (mg/kg)**				**Manganese (mg/kg)**				**Zinc (mg/kg)**			
	LB	S	SB	T	LB	S	SB	T	LB	S	SB	T
CSW0	5.2	7.3^{b}	4.1	1.5^{b}	2.1^{b}	1.6^{c}	4.8^{b}	1.5	2.0	1.1	4.3^{b}	4.9^{b}
CSW1	5.2	7.4^{b}	4.2	1.5^{b}	2.5^{a}	1.6^{c}	4.5^{b}	1.7	2.1	1.1	4.7^{a}	5.2^{a}
CSW2	5.0	7.6^{a}	4.3	1.6^{ab}	2.3^{b}	2.1^{a}	5.5^{a}	1.5	2.1	1.1	4.7^{a}	6.2^{a}
CSW3	5.1	7.6^{a}	4.2	1.8^{a}	2.3^{b}	2.0^{a}	4.9^{b}	1.6	2.0	1.1	4.0^{c}	6.5^{a}
CSW4	5.4	7.2^{b}	4.3	1.6^{ab}	2.5^{a}	1.8^{b}	4.7^{b}	1.7	1.9	1.2	4.3^{b}	6.9^{a}
F-test	ns	**	ns	*	**	**	**	ns	ns	ns	**	**

ns = not significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.
CSW = cassava starch waste; CSW0 = 0 t/ha; CSW1 = 6.25 t/ha; CSW2 = 12.5 t/ha; CSW3 = 25 t/ha; CSW4 = 50 t/ha.
LB = leaf and branch; S = stem; SB = stem base; T = tuber.

to some degree helped provide essential nutrients to the plant, whereas the soil in the experimental area provided little.

Soil chemical properties

A single application of cassava starch waste as soil amendment had a significant effect on some chemical properties of the topsoil (0–30 cm) after growing cassava for one crop. Only the soil pH, available K and available Mn contents showed no difference following the waste application. In particular, available S, Cu and Zn remained in the topsoil in significantly higher amounts when the cassava starch waste was applied at rates of 25 t/ha and 50 t/ha (Table 5) because the organic waste supplied large quantities of S and micronutrients that are the principal nutrient elements required for plant growth and development (Bernal et al., 2009). Partial effects of the organic waste supplementation were found regarding organic waste and total nitrogen. The amounts of soil organic matter remaining in the soil at harvest were still moderately low and not significantly different among treatments. This was explained by Wang et al. (2006) that under the climatic conditions where the temperature and moisture were high, the decomposition of organic matter was intense, especially in the case of this soil studied that contained mainly macro-pores for which leaching plays a role in terms of carrying away soil organic matter to the deeper zone of the soil profile. Moreover, the average nitrogen concentration in the soil declined from its initial status. This

Table 5
Chemical properties of soil as affected by cassava starch waste and nitrogen fertilizer after growing cassava for one crop.

Treatment	pH	OM	Total	Available						
	1:1 (H_2O)	(g/kg)	N (g/kg)	P (mg/kg)	K (mg/kg)	S (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Main plot: rate of cassava starch waste										
CSW0	4.78	13.9^{b}	0.054^{ab}	14.4^{a}	20.7	12.1^{c}	53.8^{b}	1.9	0.10^{c}	0.06^{d}
CSW1	4.75	15.5^{a}	0.047^{b}	15.3^{a}	23.0	12.6^{bc}	68.7^{a}	2.3	0.13^{bc}	0.13^{c}
CSW2	4.59	16.4^{a}	0.052^{ab}	11.6^{b}	22.7	13.2^{b}	65.0a^{b}	2.1	0.13^{bc}	0.15^{b}
CSW3	4.68	13.8^{b}	0.044^{b}	11.3^{b}	23.5	14.4^{a}	62.0^{ab}	2.1	0.14^{ab}	0.17^{a}
CSW4	4.59	13.2^{b}	0.057^{a}	11.0^{b}	24.3	15.3^{a}	53.1^{b}	2.0	0.15^{a}	0.17^{a}
F-test	ns	**	**	**	ns	**	**	Ns	**	**
Subplot: rate of nitrogen fertilizer										
F-test	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns
Interaction: rate of cassava starch waste × rate of nitrogen fertilizer										
F-test	ns	ns	ns	ns	ns	ns	ns	Ns	ns	ns
% CV	7.0	13.9	0.02	22.6	16.4	10.7	22.1	21.9	0.06	0.05

OM = organic matter; ns = not significant; ** significantly different at 0.01 probability level; means with different lowercase superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.
No significant difference among rate of N nor interaction at all between rate of cassava starch waste and rate of nitrogen fertilizer, thus those results are not shown in the table.
CSW = cassava starch waste; CSW0 = 0 t/ha; CSW1 = 6.25 t/ha; CSW2 = 12.5 t/ha; CSW3 = 25 t/ha; CSW4 = 50 t/ha.

result highlights that part of the organic source of N might be immobilized during decomposition or remain in organic form after one crop. There is a need for long-term experiments to confirm this result.

The study revealed that all treatments involving cassava starch waste addition resulted in significantly higher cassava fresh tuber and starch yields, plant components, nutrient accumulation in plant tissues and in some available nutrients stored in soils compared to the control with no application of this organic waste. In the context of cassava yield, cassava starch waste used as a soil amendment, particularly at the rate of 12.5 t/ha, is more effective when combined with nitrogen fertilization at the rate of 75 kg/ha which is 25 kg/ha lower than the recommended N rate for growing cassava in this type of soil. In addition to a better current harvest yield, the waste also improved some plant nutrient reserves for the next crop. This combined soil management practice can be recommended as it provided adequate supplies of balanced nutrient in a short term basis. However, soil physicochemical properties and crop production are liable to change as a result of continuous cropping. The changes in soil fertility and resultant crop productivity are matters of nutrient imbalance, which has been recognized as one of the most important factors that limit cassava yields (Howeler, 1991). Therefore, long-term field experiments should be undertaken to investigate the cumulative effect of this organic waste and for the precise monitoring of changes in soil fertility and plant productivity.

Conflict of interest

The authors declare that there are no conflicts of interest.

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