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Green Manuring Effect on Yield of Cassava-Sweet Corn Sequential Cropping on Degraded Sandy Soil, Northeast Thailand

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ABSTRACT

The green manuring effect on cassava-sweet corn sequential cropping was evaluated in a sandy Typic Plinthustult soil in Thailand. The highest fresh biomass was observed for ruzi grass (18.53 $t.ha^{-1}$) followed by local weeds (14.08 $t.ha^{-1}$), sword bean (12.69 $t.ha^{-1}$) and sun hemp (12.39 $t.ha^{-1}$). Sword bean tended to contain the highest nitrogen content (2.28%) while ruzi grass had the greatest potassium content (2.32%). The control (local weeds) had the highest phosphorus content (0.15%) but released more nitrogen than did the others with 148.65 $mg.kg^{-1}$ followed by sword bean, sun hemp and ruzi grass (133.83, 92.77 and 59.5 $mg.kg^{-1}$, respectively). The release of nitrogen was greatest at 2 wk after the incorporation of these green manures and the amount continuously reduced, while the release from local weeds ended before the others. Sun hemp was found the most suitable green manure in cassava-sweet corn sequential cropping on this soil and gave the highest tuber yield (27.19 $t.ha^{-1}$) and fresh-peeled sweet corn (4.19 $t.ha^{-1}$) but it gave the lowest starch content (30.13%) of cassava tuber. The incorporation of sword bean gave the lowest cassava yield (13.56 $t.ha^{-1}$) whereas the lowest amount of sweet corn yield (2 $t.ha^{-1}$) was obtained from the incorporation of ruzi grass. The three green manure plants showed almost no effect on soil properties due to the soil still having low residual plant nutrients and weak soil structure but ruzi grass tended to improve the soil physical properties more than did sun hemp and sword bean.

Keywords: sword bean, sun hemp, ruzi grass, finger grass, Typic Plinthustult

INTRODUCTION

Sandy soils generally have low productivity of field crops including cassava because they have inherently very low fertility, low water retention, high leaching and an unstable soil structure (Astier *et al.*, 2006; Tongglum *et al.*, 2000). In addition, soil erosion is severe, leading to soil degradation (Coelho *et al.*, 2000). Sandy soils are widely distributed in northeastern Thailand covering approximately 0.42 million ha (Office of Agricultural Economics, 2010). These soils are normally used for intensive agricultural production, particularly for cassava production, but a lack of soil improvement leads to a drastic decrease in their plant nutrient (Pattiya, 2011). Moreover, crop removal including the tuber and stem where the latter is normally used for propagation, accounts for a lower return of biomass into the soil than with other field crops, such as maize and sugarcane (Pattiya, 2011). All of these factors have resulted in a reduction in

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the cassava yield in this region for a decade with the current average yield being below 18.75 t.ha^{-1} (Office of Agricultural Economics, 2010).

Crop rotation with green manure is a solution to improving degraded sandy soils (Fischler *et al.*, 1999). Green manuring is well known for improving soil productivity by increasing the organic carbon content and fertility level of soils, particularly by supplying nutrients available to the main plants, reducing erosion, preventing any pest and disease outbreak, and subsequently increasing the yield of the following crops as widely reported. Increasing organic matter in the soil by green manuring improves the soil physical properties through increasing the stability of soil aggregates and decreasing the soil bulk density (Fischler *et al.*, 1999; Basic *et al.*, 2004; Masri and Ryan, 2005). Vegetative cover prevents the build-up of the aggregates, which could lead to the formation of surface crusts that reduce water infiltration (Coelho *et al.*, 2000). Rotation with leguminous green manure can result in a significant input of nitrogen into the soil and plant system and in subsequent crops (Fillery, 2001; Ramos *et al.*, 2001; Cobo *et al.*, 2002b; Maobe *et al.*, 2011). Generally, legumes are characterized by a low C:N ratio, a high concentration of soluble compounds and a low lignin content that favor microbial degradation (Cobo *et al.*, 2002a). Legumes fix nitrogen from the atmosphere and the incorporation of legumes into the soil releases nitrogen to the soil and reduces the need for nitrogen fertilizer (Hairiah *et al.*, 2000; Xu *et al.*, 2006). On the other hand, grasses usually present the opposite characteristics from legumes. The use of grasses as green manure can reduce nitrogen loss through temporary nitrogen immobilization during plant debris decomposition (Cobo *et al.*, 2002a; Ajayi, 2011). In addition, the fibrous root system of grass increases soil aggregation, organic matter content and improves the soil structure more than with legumes (Fullen, 2006; Fullen *et al.*, 2006). This advantage further reduces the risk of moisture deficiency in plants grown on sandy soils under rain-fed conditions (Gijsman *et al.*, 1997; Fullen *et al.*, 2006).

Farmers' acceptance of the use of green manure in the case of cassava-based production in sandy soils is rare because of the long growing period which can exceed 8 mth after planting. However, in some areas of Thailand, farmers stop growing cassava for one year and substitute maize usually at the beginning of the second peak of rain; therefore, green manure can be recommended for early in the rainy season for soil improvement purposes. The current experiment was undertaken: 1) to compare the accumulation and mineralization of nitrogen derived from different types of green manure, 2) to evaluate the effect of the green manures in cassava-based production on changes in the soil properties and 3) to measure the effects of the green manures on the subsequent yield and characters of cassava and sweet corn grown on a degraded sandy soil in northeastern Thailand. The results obtained should be useful and transferrable to cassava growers in regions where sandy soils are common.

MATERIALS AND METHODS

Study area and soil characterization

The trial was undertaken during July 2010 and November 2011. The study area was located in a farmer's field in Sikhiu district, Nakhon Ratchasima province, northeastern Thailand situated at 346 m above mean sea level in UTM zone 47 at easting 0768467 and northing 1671420 within the boundary of the sandy Warin soil series. The relief in the experimental area was undulating with a 7% slope. The area experiences a tropical savanna climate with an average annual rainfall of 1,019 mm and a temperature peak of 26.4 °C. The rainfall distribution pattern is bimodal with the first rainy season lasting from March until June and the second peak starting from August to November (Figure 1). The field trail was performed on a Typic Plinthustult soil (Soil Survey Staff, 2010). The level of the ground water table at the time of sampling in the dry season was deeper than 160 cm. The soil had a sandy to sandy loam texture with the clay content increasing slightly with depth. This deep soil had developed on a wash-over residuum derived from sandstone and had well-drained features. The soil had a very weak, fine, subangular blocky structure partly breaking into single grains in the topsoil and a weak to moderately weak and fine to medium, subangular blocky structure in the subsoils. The soil color was brown to red throughout the profile. The bulk density was moderate to moderately high with a range of 1.55–1.78 Mg.m^{-3}. The soil pH was very strongly to strongly acidic with values ranging from 4.9 to 5.4. The base saturation percentage was lower than 35% and plinthite was found within 150 cm of the mineral soil surface (Table 1). The properties of the topsoil (from 0 to 18–20 cm) and the subsoil (from 18–20 to 60 cm) prior to conducting the experiment showed very poor fertility status which was reflected by the low contents of organic matter, available phosphorus and available potassium, and the base saturation percentage and cation exchange capacity (Table 2).

Field experiment

Land preparation and cultivation management practices

Three series of experiment were conducted sequentially. First, green manure crops—sword bean, (*Canavalia enformis*), sun hemp (*Crotalaria juncea*) and ruzi grass (*Brachiaria ruzeiziensis*)—were planted, followed by cassava that was grown as the first main crop, and then sweet corn was grown as the second crop. A randomized complete block design with four replications was employed for the experiment.

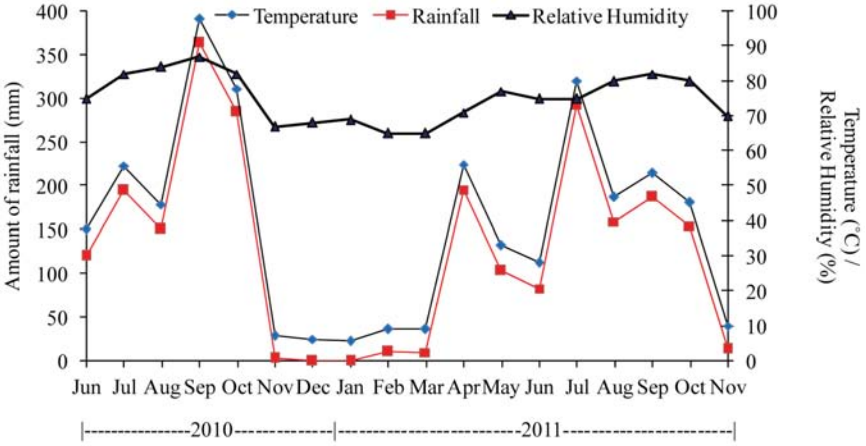

Figure 1 Average temperature, rainfall and relative humidity at the experimental site.

Table 1 Properties of a sandy Typic Plinthustult.

Depth (cm)	Horizon	pH (1:1 H$_2$O)	OM	Total N	Avail.P	Extractable K	Extractable Ca	Extractable Mg	CEC	BS	BD	Sand	Silt	Clay	Textural class
			(……g.kg^{-1}	…….)	(mg.kg^{-1})	(-------cmol.kg^{-1}-------)				(%)	(Mg.m^{-3})	(--------g.kg^{-1}-------)			
0-29	Ap	4.9	3.10	0.18	6.89	0.10	0.26	0.04	0.75	11.5	1.55	887	43	70	S
29-53	Bw	5.1	0.86	0.04	1.80	0.01	0.32	0.06	0.40	17.1	1.58	862	43	96	LS
53-80	Bt1	5.4	0.52	0.04	1.18	0.03	0.19	0.08	0.65	12.6	1.66	810	103	87	LS
80-100	Bt2	5.1	0.69	0.11	1.01	0.01	0.36	0.12	0.80	13.4	1.57	855	67	78	LS
100-126	Bt3	5.0	0.69	0.04	1.01	0.04	0.16	0.14	0.65	19.9	1.63	821	93	87	LS
126-160+	Btc	5.0	1.03	0.04	1.18	0.03	0.54	0.45	1.40	31.2	1.78	853	16	130	LS

OM = Organic matter, Avail. = Available, CEC = Cation exchange capacity, BS = Base saturation, BD = Bulk density.

Table 2 Initial properties of a sandy Typic Plinthustult used in the experiment.

Soil property	Topsoil (0 to 18–20 cm)	Subsoil (18–20 to 60 cm)
pH (1:1 H_2O)	5.2	5.3
Organic matter (g.kg^{-1})	4.46	1.72
Total N (g.kg^{-1})	0.49	0.35
Available P (mg.kg^{-1})	0.48	0.07
Available K (mg.kg^{-1})	49.87	24.63
Extractable Ca (cmol$_c$.kg^{-1})	0.80	0.93
Extractable Mg (cmol$_c$.kg^{-1})	0.39	0.48
Extractable K (cmol$_c$.kg^{-1})	0.13	0.06
Extractable Na (cmol$_c$.kg^{-1})	0.08	0.12
Sum bases (cmol$_c$.kg^{-1})	1.40	1.59
% BS	14.9	16.6
CEC (cmol$_c$.kg^{-1})	2.35	2.53

cmol$_c$ = centimol of charge, CEC = Cation exchange capacity.

The four treatments consisted of: 1) no green manure application as a control; the remaining treatments consisted of the following being sown as green manure in the cassava-based production: 2) sword bean, 3) sun hemp and 4) ruzi grass. The seed sown was based on the recommended amounts of 62.5, 31.25 and 12.5 kg.ha^{-1}, respectively. Each plot size was 10 × 10 m with spacing of 2 m between plots. Land preparation involved plowing twice using a disk plow followed by a disk harrow at an approximate depth of 30 cm. Each green manure plant crop was broadcast directly onto the soil surface while the control plot was left idle during the green manure plant growing period. Three green manure plants and the local weeds—mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*)—in the control plot were allowed to grow to a stage of 50% flowering (at 50 d) before being incorporated into the soil using a tractor equipped with 3-disk plow at an approximate depth of 30 cm. Three weeks after the incorporation, normal land preparation for growing cassava (3-disk followed by 7-disk plowing and contour ridging) was undertaken and planting used the Huai Bong 80 variety, with cassava cuttings each 25 cm long then being planted on the ridges with a spacing of 80 cm between plants and 120 cm between ridges. The cassava was harvested at age 10 mth after planting, and then all residues were incorporated into the soil by using a tractor equipped with the 3-disk plow. Two weeks after the incorporation of these residues, the soil was plowed using the 7-disk plow as preparation for growing sweet corn (Hybrix-39 variety). For all plots, the seedbed preparation was done using a jab at a depth of 5 cm. The sweet corn was planted with a spacing of 25 cm between plants and 75 cm between ridges and was harvested approximately 80 d after planting.

Complete fertilizer (15:15:15, N:P:K) of 312.5 kg.ha^{-1} was equally split and applied at age 2 mth and then at 4 mth. In the case of sweet corn, complete fertilizer (15:15:15, N:P:K) at the rate 312.5 kg.ha^{-1} was applied as a basal application before planting and top dressing was undertaken 3 wk after planting using urea (46:0:0, N:P:K) at the rate of 312.5 kg.ha^{-1}. Pest and weed controls were performed according to local practices and recommendations. All other necessary operations were undertaken as normal and were uniform for all treatments.

Statistical analysis

Analysis of variance was undertaken using the SPSS program version 10.0 and mean separation used Duncan's multiple range test (DMRT) at a significance level of $P < 0.05$.

Plant sampling and laboratory analyses

Fresh biomass samples of green manure crops and local weeds were measured at the stage of 50% flowering at 50 d after planting within an area of 4 m^2. In total, 35 cassava plants in each plot were used for plant parameter data collection on the tuber yield, starch percentage, stem weight, stem base, leaf and branch weight during harvesting time (10 mth after planting). A sample of 15 sweet corn plants in each plot was used for plant parameter data collection. Standard procedures were adopted for recording the weight of fresh ears and straw at 80 d after planting.

Plant part samples of cassava (stem, stem base, leaves and branches), sweet corn (ears and straw) and the whole part of green manure plants were collected at harvesting time. All samples were dried, ground and used for plant nutrient analysis. The total N content was analyzed by the Kjeldahl method (Jackson, 1965) after each sample was digested with H_2SO_4-Na_2SO_4-Se mixture. The amounts of total P and K in these plant parts were analyzed by digesting with an HNO_3-H_2SO_4-$HClO_4$ mixture (Johnson and Ulrich, 1959) and were determined using spectrophotometry (Murphy and Riley, 1962) and atomic absorption spectrophotometry (Westerman, 1990), respectively. The organic carbon analysis used the dry combustion method (Allison, 1965).

Soil sampling and laboratory analyses

Composite samples of the topsoil (from 0 to 18–20 cm) were collected to determine nitrogen mineralization. Disturbed and undisturbed soils samples in each plot were collected at three depths: 0–10, 10–20 and 20–30 cm at 3 wk after the incorporation of green manure and 2 wk after the incorporation of cassava residues.

Undisturbed soil samples were collected using a soil core and dried at 105 °C in an oven for determining bulk density (Blake and Hartge, 1986) and saturated hydraulic conductivity was determined by the variable head method (Klute, 1965). Other disturbed soil samples and sediments were air-dried, crushed and passed through a 2 mm sieve for general laboratory analysis. The total N content was determined by the Kjeldahl method (Jackson, 1965). Extractable NH_4^+ and NO_3^- -N were determined by the steam distillation method as outlined by Keeney (1982). The organic carbon content was measured by the Walkley-Black titration method (Nelson and Sommers, 1996). Soil was extracted by the Bray II method and subsequently the available phosphorus content was determined by the molybdate blue method (Bray and Kurtz, 1945). Available potassium was extracted from soil using 1M NH_4OAc at pH 7.0 and the amount was measured by atomic absorption spectrophotometry (Thomas, 1982). The water aggregate stability was determined by wetting a 25 g sample of 1-2 mm soil aggregate on a 250 mm screen for 10 min and subsequent wet sieving for 10 min (Kemper and Rosenau, 1986).

Nitrogen mineralization

The rates and controls of net nitrogen release were determined by incubation of the different green manures with soil collected from the experimental site according to the method developed by Mohammed (2005). Dry green manure (leaves and succulent twigs) was mixed with moist soil and incubated in a glass bottle for 8 wk. The net N mineralization from the green manure was estimated by the accumulation of extractable ammonium and nitrate minus the accumulation in the soil alone.

The incubation was carried out in glass bottle of 25 mL capacity. Topsoil samples were amended with the desired plant residues at a rate equal to that measured from the field experiment. The soil and residues were thoroughly mixed and adjusted to 60% field capacity with deionized water. Each of the incubation bottles was closed with parafilm in which three holes were made with a pin to allow gaseous exchange with the atmosphere. Then, the treated soil samples were incubated in the laboratory at 30 °C for the required periods (0, 1, 2, 3, 4, 5, 6, 7 and 8 wk after incubation). Throughout the incubation period, to prevent the development of anaerobic conditions, the incubation bottles were aerated every three days by opening the parafilm. At each interval, the loss in weight of each incubation bottle was checked and deionized water was added to adjust each sample to the original weight.

The samples of each week's incubation were analyzed for extractable mineral N (NH_4^+ and NO_3^-) immediately after mixing the soil and plant residues together. At the end of each of the specified incubation periods, the incubation bottles were re-randomized.

RESULTS AND DISCUSSION

Green manure biomass and their compositions

The fresh biomass content of the different green manures at the flowering stage and their plant nutrient compositions were not statistically different (Figure 2). Ruzi grass tended to give the highest fresh biomass content of 18.53 $t.ha^{-1}$ and gave the significantly highest dry biomass content of 5.40 $t.ha^{-1}$. The dry biomass weight of local

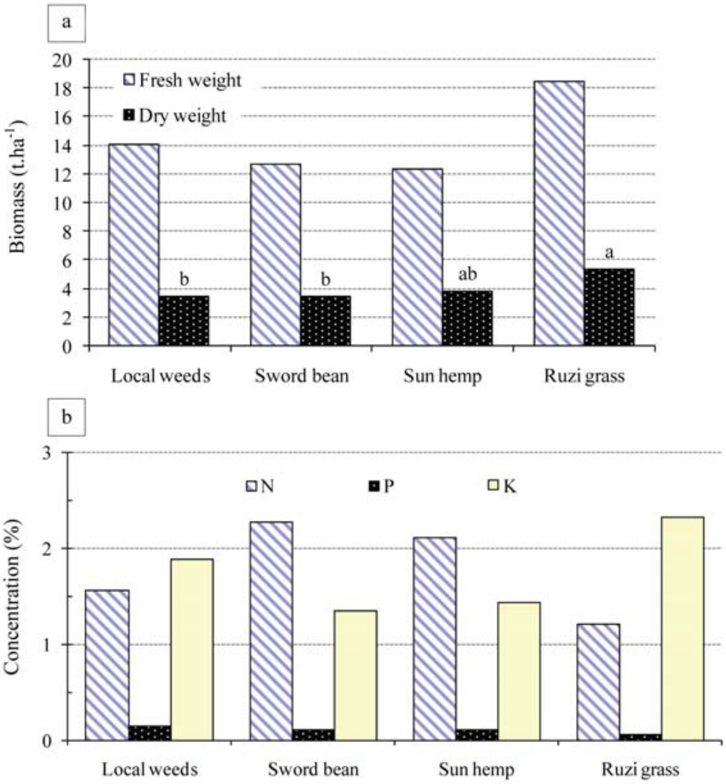

Figure 2 Biomass of different green manures: (a) at flowering stage and (b) their major plant nutrient compositions. The different lowercase letters indicate a significant difference at $P < 0.05$. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

weeds—mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*)—sword bean and sun hemp were not statistically different, though sun hemp tended to produce the lowest fresh biomass content of 12.39 t.ha^{-1} but its dry biomass content of 3.86 t.ha^{-1} was ranked second after ruzi grass. Local weeds tended to produce a higher amount of fresh biomass but a lower amount of dry biomass when compared to the production by sword bean (14.08 and 3.48 t.ha^{-1} compared to 12.69 and 5.46 t.ha^{-1}, respectively). Sword bean and sun hemp contained the highest amounts of nitrogen followed by the amounts of potassium and phosphorus, respectively. Ruzi grass and local weeds had the highest potassium content followed by nitrogen and phosphorus, respectively (Figure 2).

Nitrogen mineralization

Most commonly, the nitrogen released from the green manure amended the soil during the incubation period in the form of NH_4^+-N rather than in the form of NO_3^--N with the content ranging from 22.99 to 105.67 and from 42.88 to 99.68 mg.kg^{-1}, respectively. Local weeds released the highest ammonium content when compared to other green manures with a value of 63.24 mg.kg^{-1} especially at 2 wk after incubation. The amounts observed in soil amended with sword bean, sun hemp and ruzi grass are shown in Figure 3. The NO_3^--N release trends were not different among the green manures, with sword bean and ruzi grass tending to release the highest and the lowest amount respectively (Figure 3). These results showed a relationship with C:N ratio of

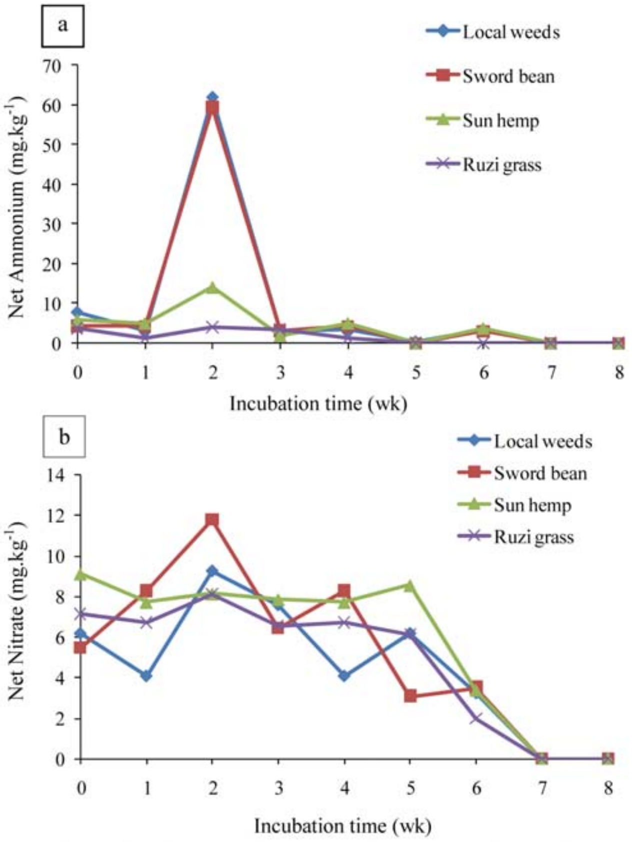

Figure 3 Changes in (a) ammonium and (b) nitrate in a sandy Typic Plinthustult soil incubated with different green manures. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

these plants (Figure 4). The available nitrogen in the soil was released most by local weeds (148.65 mg.kg^{-1}) followed by sword bean (133.83 mg.kg^{-1}), sun hemp (92.77 mg.kg^{-1}) and ruzi grass (59.5 mg.kg^{-1}), respectively. Ruzi grass had a low nitrogen content and greater C:N ratio, resulting in lower nitrogen release (Fillery, 2001; Thompson and Fillery, 2002)

The nitrogen release patterns were similar irrespective of the green manure as shown in Figure 3. The soil available nitrogen (NH_4^+- N and NO_3^--N) was initially low at the end of the first week of green manure application but increased rapidly after the second week, then the amount of NO_3^--N slightly decreased every week and the NH_4^+- N content decreased rapidly by the third week. The nitrogen release patterns were similar to those previously studied by Xu *et al.* (2006), Jude (2009) and Maobe *et al.* (2011). It is noted that mineralization of plant material added to the soil is initially fast due to the breakdown of the more easily decomposable components, but it slows down subsequently until stabilization of the organic residue is achieved (Maobe *et al.*, 2011). Moreover, the nitrogen release patterns of the legumes were similar, especially the NO_3^--N pattern which was possibly because of the similarity in the chemical composition of the plant residues.

In addition, N release from local weeds and ruzi grass ended at 8 wk after incubation with the release from local weeds ending before the others. In the case of the legumes (sword bean and sun hemp), nitrogen was continually released until the end of the incubation period which was consistent with the study of Jude (2009) in South Africa who found that N release from leguminous plants ended at 16 wk and sun hemp released nitrogen more than mucuna and lablab, respectively.

When the total N released from the incorporated green manures was compared with that from local weeds, it was found that local weeds tended to release the highest total N (NH_4^+ -N and NO_3^--N) accounting for 148.65 g.kg^{-1} which was slightly higher than was released by sword bean (133.83g.kg^{-1}) and sun hemp (92.77 g.kg^{-1}) and the lowest amount was 59.50 g.kg^{-1} by ruzi grass. However, the nitrogen concentration in the cassava component collected at the time of harvest showed no relationship with these amounts of N released from the different green manures and local weeds.

Effect of green manure on cassava and sweet corn

Green manure had a significant effect on the fresh tuber, stem and stem base weights,

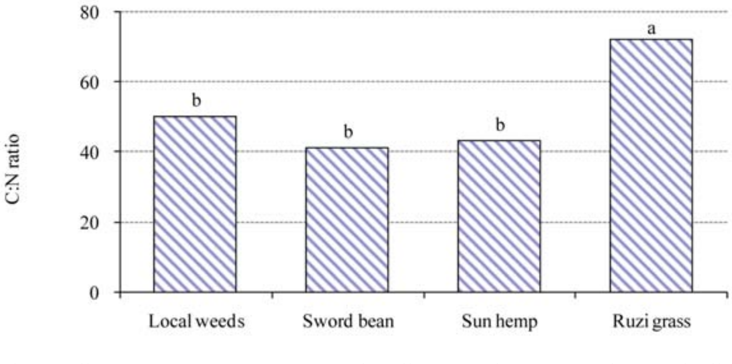

Figure 4 C:N ratio of different green manures. The different lowercase letters indicate a significant difference at $P < 0.05$. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

while there was no significant different among the green manures with regard to the starch content and above ground biomass weight (Table 3). Sun hemp tended to produce a lower amount of fresh biomass when compared to that produced by the other green manures; however, it gave the highest fresh tuber yield of 27.19 t.ha^{-1} and tended to give an above ground biomass of 9.5 t.ha^{-1} but potentially gave the lowest starch content of 30.13%. This is interpreted as the result of the high nitrogen content in the soil that was released during the decomposition of this plant (Figure 3). Consequently, a high nitrogen content could enhance vegetative plant growth rather than increase the starch content in the tuber (Westerman, 1990; Nakviroj *et al.,* 2002). The fresh tuber yield of 21.38 t.ha^{-1} and the above ground biomass of 6.5 t.ha^{-1} obtained from the plot covered by local weeds were higher than those from the plots of ruzi grass (15.69 and 6.11 t.ha^{-1}, respectively) and sword bean (13.69 and 6.11 t.ha^{-1}, respectively). The starch content (31.75%) of cassava under local weeds tended to be the highest. This was due to nitrogen immobilization by the grass residues during decomposition as found by previous reports (Clark *et al.,* 1997; Vaughan and Evanylo, 1998).

Green manure plants had no effect on the concentrations of plant nutrients in each plant part—the tuber, leaves and branches, stem and stem base of cassava. The highest uptake amounts of nitrogen, phosphorus and potassium in all parts of cassava (45.19–193.44, 1.81–7.5 and 1.56–2.19 kg.ha^{-1}, respectively) were found in the plot incorporated with sun hemp (Table 4), which coincided with the highest cassava yield. In addition, all cassava parts tended to have more nitrogen (21.25–193.44 kg.ha^{-1}) than phosphorus (0.88–7.5 kg.ha^{-1}) and potassium (0.88–2.19 kg.ha^{-1}), while the highest uptakes of nitrogen, phosphorus and potassium were found in the leaves and branches (13.83–30.95 kg.ha^{1}) with lower amounts in the stem (4.81–75 kg.ha^{-1}) and tuber (1.63–2.38 kg.ha^{-1}) as shown in Table 4. These results can be interpreted as showing that the incorporation of cassava residues such as leaves and branches and stems should be recommended because this practice evidently helps increase plant nutrient availability, and of nitrogen availability in particular, for a following crop (Pattiya, 2011). However, the timing for growing the next crop should be taken into account because of the high C:N ratio of the plant residues, especially in the case of cassava stem that is likely to induce nitrogen deficiency due to immobilization as reported by Mohammed (2005**).**

Green manuring had no effect on the sweet corn production, plant nutrient concentration

Table 3 Effect of green manure on yield and components of cassava grown on a sandy Typic Plinthustult.

Green manure	Starch (%)	Tuber yield	Stem weight	Stem base weight	Leaves and branches weight	Above ground biomass weight
		(-------------------------------------t.ha^{-1}	-------------------------------------	-------------------------------------	-------------------------------------	-------------------------------------)
Local weeds	31.8	21.38^{ab}	2.13^{b}	2.5^{ab}	1.84	6.47
Sword bean	30.9	13.56^{b}	1.81^{b}	2.44^{ab}	1.86	6.11
Sun hemp	30.1	27.19^{a}	3.56^{a}	3.06^{a}	2.9	9.53
Ruzi grass	31.0	15.69^{b}	1.88^{b}	2.38^{b}	1.86	6.11
F-test	ns	*	*	*	ns	ns

* = Significant difference at 95% confidence level, ns = Not significant at 95% confidence level.

a,b = Means in the same column followed by the same lowercase letter are not significantly different using Duncan's multiple range test. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

or plant nutrient uptake. Sweet corn grown after sun hemp and cassava produced the highest fresh ear yield of 4.19 t.ha^{-1} and the lowest straw weight of 10.11 t.ha^{-1} (Figure 5). However, the lowest amount of fresh peeled sweet corn (2 t.ha^{-1}) was obtained from the incorporation of ruzi grass. In addition, using sun hemp as green manure resulted in the largest nitrogen accumulation in sweet corn (Adriano *et al.*, 2006) as shown in Table 5. These results were consistent with the amount of above ground biomass of cassava produced using different green manures because the soil incorporated with sun hemp gave the highest above ground biomass of cassava and more plant nutrients in these residues might have had a subsequent result on the sweet corn that was grown after it.

Effect of green manure on soil properties

The effect of green manure on the properties of the topsoil was not clear. The lowest bulk density (1.40 Mg.m^{-3}) at a depth between 10 and 20 cm was obtained from the plot using sun hemp as a green manure while incorporation of sword bean into the soil gave the highest bulk density (1.52-1.67 Mg.m^{-3}) as shown in Figure 6. However, this result was inconsistent with the cassava tuber yield. Nevertheless, the incorporation of sword bean tended to produce better water stable aggregation (16.42–20.30 %)

Table 4 Effect of green manure on nutrients uptake of cassava.

Treatment	Tuber			Stem			Leaves and branches			Stem base		
	N	P	K	N	P	K	N	P	K	N	P	K
	(-----kg.ha^{-1}-----)			(------kg.ha^{-1}------)			(------kg.ha^{-1}------)			(------kg.ha^{-1}------)		
Local weeds	29.00	1.31	1.63	30.69	4.75	1.13	149.31	5.88	2.19	43.81	2.50	1.38
Sword bean	21.25	0.88	1.06	19.44	2.44	0.88	86.44	4.81	1.81	34.06	1.63	0.88
Sun hemp	52.75	1.81	2.00	45.19	5.13	1.69	193.44	7.50	2.19	57.44	2.88	1.56
Ruzi grass	22.69	1.00	1.13	27.38	3.50	1.19	92.38	4.88	1.63	30.81	1.88	1.19
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns = Not significant at 95% confidence level.

Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

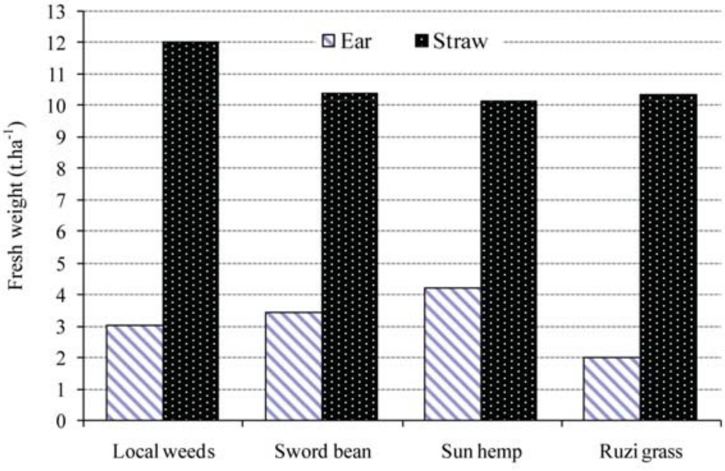

Figure 5 Effect of green manure and cassava residues on yield and straw of sweet corn grown on a sandy Typic Plinthustult soil. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

in the soil while the plot incorporated with ruzi grass tended to have greater saturated hydraulic conductivity (8.85–55.83 cm.hr^{-1}) than did the soil samples with other green manures. There was no effect of different green manures on the organic matter, total nitrogen, available phosphorus or available potassium contents with the amounts ranging from 0.25 to 0.44 g.kg^{-1}, 0.15 to 0.20 g.kg^{-1}, 6.60 to 11.35 mg.kg^{-1} and 21.57 to 49.24 mg.kg^{-1}, respectively, (Figure 7). However, these major plant nutrients were low. This reflects the nature of these coarse-textured soil types that have very low organic matter and cation exchange capacity and are incapable of retaining plant nutrients within the soil against leaching (Coelho *et al.*, 2000; Tongglum *et al.*, 2000).

Changes in the physical and chemical properties of the soils as affected by cassava residues were comparable to the effect of the green manure trends (Figures 8 and 9). Moreover, green manure crops slightly improved the soil physical properties as indicated by the greater amounts of organic matter and plant nutrients that remained in the soil when compared to incorporation of cassava residues. This was because cassava residues generally have more lignin and other material

Table 5 Effect of green manure and cassava residues on nutrients uptake of sweet corn.

Green manure	Uptake by sweet corn (kg.ha^{-1})		
	Nitrogen	Phosphorus	Potassium
Local weeds	93.31	14.56	62.94
Sword bean	107.25	16.69	138.94
Sun hemp	119.31	16.56	91.44
Ruzi grass	61.75	9.88	37.63
F-test	ns	ns	ns

ns = Not significant at 95% confidence level.
Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

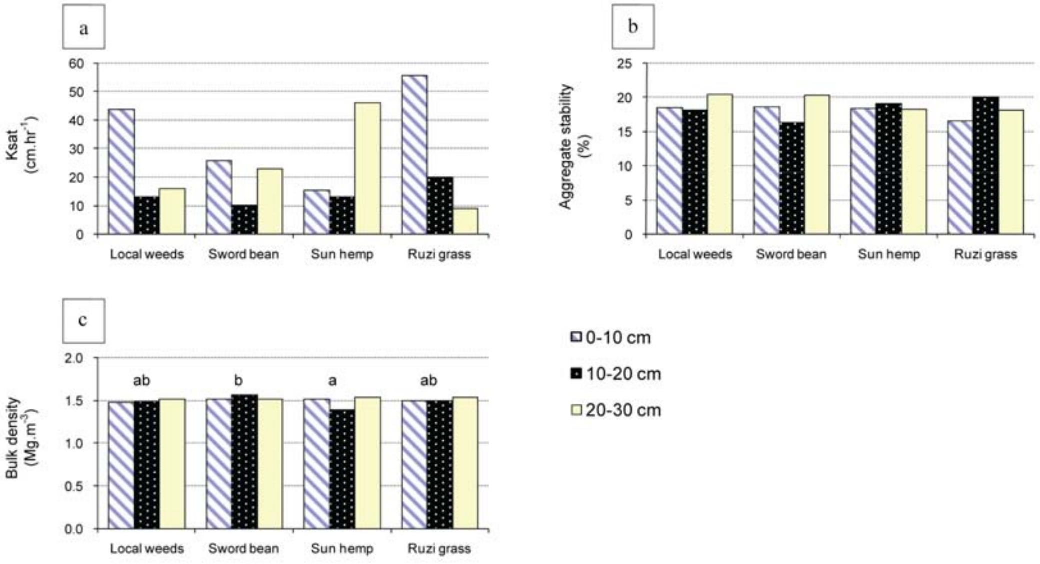

Figure 6 Effect of green manuring on: (a) hydraulic conductivity, (b) aggregate stability and (c) bulk density of a sandy Typic Plinthustult soil. The different lowercase letters indicate a significant difference at $P < 0.05$ using Duncan's multiple range test. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

resistant to decomposition than do the green manure plants, especially in the case of legumes (Ajayi, 2011) leading to different decomposition and mineralization rates that affect the soil properties (Xu *et al.*, 2006).

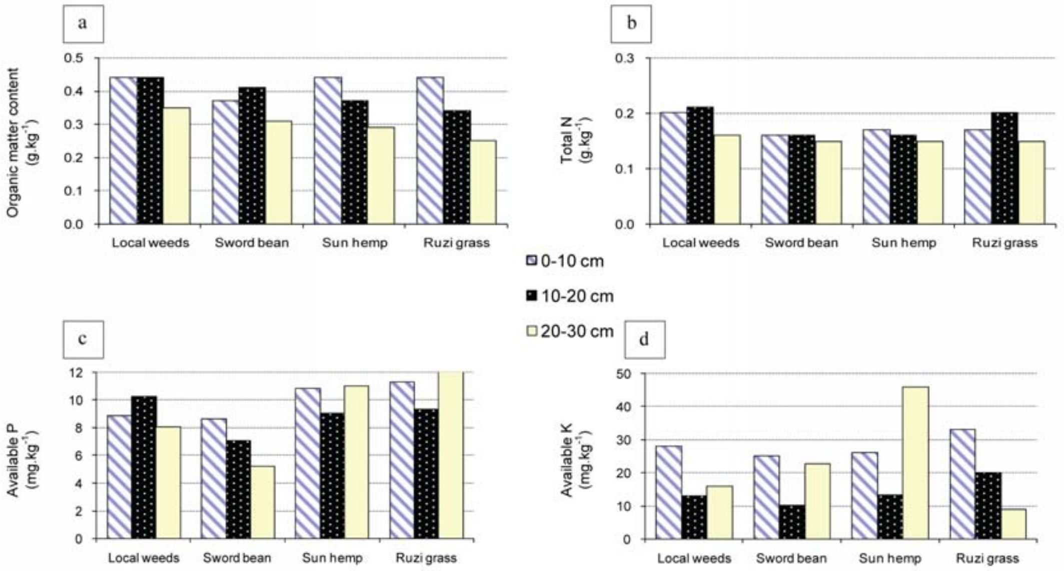

Figure 7 Effect of green manuring on: (a) organic matter (b) total nitrogen, (c) available phosphorus and (d) available potassium contents of a sandy Typic Plinthustult soil. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

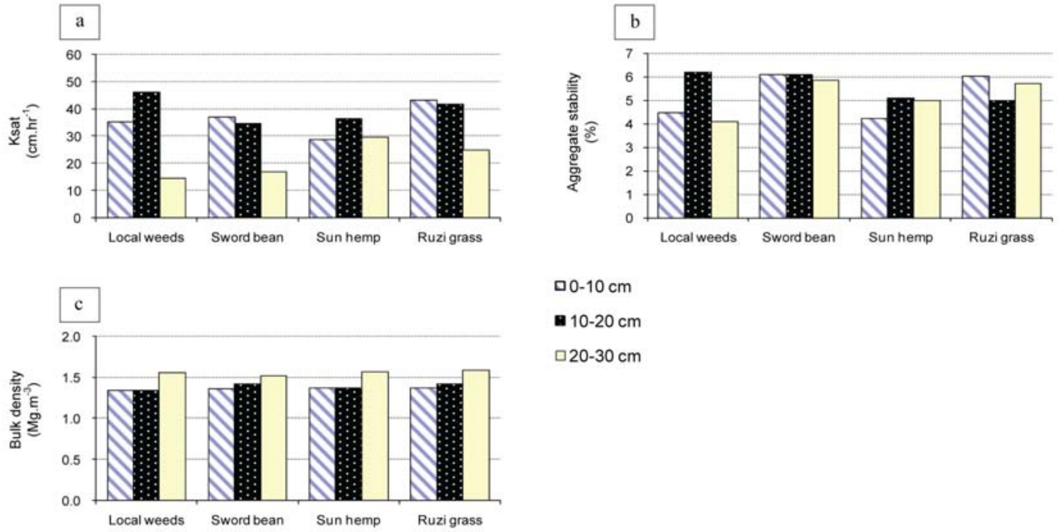

Figure 8 Effect of cassava residue incorporation on hydraulic conductivity (a), aggregate stability (b) and bulk density (c) of a sandy Typic Plinthustult soil. The different lowercase letters indicate a significant difference at $P < 0.05$ using Duncan's multiple range test. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

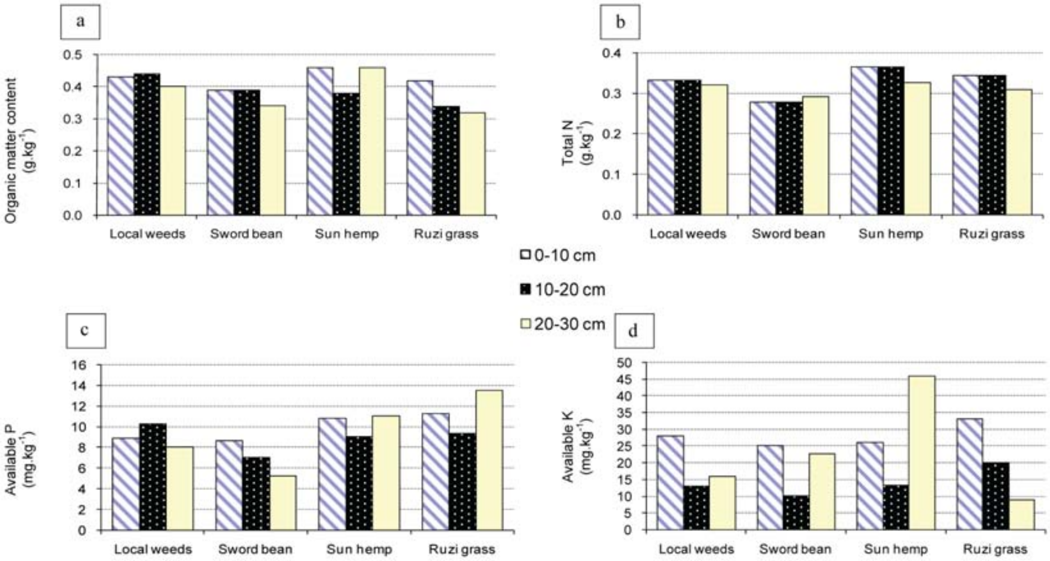

Figure 9 Effect of cassava residue incorporation on: (a) organic matter, (b) total nitrogen, (c) available phosphorus and (d) available potassium contents of a sandy Typic Plinthustult soil. Local weeds in the control were mainly finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*).

CONCLUSION

The use of green manure in cassava-sweet corn sequential cropping on a sandy soil (Typic Plinthustult) potentially increased the yield of cassava. Sun hemp and local weeds flourished after the land was left idle for a few months and comparatively, this gave the highest fresh cassava tuber yield and fresh peeled sweet corn and thus supports the use of green manure plants. Local weeds released the highest nitrogen content compared to other green manures, especially at 2 wk after incubation. However, these green manures rarely improved the soil quality as indicated by the low fertility status and the instability of the soil structure which both remained unchanged. Ruzi grass (*Brachiaria ruzeiziensis*), finger grass (*Digitaria bioformis* Willd) and coat buttons (*Tridox procumbens*) were found to have potential in improving the physical properties of the soil.

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