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Influences of Green Manures and N-fertilizer Management on Nutrient Uptakes and Yield of Cassava on a Degraded Sandy Soil

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ABSTRACT

The effects of green manures combined with nitrogen fertilizer rates on cassava was studied on a Warin soil, having a very sandy nature, in Nakhon Ratchasima province. Three treatments comprising ruzi grass, sun hemp and no green manure incorporation (local weeds) as a control, were tested in a split-plot design. Four nitrogen rates (0, 7.5, 15 and 22.5 kg.rai^{-1} N) as subplots were also studied. Ruzi grass as well as local weeds (mainly jungle rice, crabgrass and goat buttons) contained the highest potassium content of 2.32 and 2.16%, respectively, whereas sun hemp consisted of the highest nitrogen content (2.11%). The amounts of available nitrogen released from ruzi grass and sun hemp were almost identical (74.69–75.55 mg.kg^{-1}) and significantly higher than that obtained from local weeds (55.72 mg.kg^{-1}). Green manure had a clear effect on the cassava yield and plant nutrient uptake whereas N fertilizer had none. Sun hemp and local weed gave the highest fresh tuber yield (4.01 and 3.65 t.rai^{-1}) and above-ground biomass (1.34 and 1.13 t.rai^{-1}) of cassava while the starch content was likely to be low, especially in the case of using sun hemp as green manure (30.83%). The cassava yield and above-ground biomass tended to increase with no significant difference but the starch content significantly decreased with increasing rates of N fertilizer. Nitrogen applied at the rate of 22.5 kg.rai^{-1} N gave the highest fresh tuber yield of 3.50 t.rai^{-1} of the nitrogen only treatments. Sun hemp green manuring followed by the application of N fertilizer at the rate of 15 kg.rai^{-1} N gave the significantly highest fresh tuber yield of 4.35 t.rai^{-1} while the lowest amount of 2.13 t.rai^{-1} was produced by the plot using ruzi grass as green manure without any additional N fertilizer.

Keywords: tropical soils, crop rotation, cropping system, cassava Huay Bong 80 variety

INTRODUCTION

Cassava (*Manihot esculenta* Crantz.) is an important economic crop in Thailand, particularly in the northeastern region, which is the largest area for cassava production covering 53% of the total planting area of the country (Office of Agricultural Economics, 2010). Cassava can be grown on a great variety of soils, with over 80% of the soils growing cassava in this region having sandy or coarse texture and being characterized by excessive leaching with a low soil fertility level, low buffer capacity and poor physical properties (Duangpatra, 1998). Generally, these soils are used

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for intensive field crop production but with a lack of soil improvement, thus leading to a decline in soil productivity and as a consequence, cassava yields have declined in recent decades (Chan, 1980; Sitthibusya *et al*., 1988; Howeler, 1991).

To maintain soil fertility, and therefore sustain cassava productivity, improvements in crop management are necessary. Rotation cropping with green manure, especially between legume and economic crops are well known to improve soil productivity and to increase the yield of the subsequent main crops as shown in several reports (Fischler *et al.*, 1999; Adriano *et al.*, 2006; Maobe *et al.*, 2011). Moreover, plant nutrients available to plants, especially in the case of nitrogen, can evidently be supplied by green manure (Hulugalle *et al.*, 1987). Nitrogen fixed by legumes can be released to the soil through the decomposition process as shown by Jude (2009). Incorporation of sun hemp into the soil released N in the range 121–170 mg.kg^{-1} for the following crop. Using a legume such as *Centrosema macrocarpum*, *Stylosanthes guianensis* or *Canavalia* spp. successfully decreased the use of N fertilizer while a satisfactory yield of many economic crops can be obtained (Hairiah *et al.*, 2000; Muhr *et al.*, 2002; Maobe *et al.*, 2011). However, excessive nitrogen fertilization can be harmful to plant growth due to the acceleration of vegetative growth instead of productive growth (Paisancharoen *et al.*, 2002a, 2002b). Similarly, storage root formation and starch accumulation are likely to be limited in the case of tuber root crops such as cassava (Hagens and Sittibusaya, 1990; Howeler, 2002); consequently, unwarranted above-ground biomass increases at the expense of a decrease in the tuber starch content (Howeler, 2002; Paisancharoen *et al.*, 2002b; Riyaphan *et al.*, 2010). Grasses usually have the opposite characteristics from legumes when used as green manure. However, the fibrous root system of grass improves the soil structure more than legumes (Gijsman *et al.*, 1997; Fullen, 2006; Fullen *et al.*, 2006). This advantage further reduces the risk of moisture deficiency in plants particularly when grown on sandy soils under rain-fed conditions, which are common in northeastern Thailand. Therefore, this research determined the combined effect of green manures and the nitrogen fertilizer rate on cassava plant nutrient concentration and uptake in order to find a suitable nitrogen management regime for green manure-cassava crop practice that would enable the yield of cassava grown on degraded sandy soils to be increased.

MATERIALS AND METHODS

Study area and soil characteristics

The trial was set up in the area of a Warin soil boundary at Ban Non Somboon, Sikhio district, Nakhon Ratchasima province during June 2010 and March 2012. The study area is undulating with 7% slope and an elevation of 346 m above mean sea level. The depth of the ground water table at the time of sampling in the dry season was deeper than 160 cm. The average annual rainfall is 1,212 mm with a mean temperature of 27 ^{o}C (Thai Meteorological Department, 2011).

The soil in the study area was derived from sandstone; therefore, the soil was dominated by sand particles with a content of greater than 800 g.kg^{-1}, indicating its textural narrowness that ranged from sand to loamy sand. The soil pH was strongly acid (4.9–5.4) and uniform with depth. The base saturation percentage was lower than 35% and plinthite was found at a depth of 126 cm from the surface. This soil is classified as a Typic Plinthustult (Soil Survey Staff, 2010). The properties of the soil before conducting the experiment were characterized by a very poor fertility status reflected by the low contents of organic matter (4.46–1.72 g.kg^{-1}), available phosphorus (0.48–0.07 mg.kg^{-1}) and potassium (49.8–24.6 g.kg^{-1}), the low base saturation percentage (14.9–16.6 g.kg^{-1}) and the low cation exchange capacity (2.35–2.53 cmol$_c$.kg^{-1}) as shown in Table 1.

Table 1 Physico-chemical properties of Warin soil prior to conducting the experiment.

Soil property	Topsoil (0–30 cm)	Subsoil (30–60 cm)
Particle size distribution		
Sand ($g.kg^{-1}$)	887.00	836.00
Silt ($g.kg^{-1}$)	43.00	73.00
Clay ($g.kg^{-1}$)	70.00	91.00
Soil textural class	Sandy	Sandy loam
Soil pH (1:1 H_2O)	5.20	5.30
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
Base saturation (%)	14.90	16.60
Cation exchange capacity ($cmol_c.kg^{-1}$)	2.35	2.53

Experimental design and land preparation

Split plots in a randomized complete block with four replications were established. The plot size of each main treatment was 20 × 20 m. The main plot treatments consisted of two green manure plants, ruzi grass (*Brachiaria ruzeiziensis*) and sun hemp (*Crotalaria juncea*) and no green manure application (with local weeds). The seeding rates used for these two manuring plants were 2 and 5 $kg.rai^{-1}$, respectively as recommended by Land Development Department (2006).

The soil was plowed twice using 3–disk followed by 7–disk plowing. Seeds of the green manure plants were sown directly on the soil surface. Local weeds—mainly jungle rice, (*Echinochloa colana* (L.) *Link*), crabgrass (*Digitaria biformis* Willd), and goat buttons (*Tridox procumbens*)—in the control plot were taken into account and incorporated at the same time as the two green manure plants at the 50% flowering stage. Three weeks after the plants had been allowed to completely ferment in the soil, normal land preparation for growing cassava, Huay Bong 80 variety, (3–disk followed by 7–disk plowing and contour ridging) was done with a distance between rows and plants of 120 and 80 cm, respectively.

Each main plot was separated into four subplots 10 × 10 m in size. A 15-15-15 formula (N-P-K) of complete fertilizer was applied at the rate of 100 $kg.rai^{-1}$ (15 $kg.ha^{-1}$ N) as generally recommended by Field Crops Research Institute (2008) for growing cassava on sandy soils. The rates of nitrogen fertilizer used in the experiment were adapted to 0, 7.5, 15 and 22.5 $kg.rai^{-1}$ N for each subplot. Phosphorus and potassium at the rates of 15 $kg.rai^{-1}$ P_2O_5 and 15 $kg.rai^{-1}$ K_2O were also applied to all subplots. Nitrogen, phosphorus and potassium fertilizers in the form of urea (46-0-0), triple super phosphate (0-46-0) and potassium chloride (0-0-60) were split equally and applied on the ridge between cassava plants at age 2 and 4 mth. Pest and weed controls were performed according to general local practices and recommendations. All other necessary operations were kept normal and uniform for all treatments.

Soil and plant collections

Site characterization of the studied area was also carried out according to standard field methods (Soil Survey Division Staff, 1993) as a reference for technology transfer purposes. Composite samples of the topsoil (0–30 cm) and subsoil (30–60 cm) horizons were collected to determine soil properties prior to the experiment. Additionally, the topsoil samples of each plot were collected 3 wk after the green manures and local weeds had been incorporated into the soils.

The fresh biomass of the green manure crops and local weeds was measured within a 4 m^2 area at the 50% flowering stage, at 50 days after planting. Samples of 25 cassava plants in each plot were used for plant parameter data collection such as fresh tuber yield, starch percentage, stem, stem base, leaf and branch weights with collections during harvesting time (10 mth after planting). All parts of green manure plants were sampled before the incorporation and plant part samples of cassava were collected at the harvesting time to determine plant nutrient concentrations.

Laboratory analyses

Laboratory analyses of the physico-chemical properties of soils, plant nutrient compositions in each part of cassava (leaf and branch, stem, stem base, above-ground biomass and tuber) and whole parts of green manure plants were carried out, based on standard methods. Soil samples were air-dried, crushed and passed through a 2 mm sieve for general laboratory analysis. Particle size distribution was determined by the pipette method (Gee and Bauder, 1986). Soil pH was measured in water with a ratio of 1:1 and determined using a pH meter (National Soil Survey Center, 1996). The organic carbon content was measured using the Walkley-Black titration method (Nelson and Sommers, 1996). The total N content was determined using the Kjeldahl method (Jackson, 1965). The extractable NH_4^+ and NO_3^--N were determined using the stream distillation method as outlined by Keeney (1982). Soil was extracted using the Bray II method and subsequently, the available phosphorus content was determined using the molybdenum blue method using a spectrophotometer at 880 nm (Bray and Kurtz, 1945). Extractable bases of Ca, Mg, K and Na were extracted from soil using 1M NH_4OAc at pH 7.0 and the amounts were measured using atomic absorption spectrophotometry (AAS) according to Thomas (1982). The cation exchange capacity of soil samples was measured according to Chapman (1965).

All plant samples were dried, ground and used for plant nutrient analysis. The total N content was analyzed using the Kjeldahl method (Jackson, 1965) after each sample was digested with a H_2SO_4-Na_2SO_4-Se mixture. The amounts of total P and K in these plant parts were analyzed by digesting with a HNO_3-H_2SO_4-$HClO_4$ mixture (Johnson and Ulrich, 1959) and were determined using ultra-violet spectrophotometry (Murphy and Riley, 1962) and AAS (Westerman, 1990), respectively. The organic carbon analysis was done using the dry combustion method (Allison, 1965).

Statistical analyses

Statistical analysis was undertaken to determine the analysis of variance using the SPSS software program (SPSS Inc,; Chicago, Il, USA) and mean separation was tested using Duncan's multiple range test at a significant level of P < 0.05.

RESULTS AND DISCUSSION

Green manure biomass and its composition

Dry biomass differed significantly among the different types of green manures and a significant difference in plant nutrient contents was observed. Ruzi grass gave the highest biomass content of 0.86 $t.rai^{-1}$ followed by 0.62 and 0.56 $t.rai^{-1}$ obtained from sun hemp and local weeds, respectively. Ruzi grass and local weeds contained the highest potassium content of 2.32 and 2.16%, respectively, whereas sun hemp produced the highest nitrogen content (2.11%). The phosphorus concentration showed no significant difference among the three types of green manures (0.10–0.14%). Local weeds tended to contain the highest content of phosphorus (Table 2).

Available nitrogen released from green manure decomposition

Nitrogen availability in the soil, as affected by the decomposition of two green manures, ranged between 74.69 and 75.55 $mg.kg^{-1}$, which was significantly higher than that released from local weeds (55.72 $mg.kg^{-1}$). Considering the two forms of available N, (NH_4^+-N and NO_3^--N), the amounts derived from the release of two green manures were almost identical and clearly higher than that obtained from local weeds (Figure 1). Significantly, the highest contents of NH_4^+-N (39.06 $mg.kg^{-1}$) and NO_3^--N (39.48 $mg.kg^{-1}$) were obtained from the soil incorporated with ruzi grass and sun hemp, respectively, and

Table 2 Biomass of green manures at the flowering stage and their plant nutrient compositions.

Treatment	Fresh weight ($t.rai^{-1}$)	Dry weight ($t.rai^{-1}$)	Plant nutrient composition N (%)	P (%)	K (%)	Organic content (%)
Ruzi grass	3.00	0.86^{a}	1.22^{c}	0.10	2.32	48.0
Sun hemp	1.98	0.62^{ab}	2.11^{a}	0.12	1.43	52.5
Local weeds[1]	2.25	0.56^{b}	1.56^{b}	0.14	2.16	53.5
F-test[2]	ns	*	**	ns	ns	ns
Coefficient of variation (%)	22.8	19.9	7.0	26	9.8	8.0

Local weeds = Jungle rice, crabgrass and coat buttons.

*,** = Significant difference at 0.05 and 0.01 probability levels, respectively, means with different lowercase letters in the same column indicate a significant difference according to Duncan's multiple range test at $P < 0.05$.

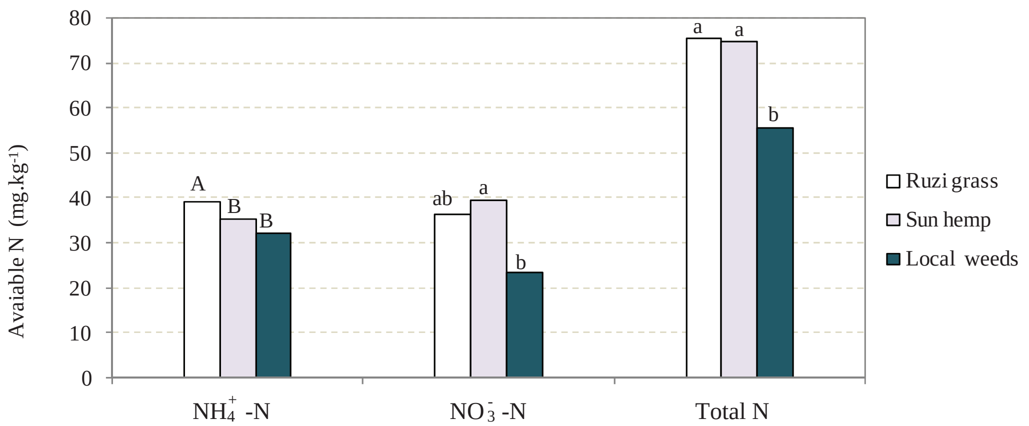

Figure 1 Available nitrogen of soil after incorporation of different green manure plants. Small and capital letters above columns are significantly different at $P < 0.05$ and $P < 0.01$ probability levels, respectively, according to Duncan's multiple range test. Local weeds consist of jungle rice, crabgrass and coat buttons.

local weeds significantly released the lowest contents of both NH_4^+-N and NO_3^--N with amounts of 32.20 and 23.52 $mg.kg^{-1}$, respectively (Figure 1). This was consistent with the wide range in the C:N ratio for the local weeds (Table 2). These results were not consistent with a previous work reported by Jude (2009) who found that the highest available nitrogen content of 120–170 $mg.kg^{-1}$ was released from sun hemp decomposition.

Cassava components as affected by green manure and N fertilizer rate

Green manure had a clear effect on the cassava components except for the starch content (Table 3). Sun hemp tended to produce the lowest amount of biomass (Table 3) but it gave the highest fresh tuber yield of 4.01 $t.rai^{-1}$ and above-ground biomass of 1.34 $t.rai^{-1}$, while the starch content was the lowest (30.83%) as shown in Table 3. This result did not coincide with the amount of available nitrogen content released in soils in addition to the highest nitrogen content in its composition. This reflects the nature of these coarse-textured soils, having very low organic matter and cation exchange capacity that was incapable of retaining plant nutrients, especially cations such as NH_4^+, within the soils against leaching (Astier *et al.*, 2006, Brady and Weil, 2008). However, the cassava yield components were similar to the incorporation of local weeds. Nevertheless, ruzi grass gave the lowest above-ground biomass of 0.87 $t.rai^{-1}$, which was inconsistent with it producing the highest phosphorus uptake in the stem (0.28 $kg.rai^{-1}$) as shown in Table 5. Moreover, the cassava yield was the lowest (2.46 $t.rai^{-1}$), coinciding with the lowest nitrogen (11.43 $kg.rai^{-1}$) and potassium (5.64 $kg.rai^{-1}$) uptakes in tuber (Tables 4 and 6).

The cassava yield and the above-ground biomass tentatively increased but the starch content significantly decreased with an increased rate of N fertilizer where the rate of 22.5 $kg.rai^{-1}$ N produced the highest fresh tuber yield of 3.5 $t.rai^{-1}$ of the applications on N (Table 3). The highest value (31.93%) of starch content was found in the treatment without the application of N and increasing N rates seemed to decrease the starch content, perhaps because the high nitrogen content in the soil could enhance cassava in terms of improving the vegetative growth rather than the formation of storage roots (Howeler, 2002). A better response by cassava in terms of the yield and above-ground biomass was detected. However, the starch content in the tuber decreased as generally reported (Riyaphan *et al.*, 2010). This was likely due to a plant nutrient imbalance, especially between nitrogen and potassium, which was responsible for the low production of starch (Mengel and Kirkby, 1987 Hagens and Sittibusaya, 1990; Howeler, 2002 Paisancharoen *et al.*, 2002a,b; Howeler).

There was no interaction between green manure and N fertilization in terms of the effect on cassava characters except for the fresh tuber yield (Table 3). Sun hemp used as a green manure followed by the application of N fertilizer at the rate of 15 $kg.rai^{-1}$ N produced the highest fresh tuber yield (4.35 $t.rai^{-1}$) while the lowest amount of 2.13 $t.rai^{-1}$ resulted from using ruzi grass without N fertilization. However, the increasing rate of N fertilizer, both with and without green manures, tended to increase the above-ground biomass content and fresh tuber yield (Table 3).

Nutrient concentrations in cassava plant parts

All cassava plant parts (tuber, leaf and branch, stem and stem base) tended to contain more nitrogen (1.3–5.62 %) than potassium (0.54–1.06%) and phosphorus (0.06–0.31%).

The highest nitrogen content of 1.17% in the cassava tuber was observed in the plot incorporated with sun hemp (Table 4) because it had the highest nitrogen content in its composition. N contents of 1.42 and 1.35% were found in the plots incorporated with local weeds and ruzi grass, respectively (Table 4). Moreover, sun hemp as well as local weeds gave the highest potassium accumulated in the cassava tuber with contents

Table 3 Effect of green manures and N fertilizer on yield components of cassava grown on a sandy Warin soil.

Treatment	Tuber yield ($t.rai^{-1}$)	Stem weight ($t.rai^{-1}$)	Leaf and branch weight ($t.rai^{-1}$)	Stem base weight ($t.rai^{-1}$)	Above-ground biomass weight ($t.rai^{-1}$)	Starch content (%)
GM						
A	2.46^{b}	0.25^{c}	0.25^{b}	0.37^{b}	0.87^{b}	31.51
B	4.01^{a}	0.49^{a}	0.41^{a}	0.44^{a}	1.34^{a}	30.83
C	3.63^{a}	0.38^{b}	0.36^{a}	0.40^{ab}	1.13^{a}	31.26
F-test	**	**	*	*	**	ns
N-rate						
N0	3.04	0.32	0.31	0.35	0.98	31.93^{a}
N1	3.50	0.41	0.34	0.40	1.16	31.57^{ab}
N2	3.43	0.40	0.35	0.42	1.17	30.96^{ab}
N3	3.50	0.36	0.35	0.44	1.15	30.36^{b}
F-test	ns	ns	ns	ns	ns	*
GM×N-rate						
AN0	2.13^{d}	0.22	0.20	0.27	0.70	2.13
AN1	2.43^{cd}	0.23	0.22	0.33	0.78	2.43
AN2	2.51^{bcd}	0.30	0.30	0.38	0.97	2.51
AN3	2.78^{abcd}	0.27	0.27	0.49	1.03	2.78
BN0	3.82^{abc}	0.46	0.42	0.43	1.36	3.82
BN1	4.13^{ab}	0.54	0.38	0.44	1.04	4.13
BN2	4.35^{a}	0.57	0.46	0.49	1.52	4.35
BN3	3.75^{abcd}	0.40	0.36	0.41	1.18	3.75
CN0	3.15^{abcd}	0.28	0.30	0.35	0.93	3.15
CN1	3.94^{abc}	0.47	0.43	0.43	1.33	3.94
CN2	3.42^{abcd}	0.34	0.30	0.40	1.04	3.42
CN3	3.99^{abc}	0.41	0.41	0.40	1.23	3.99
F-test	*	ns	ns	ns	ns	ns
Coefficient of variation (%)	28.3	32.8	34.6	20.5	24.6	4.9

A = Ruzi grass, B = Sun hemp, C = Local weeds (jungle rice, crabgrass and goat button).
N0 = 0 $kg.rai^{-1}$ N; N1 = 7.5 $kg.rai^{-1}$ N; N2 = 15 $kg.rai^{-1}$ N; N3 = 22.5 $kg.rai^{-1}$ N.
ns = Not significant; *,** = Significant difference at 0.05 and 0.01 probability levels, respectively. Means with different lowercase letters in the same column indicate a significant difference according to Duncan's multiple range test at $P<0.05$.

of 0.71 and 0.72%, respectively (Table 6). This result coincided with the fresh tuber yield obtained because potassium assists in the translocation of carbohydrates from leaves to tubers (Imas and Bansal, 1999) leading to an expansion of tuber size (Howeler and Cadavid, 1990; Trehan *et al.*, 2001), which, in turn, increases the yield. Ruzi grass significantly induced the highest phosphorus content in the cassava stem (0.28%), whereas phosphorus accumulated in this plant part was

Table 4 Effect of green manures and N fertilizer on nitrogen concentration and uptake cassava plant parts.

Treatment	N concentration (%)				N uptake (kg.rai^{-1})			
	Leaf and branch	Stem	Stem base	Tuber	Leaf and branch	Stem	Stem base	Tuber
GM								
A	4.70	1.44	1.83	1.35^{b}	4.69	1.08^{b}	2.86	11.4^{c}
B	6.87	1.42	1.99	1.71^{a}	6.87	2.30^{a}	3.66	22.7^{a}
C	6.28	1.30	1.64	1.42^{b}	6.28	1.45^{b}	2.59	16.8^{b}
F-test	ns	ns	ns	**	ns	**	ns	**
N-rate								
N0	5.07	1.35^{b}	1.36^{b}	1.38^{b}	5.07	1.25	2.07^{b}	14.1
N1	5.80	1.02^{b}	1.87^{a}	1.46^{b}	5.80	1.32	3.01^{ab}	17.3
N2	6.70	1.40^{b}	1.97^{a}	1.40^{b}	6.70	1.68	3.22^{ab}	15.7
N3	6.22	1.78^{a}	2.07^{a}	1.74^{a}	6.22	2.19	3.84^{a}	20.8
F-test	ns	**	*	*	ns	ns	*	ns
GM×N-rate								
AN0	3.74	1.44	1.50	1.26	3.73	0.88	1.79	9.0
AN1	4.08	1.39	1.92	1.33	4.08	1.12	2.47	11.4
AN2	5.61	1.24	1.69	1.34	5.61	1.01	2.27	11.0
AN3	5.36	1.67	2.19	1.50	5.36	1.30	4.91	14.3
BN0	6.25	1.06	1.62	1.52	6.25	1.69	3.11	18.8
BN1	6.34	0.92	1.89	1.64	6.34	1.76	3.41	23.9
BN2	9.25	1.69	2.21	1.66	9.25	2.68	4.22	22.3
BN3	5.63	2.03	2.23	2.00	5.63	3.06	3.91	25.7
CN0	5.23	1.57	0.97	1.36	5.23	1.17	1.33	14.5
CN1	6.99	0.75	1.79	1.43	6.99	1.10	3.15	16.6
CN2	5.24	1.26	2.00	1.19	5.24	1.36	3.18	13.7
CN3	7.67	1.64	1.79	1.71	7.68	2.19	2.71	22.6
F-test	ns	ns	ns	ns	ns	ns	ns	ns
Coefficient of variation (%)	44.80	32.80	28.12	17.84	35.0	24.6	23.8	37.26

A = Ruzi grass, B = Sun hemp, C = Local weeds (jungle rice, crabgrass and goat button).

N0 = 0 kg.rai^{-1} N; N1 = 7.5 kg.rai^{-1} N; N2 = 15 kg.rai^{-1} N; N3 = 22.5 kg.rai^{-1} N.

ns = Not significant; *,** = Significant difference at 0.05 and 0.01 probability levels, respectively. Means with different lowercase letters in the same column indicate a significant difference according to Duncan's multiple range test at $P<0.05$.

statistically no different in the plots incorporated with sun hemp and local weeds (Table 5).

The rate of applied N fertilizer had a clear effect on the content of nitrogen accumulated in cassava stem, stem base and tuber (Table 4). The application of nitrogen fertilizer at the highest rate (22.5 kg.rai^{-1} N) produced the significantly highest nitrogen content in the stem, stem base and tuber with respective values of 1.78, 2.07 and 1.74% (Table 4). Applying no nitrogen as fertilizer gave the lowest nitrogen contents of 1.35 and 1.38% in the cassava stem and tuber, respectively. However,

Table 5 Effect of green manures and N fertilizer on phosphorus concentration and uptake in cassava plant parts.

Treatment	P concentration (%)				P uptake (kg.rai^{-1})			
	Leaf and branch	Stem	Stem base	Tuber	Leaf and branch	Stem	Stem base	Tuber
GM								
A	0.25	0.28^{a}	0.11	0.06	0.25	0.19^{b}	0.17	0.51^{b}
B	0.37	0.21^{b}	0.11	0.06	0.37	0.32^{a}	0.20	0.85^{a}
C	0.34	0.22^{b}	0.11	0.06	0.34	0.24^{b}	0.17	0.73^{a}
F-test	ns	*	ns	ns	ns	**	ns	**
N-rate								
N0	0.27	0.28	0.11	0.06	0.37	0.26	0.20	0.62
N1	0.30	0.21	0.11	0.06	0.33	0.26	0.20	0.74
N2	0.37	0.22	0.12	0.06	0.27	0.24	0.16	0.69
N3	0.33	0.24	0.11	0.06	0.30	0.24	0.17	0.73
F-test	ns	ns	ns	ns	ns	ns	ns	ns
GM×N-rate								
AN0	0.19	0.36	0.11	0.06	0.19	0.20	0.13	0.44
AN1	0.19	0.26	0.11	0.06	0.19	0.19	0.14	0.51
AN2	0.33	0.24	0.13	0.07	0.33	0.19	0.17	0.53
AN3	0.30	0.27	0.10	0.06	0.30	0.18	0.23	0.55
BN0	0.34	0.22	0.10	0.06	0.34	0.34	0.19	0.77
BN1	0.33	0.21	0.11	0.07	0.33	0.31	0.19	0.95
BN2	0.49	0.19	0.11	0.07	0.49	0.30	0.22	0.86
BN3	0.31	0.23	0.11	0.07	0.31	0.34	0.19	0.83
CN0	0.29	0.28	0.11	0.06	0.29	0.19	0.15	0.64
CN1	0.38	0.16	0.10	0.06	0.37	0.23	0.17	0.78
CN2	0.29	0.25	0.13	0.06	0.29	0.28	0.20	0.68
CN3	0.39	0.21	0.11	0.06	0.39	0.26	0.16	0.81
F-test	ns	ns	ns	ns	ns	ns	ns	ns
Coefficient of variation (%)	42.2	32.6	2.8	1.6	12.3	6.5	15.6	34.2

A = Ruzi grass, B = Sun hemp, C = Local weeds (jungle rice, crabgrass and goat button).
N0 = 0 kg.rai^{-1} N; N1 = 7.5 kg.rai^{-1} N; N2 = 15 kg.rai^{-1} N; N3= 22.5 kg.rai^{-1} N.
ns = Not significant; *,** = Significant difference at 0.05 and 0.01 probability levels, respectively. Means with different lowercase letters in the same column indicate a significant difference according to Duncan's multiple range test at $P<0.05$.

there were no statistical differences among the applied rates of 7.5 and 15 kg.rai^{-1} N.

Nitrogen fertilizer rates and the interaction between green manure and N fertilization had no effect on the phosphorus and potassium concentration in cassava plant parts (Table 5 and 6). The relative proportion of plant nutrient concentrations in each plant part of cassava as affected by green manure and N fertilizer is given in Figure 2. Nitrogen, phosphorus and

Table 6 Effect of green manures and N fertilizer on potassium concentration and uptake in cassava plant parts.

Treatment	K concentration (%)				K uptake (kg.rai^{-1})			
	Leaf and branch	Stem	Stem base	Tuber	Leaf and branch	Stem	Stem base	Tuber
GM								
A	0.89	0.67	0.60	0.69	0.89	0.48^{b}	0.86	5.63^{b}
B	1.27	0.60	0.57	0.71	1.27	0.90^{a}	1.02	9.34^{a}
C	1.16	0.54	0.59	0.72	1.16	0.63	0.92	8.49^{a}
F-test	ns	ns	ns	ns	ns	**b	ns	**
N-rate								
N0	0.96	0.63	0.56	0.72	0.96	0.63	0.83	7.19
N1	1.05	0.55	0.58	0.68	1.05	0.70	0.92	7.93
N2	1.17	0.61	0.64	0.72	1.17	0.65	1.01	8.02
N3	1.25	0.63	0.55	0.70	1.25	0.70	0.98	8.14
F-test	ns	ns	ns	ns	ns	ns	ns	ns
GM×N-rate								
AN0	0.66	0.64	0.55	0.70	0.66	0.36	0.61	5.03
AN1	0.69	0.59	0.60	0.63	0.68	0.42	0.76	5.22
AN2	1.02	0.78	0.71	0.73	1.02	0.62	0.95	5.95
AN3	1.20	0.67	0.53	0.70	1.20	0.50	1.11	6.31
BN0	1.23	0.61	0.53	0.73	1.23	0.99	1.00	8.74
BN1	1.10	0.58	0.53	0.67	1.10	0.92	0.93	9.90
BN2	1.58	0.58	0.63	0.76	1.58	0.79	1.16	10.05
BN3	1.16	0.65	0.59	0.68	1.16	0.91	1.01	8.68
CN0	3.97	0.62	0.60	0.74	0.97	0.55	0.88	7.79
CN1	1.35	0.49	0.61	0.73	1.35	0.75	1.08	8.68
CN2	0.90	0.49	0.59	0.68	0.90	0.53	0.92	8.06
CN3	1.41	0.56	0.54	0.72	1.40	0.68	0.80	9.43
F-test	ns	ns	ns	ns	ns	ns	ns	ns
Coefficient of variation (%)	41.4	30.9	17.9	14.2	15.8	11.2	28.9	34.2

A = Ruzi grass, B = Sun hemp, C = Local weeds (jungle rice, crabgrass and goat button).
N0 = 0 kg.rai^{-1} N; N1 = 7.5 kg.rai^{-1} N; N2 = 15 kg.rai^{-1} N; N3 = 22.5 kg.rai^{-1} N.
ns = Not significant; *,** = Significant difference at 0.05 and 0.01 probability levels, respectively. Means with different lowercase letters in the same column indicate a significant difference according to Duncan's multiple range test at $P<0.05$.

potassium accumulated mostly in leaves and branches followed by stems, tubers and the stem base of cassava, respectively. The incorporation of cassava residues, mainly leaves and branches, is beneficial and should be recommended to increase plant nutrient availability for a following crop, particularly with regard to nitrogen. Moreover the concentrations of nitrogen, phosphorus and potassium in each plant part were in the same range as reported in recent studies (Plengsuntia,

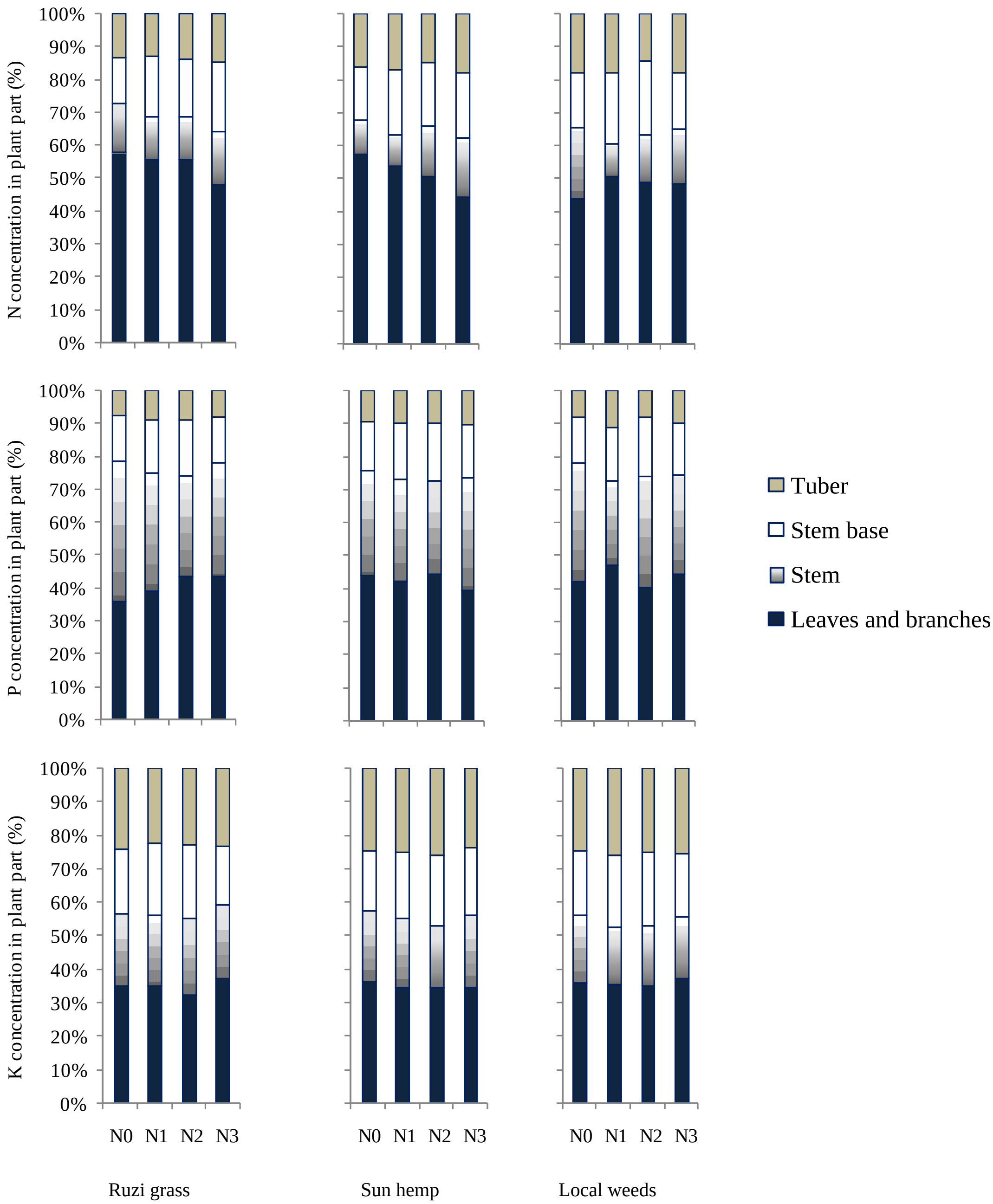

Figure 2 Relative proportion of nitrogen, phosphorus and potassium concentrations in each plant part of cassava (converted to 100%) as affected by incorporated green manures and applied N fertilizer.

2012; Kanjana, 2013; Surin, 2013) that were carried out on coarse-textured soils in northeast Thailand. Those ranges were: 3.21–3.54% N, 0.19–0.26% P and 0.81–1.13% K in leaves and branches, 0.8–1.05% N, 0.06–0.11% P and 0.47–0.82% K in stems, 0.41–0.51% N, 0.05–0.06% P and 0.59–0.80% K in tubers and 0.98–1.19% N, 0.08–0.11% P and 0.48–0.76% K in the stem base of cassava.

CONCLUSION

Using only green manure or a combination with N fertilizer clearly had a positive impact on the response of cassava in terms of yield and above-ground biomass. The application of sun hemp followed by N fertilization at the rate of 15 $kg.rai^{-1}$ N gave the highest fresh tuber yield and this combined practice should be recommended for growing cassava on a sandy Warin soil. Nevertheless, growing cassava in this soil without green manure needed a high rate (22.5 $kg.rai^{-1}$ N) of N fertilizer, as shown by the results of the study, to produce the highest cassava yield. Local weeds (mainly jungle rice, crabgrass and goat buttons) flourished after the land had been left idle for 50 d and released the significantly lowest available nitrogen in both NH_4^+ and NO_3^- forms but gave the highest fresh cassava tuber yield which was statistically different from that when incorporated with sun hemp. Thus, it can be recommended farmers should delay growing cassava for a few months and leave the land covered by local weeds followed by plowing to incorporate them into the soil; however, the farmers must ensure that the weeds are incorporated into the soil before reaching the flowering stage in order to control the spread of unwanted weeds in the following cassava crop. This practice is recommended where farmers do not want to invest in growing the recommended green manures.

The rate of nitrogen fertilizer had a greater effect on plant nutrient concentrations in cassava plant parts than did green manure, particularly in the case of nitrogen. However, the nitrogen fertilizer rate and green manure showed no interaction in terms of the effect on plant nutrient concentrations in cassava plant parts. As major plant nutrients were stored in substantial amounts in the leaves and branches of cassava, the incorporation of this crop residue into the soil is strongly recommended as, to some degree, it returns these nutrients into the soil for a following crop.

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