Kasetsart J. (Nat. Sci.) 47 : 492 - 505 (2013)

Enhancing Sustainable Cassava Production in Hilly Areas of Van Yen, Yen Bai Province, Vietnam

Nguyen Thanh Trung[1, 2], Sutkhet Nakasathien[2,*] and Vichan Vichukit[2]

ABSTRACT

Low awareness on sustainable production and farming techniques are major factors limiting cassava (*Manihot esculenta* Crantz) production in the northern mountainous region of Vietnam. In 2011, three experiments were conducted in Van Yen District of Yen Bai province, Vietnam, to determine the appropriate plant density (a control at 10,000 plants.ha^{-1}, high stocking at 12,500 plants.ha^{-1} and extra-high stocking at 14,000 plants.ha^{-1}), the proper NPK+S fertilizer level (low at 800 kg.ha^{-1}, a control at 1,000 kg.ha^{-1}, a high level at 1,200 kg.ha^{-1} and an extra-high level at 1,400 kg.ha^{-1}), as well as incorporating the study of a suitable cassava intercropping system for controlling soil erosion. The high density and high fertilizer levels significantly increased the fresh root yield, harvest index, root dry matter and starch content compared to those of the control. However, these parameters were not different at both the extra-high density and extra-high fertilizer levels from those of the high density and high fertilizer levels. In addition, there were no significant differences in the sprouting percentage, the stem diameter with increased stocking and the fertilizer level. It was found that cassava intercropped with peanut, using *Tephrosia candida* hedgerows, not only considerably increased the plant height, fresh root yield, harvest index, root dry matter and starch content, but also effectively decreased the dry soil loss compared to mono-cropping.

Keywords: cassava, plant density, fertilizer levels, cropping systems, growth and yield

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the sixth most important crop after wheat, rice, maize, potato, and barley, because of its tolerance to drought, poor soil conditions and generally difficult crop environments (Lebot, 2009). In Vietnam, cassava is the third principal food crop and plays a crucial role as an important source of cash income for small farmers. In the northern mountainous region, cassava has been planted on around 110,000 ha, and accounts for 20% of the total cassava area in Vietnam (Kim *et al.*, 2008). However, the cassava yield and production in this area is only 12.0 t.ha^{-1} and 1.32 million t, respectively, while the average national yield is higher at 16.9 t.ha^{-1} (Kim *et al.*, 2008). Furthermore, knowledge on the yield potential, exploitable yield gaps, farming practices and awareness on sustainable production is still limited. The productivity of cassava can be increased by using suitable cultivation methods

[1] Hanoi University of Agriculture, Hanoi, Vietnam.
[2] Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok 10900, Thailand.
[*] Corresponding author, e-mail: agrskn@ku.ac.th

Received date : 15/03/13 Accepted date : 29/05/13

of production, including an appropriate density, fertilizer application and soil erosion control (Leihner, 2002).

Plant density is considered one of the most important parameters in crop management practice; Toro and Atlee (1980) concluded that the optimum plant density of cassava is highly dependent on edaphic and climatic factors, cassava varieties, soil fertility, cultivation practices and the final utilization of the roots. Wargiono (1987) reported that yields of the non-branching cultivars increased by increasing the plant population from 15,000 to 20,000 plants.ha^{-1}. In Vietnam, Hy *et al.* (1996) indicated that on the more fertile Latosols, the best plant population for two cassava popular varieties (KM60 and KM94) ranged from 10,000 to 14,000 plants.ha^{-1}, while on the more infertile Podzolic soils, a population range of 12,000–16,000 plants.ha^{-1} gave the highest yield and profits of two cassava varieties. When root production is the only objective, the optimal density is 10,000 plants.ha^{-1} (1×1 m), which is adequate for commercial-sized fresh roots (Lebot, 2009).

Because of cassava's tolerance to difficult conditions, one of the most serious problems in cassava production is the lack of fertilizer application (Kim *et al.*, 2008). Nevertheless, fertilizer is ordinarily applied to cassava fields at low rates in some areas, depending on the economic status of the farmer, the price of cassava and the cost of fertilizer. Current fertilizer recommendations for cassava are still very general and not sufficiently specific to allow farmers to optimize fertilizer use. The rate of 100 kg.ha^{-1} N, 50 kg.ha^{-1} P_2O_5 and 100 kg.ha^{-1} K_2O is recommended in general (Sittibusaya *et al.*, 1993). In Vietnam, the best fertilizers for cassava were in the ratio 2: 1: 2 of N: P_2O_5: K_2O, and the optimum level varied from 80-40-80 kg.ha^{-1} to 160-80-160 kg.ha^{-1} (Hy *et al.*, 2000).

Soil erosion is influenced by the climate, topography, vegetation, soil type and human endeavors and must be considered as an important factor in considering the expansion of cassava areas. Tongglum *et al.* (1990) indicated that intercropping cassava with peanut, mungbean and soybean was very effective in reducing soil loss, with an average soil loss of 25.7 t.ha^{-1}.yr^{-1}, compared to 53.2 t.ha^{-1}.yr^{-1} for the conventional mono-cropped cassava. In China, the results of an experiment conducted on 12% slope at the Guangxi Subtropical Crops Research Institute from 1990 to 1992 showed that contour ridging and peanut intercropping significantly reduced soil losses (65% and 60%, respectively) without seriously affecting cassava yield (Yinong *et al.*, 1993). Hedgerows of green trees to protect cassava-cultivated areas from soil erosion also showed that the productivity had increased by 20% compared to the control without tree bands (Phien and Vinh, 2007).

Only a few researchers have studied cassava agronomy in the northern mountainous region of Vietnam with the main objective of helping smallholders increase their cassava production and income. Thus, this study was proposed to determine suitable farming practices and the optimal cassava cropping system in order to reduce soil erosion.

MATERIALS AND METHODS

Three field experiments were conducted in the Dong Mau commune, Van Yen district, Yen Bai province, Vietnam in 2011. A new promising cassava variety KM21-12 was used which has good plant architecture, is non-branching or seldom branching with a high starch content and dry matter percentage, and an especially high yield (27–39% higher than local varieties). Organic and chemical fertilizers used in all experiments were farmyard manure and NPK+S (8:10:3:9), respectively.

Experiment 1 - Plant density trial

The experiment was laid out in a randomized complete block design (RCBD) with three replications and individual plot areas of 30 m^2. Treatments consisted of: three plant densities—10,000 $plants.ha^{-1}$ as control planted at 1×1 m; 12,500 $plants.ha^{-1}$ planted at 1×0.8 m]; and 14,000 $plants.ha^{-1}$ planted at 0.9×0.8 m. Before planting, the crops were fertilized with 10,000 kg. ha^{-1} organic fertilizer and 1,000 kg. ha^{-1} NPK+S.

Experiment 2 - Fertilizer application trial

The experiment was laid out in an RCBD with three replications and each plot area was 30 m^2. The plant density used in this experiment was 10,000 $plants.ha^{-1}$ (1×1 m). Treatments consisted of four fertilizer levels (800 kg. ha^{-1} NPK+S as the low level; 1,000 kg. ha^{-1} NPK+S –as the control; 1,200 kg. ha^{-1} NPK+S –as the high level and 1,400 kg. ha^{-1} NPK+S –as the extra-high level). Before planting, the crops were fertilized with 10,000 kg. ha^{-1} organic fertilizer.

Experiment 3 - On-farm soil erosion trial

The experiment was laid out on a slope of 13% and plot area was 70 m^2. The peanut variety used in this experiment was L26. The cassava density was 10,000 $plants.ha^{-1}$ (1×1 m). Two rows of peanuts were planted alternately with two rows of cassava. The hedgerow width was 0.5 m. Before planting, the crops were fertilized with 10,000 kg. ha^{-1} organic fertilizer and 1,000 kg. ha^{-1} NPK+S. The experiment consisted of seven treatments: E1, cassava (C)+peanut (P)+*Paspalum atratum* hedgerows; E2, C+*Paspalum atratum* hedgerows; E3, C+P+*Pennisetum purpureum* hedgerows; E4, C+*Pennisetum purpureum* hedgerows; E5, C without hedgerows (control); E6, C+P + *Tephrosia candida* hedgerows; and E7, C+*Tephrosia candida* hedgerows.

Data collection

Cassava agronomic characteristics (Experiments 1, 2 and 3)

The sprouting percentage was determined at age 2 wk after planting by counting the number of sprouted stem cuttings in each plot. The stem diameter in centimeters was assessed at harvest. The plant height in centimeters was measured on the main stem, from the ground to the first unexpanded leaf. The number of roots per plant, the weight of fresh roots per plant in grams, the fresh root yield in tonnes per hectare and the total plant fresh weight in grams were also determined. The harvest index was calculated as the proportion of root weight to the total plant weight on a fresh weight basis at harvest. Root dry matter as a percentage was determined from the weight of samples before and after drying in the oven at 105 °C for 6 hr. The starch content was determined by weighing in air about 4–5 kg of fresh cassava storage roots from each plot and then weighing under water to measure the starch content using the Reinmann scale. The fresh starch content was calculated using the equation: starch content = 210.8×(weight in air/weight in air – weight in water) – 213.4.

Soil erosion (Experiment 3)

A soil trap was built along the edge of each plot to collect the eroded soil that accumulated from planting to harvesting. The dry soil eroded from each plot was weighed and expressed on a tonne per hectare basis.

Statistical analysis

Analysis of variance was carried out using Microsoft Office Excel (version 2007); Microsoft, Redmond, WA, USA) and IRRISTAT 5.0 (International Rice Research Institute; Metro Manila, Philippines) software. The differences between treatment means were considered significant at the $P < 0.05$ level by the use of least significant differences.

RESULTS AND DISCUSSION

Effects of plant density on cassava growth and development

The sprouting percentage indicates the ability of cassava cuttings to develop a plumule and a radical. The plumule develops to form the shoot while the radical will form the root, which later becomes the cassava root. Thus, the emergence of cassava stakes is an indication of the viability of the planting material. The cassava sprouting percentages resulting from different plant densities are shown in Table 1. At 14 days after planting (DAP) there were no significant differences in the sprouting percentages between the three treatments.

The stem diameter is the botanical characteristic that demonstrates the capability for growth and development in cassava. A larger stem diameter promotes better nutrient and water transportation and also increases structural support (Gardner *et al.*, 1985). In addition, stems with an appropriate diameter can be reserved to make cassava cuttings. Table 1 also shows plant density had no effect on the cassava stem diameter.

One of the commonest expressions to show the effect of competition is the effect of density on plant height. Greater height gives a competitive advantage by enabling the shading of neighbors. Cassava plants have been reported to be much taller at higher plant populations than at lower ones (Enyi, 1973; Cock *et al.*, 1977) indicating that as the density increases and competition for light is intensified, the plant height was substantially increased. In addition, the cassava height also gives an indication of the availability of nutrients responsible for the growth of plant tissues. As shown in Table 1, there were no differences in the plant height pattern among all treatments. Therefore, the results revealed that the studied cassava densities had no effect on the cassava growth and development at this location.

Effects of plant density on cassava yield and yield components

The number of storage roots per plant (Table 2) varied with plant populations, ranging from 10.5 to 11.3 roots per plant. The maximum root number was 11.3 in the control treatment, followed by 11.1 at a stocking of 12,500 plants.ha^{-1}, while the lowest was 10.5 with a stocking of 14,000 plants.ha^{-1}. However, there were no significant differences in the number of roots when the plant population was increased from 10,000 to 12,500 plants.ha^{-1} and from 12,500 to 14,000 plants.ha^{-1}. This result was consistent with the results of Leihner (1979), who reported that the number of roots decreased as the plant stocking rate increased.

Table 1 Effects of different plant densities on cassava growth and development.

Density (plants.ha^{-1})	Sprouting percentage (%)	Stem diameter (cm)	Plant height (cm)
10,000 (control)	98.9^{a}	2.3^{a}	212.0^{a}
12,500	97.2^{a}	2.3^{a}	218.5^{a}
14,000	96.0^{a}	2.2^{a}	211.9^{a}

^{a} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

Table 2 Effects of different plant densities on cassava yield and yield components.

Density (plants.ha^{-1})	Number of roots per plant	Weight of roots per plant (g)	Weight of individual roots per plant (g)	Fresh root yield (t.ha^{-1})
10,000 (control)	11.3^{a}	3,265^{a}	295.7^{a}	32.6^{b}
12,500	11.1^{ab}	3,033^{b}	277.5^{ab}	37.9^{a}
14,000	10.5^{b}	2,714^{c}	264.0^{b}	38.0^{a}

^{a,b,c} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

A statistical analysis of the weight of individual roots showed the same trend with the number of roots per plant (Table 2). Cassava planted at 10,000 plants.ha^{-1} produced the highest weight of individual roots of about 295.7 g, followed by 277.5 g planted at the high density, while cassava planted at the extra-high density gave the lowest weight of individual roots of about 264.0 g. There was also no significant difference in the weight of individual roots when the plant density was increased from 10,000 to 12,500 and from 12,500 to 14,000 plants.ha^{-1}.

Plant density had significant effects on the average fresh root weight per plant (Table 2). The control treatment produced both the highest number of roots and the greatest individual root weight per plant and also produced the highest average fresh root weight per plant of about 3,265 g. The fresh root weight per plant increased from 2,714 g to 3,033 g measured under plant populations of 14,000 and 12,500 plants.ha^{-1}, respectively.

The fresh root yield of cassava at different densities is shown in Table 2. There was a significant increase in the root yield when the plant population increased from 10,000 to 12,500 and then to 14,000 plants.ha^{-1}. The fresh root yield produced from the control was 32.6 t.ha^{-1}, while it was 37.9 and 38.0 t.ha^{-1} at the high density and extra-high density levels, respectively, which were about 16% higher than that of control. However, there were no significant differences in the fresh root yield with increased plant density from 12,500 to 14,000 plants.ha^{-1}. At the high and extra-high plant densities, any gain in total yield per hectare due to the addition of extra plants was offset by the decrease in the individual root weight per plant. According to Gardner *et al.* (1985), the yield response to increasing plant density is asymptotic. If the population is too dense, the only loss is from the greater cutting expense. Although there is no loss from exceeding the critical plant density, there is also no gain because no more than 100% of the solar radiation can be intercepted. Thus, the results suggested that 12,500 plants.ha^{-1} is the most appropriate density for cassava root yield at this location.

Effects of plant density on harvest index, root dry matter and starch content

The statistical analysis of the total plant fresh weight under different plant densities is shown in Table 3. The plant fresh weight was significantly reduced by about 16% and 24% when the plant density was increased to the high and extra-high levels compared to the control. The control treatment produced the highest plant fresh weight of 5,935 g, followed by 12,500 plants.ha^{-1} of about 5,005 g, and finally 14,000 plants.ha^{-1} of 4,527 g. The results were consistent with Gardner *et al.* (1985), who reported that the maximum individual plant fresh weight is reduced by the increasing competition resulting from greater plant density (the competition factor). This relationship also represents conditions of either limiting radiation or limiting nutrients and water supply.
According to Gardner *et al.* (1985), the harvest index gives an insight into the partitioning of

Table 3 Effects of different plant densities on plant fresh weight, harvest index, root dry matter and starch content.

Density (plants.ha^{-1})	Plant fresh weight (g)	Harvest index	Root dry matter (%)	Starch content (%)
10,000 (control)	5,935^{a}	0.55^{b}	38.5^{b}	27.6^{b}
12,500	5,005^{b}	0.61^{a}	38.9^{a}	27.9^{a}
14,000	4,527^{c}	0.60^{a}	38.6^{b}	27.4^{c}

^{a,b,c} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

photosynthates between the sink or storage organ (roots) and the source (shoots). A high value shows that most of the photosynthates are transported to the roots (high sink capacity). It also means that in cassava a high root yield is produced. As shown in Table 3, the control treatment had the lowest harvest index of 0.55, while the treatments at 12,500 and 14,000 plants.ha^{-1} had similar harvest indices of 0.60 and 0.61, respectively. The results suggested that the harvest index would be higher when increasing the plant density.

The results from Table 3 also show the root dry matter contents of different plant densities. The cassava plant population of 12,500 plants. ha^{-1} obtained the highest root dry matter content of about 38.9%. There were similar levels for the root dry matter content for the stocking levels of 10,000 and 14,000 plants.ha^{-1}, of about 38.5 and 38.6%, respectively. When the plant density was increased from 10,000 to 12,500 plants.ha^{-1}, the root dry matter content tended to be higher, whereas the root dry matter content considerably decreased as the cassava plant density increased progressively from 12,500 to 14,000 plants.ha^{-1}.

As revealed in Table 3, the starch content was highly influenced by plant densities. The highest starch content was reached from plant density of 12,500 plants ha^{-1}, about 27.9%. Starch content markedly increased when increasing plant population from 10,000 to 12,500 plants ha^{-1}. In contrast, starch content drastically reduced at plant population of 14,000 plants ha^{-1} as compared to 12,500 plants ha^{-1}. The lowest starch content was obtained from plant density of 14,000 plants ha^{-1}, followed by the control treatment, about 27.4 and 27.6%, respectively. The results show the same trend with root dry matter content, and also suggest that 12,500 plants ha^{-1} is the most appropriate plant density for root dry matter and starch content of cassava production at this location.

Effects of fertilizer application levels on cassava growth and development

The cassava sprouting percentage and stem diameter as influenced by fertilizer application levels are shown in Table 4. Similarly to plant density, different fertilizer levels had no effects on the sprouting percentage and stem diameter among all treatments.

Different fertilizer levels had a considerable effect on the growth pattern in terms of cassava plant height, as measured at 30 d intervals from 40 DAP, especially at harvest (Table 4). The treatment with the minimum fertilizer rate resulted in the lowest plant height. This was probably due to the insufficient supply of nutrients which inhibited cassava height growth. Edwards *et al.* (1977) and Spear *et al.* (1978) suggested that cassava has low phloem mobility, resulting in a slow redistribution of nutrients in the plant. Thus when the supply of nutrients is inadequate, cassava decreases its growth rate to match the decrease in the rates of nutrient uptake. Lozano (1976) also reported that cassava suffering from N deficiency frequently showed stunted growth. The treatments with fertilizer rates at 1,200 and

Table 4 Effects of fertilizer application levels on cassava growth and development.

NPK+S fertilizer level (kg.ha^{-1})	Sprouting percentage (%)	Stem diameter (cm)	Plant height (cm)
800	93.3^{a}	2.3^{a}	216.1^{c}
1,000 (control)	96.7^{a}	2.4^{a}	221.7^{b}
1,200	96.7^{a}	2.4^{a}	225.7^{a}
1,400	96.7^{a}	2.4^{a}	225.9^{a}

^{a,b,c} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

1,400 kg.ha^{-1} obtained similar plant heights of 255.7 and 255.9 cm, respectively, followed by the control treatment with a plant height of 221.7 cm, and finally the fertilizer rate at 800 kg.ha^{-1} with only 216.1 cm.

Effects of fertilizer application level on cassava yield and yield components

The storage root number per plant as affected by fertilizer levels is shown in Table 5. Among all treatments, there were significant differences. The highest root number of 12.8 roots per plant was obtained with the fertilizer applied at 1,200 kg.ha^{-1}, closely followed by both the control treatment and fertilizer applied at 1,400 kg.ha^{-1} with values of about 12.1 and 12.2 roots per plant, respectively, and finally the minimum fertilizer level produced 11.3 roots per plant. Nevertheless, there were no significant differences in the root number when the fertilizer level was increased from 800 to 1,000, to 1,200 and to 1,400 kg.ha^{-1}. This suggests that the fertilizer level at 1,200 kg.ha^{-1} produced the highest root number per plant at this location.

The production of cassava storage roots was highly affected by the level of fertilizer application. The average weight of root per plant and of individual roots per plant is shown in Table 5. The weight of individual roots per plant at different fertilizer levels displayed the same trend as the number of roots. There were no significant differences in weight of individual roots per plant when the fertilizer level decreased from 1,000 to 800 kg.ha^{-1}, or increased from 1,000 to 1,200 and to 1,400 kg.ha^{-1}. The extra-high fertilizer level produced the highest weight of per plant of about 301.3 g, followed by the fertilizer applied at 1,200 and 1,000 kg.ha^{-1} with values of 285.2 and 271.5 g, respectively. The lowest weight of individual roots per plant was 259.1 g at the low fertilizer level.

As both fertilizer treatments at 1,400 and 1,200 kg.ha^{-1} produced a high number of roots and weight of individual roots per plant, they also produced the highest weights of roots per plant of 3,617 and 3,601 g, respectively. The control treatment produced 3,250 g of roots per plant while the low fertilizer level treatment produced only 2,875 g of roots per plant.

According to Yinong *et al.* (1993), N, P, and K fertilizer application had a significant effect on increasing the cassava root yield. In the current study, the different fertilizer levels resulted in a significant variation in cassava fresh root yield (Table 5 and Figure 1). The maximum fresh root yields were observed with fertilizer applications of 1,400 and 1,200 kg.ha^{-1} with 36.2 and 36.0 t.ha^{-1}, respectively. The control treatment produced 31.3 t.ha^{-1}, while the lowest fresh root yield of 28.8 t.ha^{-1} was associated with the fertilizer applied at 800 kg.ha^{-1}. The results indicated that the high and extra-high fertilizer levels gave the same higher fresh root yield because of a proliferation of dry matter in the storage roots when the nutrient concentration in the soil solution increased. However, when the fertilizer level was

Table 5 Effects of different fertilizer levels on cassava yield and yield components.

NPK+S fertilizer level (kg.ha^{-1})	Number of roots per plant	Weight of roots per plant (g)	Weight of individual root per plant (g)	Fresh root yield (t.ha^{-1})
800	11.3^{b}	2,875^{c}	259.1^{c}	28.8^{c}
1,000 (control)	12.1^{ab}	3,250^{b}	271.5^{bc}	31.3^{b}
1,200	12.8^{a}	3,601^{a}	285.2^{ab}	36.0^{a}
1,400	12.2^{ab}	3,617^{a}	301.3^{a}	36.2^{a}

^{a,b,c} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

increased from 1,200 to 1,400 kg.ha^{-1}, there were no significant differences in fresh root yield, nor in the other yield components.

Effects of fertilizer levels on cassava harvest index, root dry matter and starch content

Table 6 shows the effect of the fertilizer application level on the total plant fresh weight of cassava. The highest plant fresh weight of about 6,380 g was observed with the fertilizer application of 1,400 kg.ha^{-1} and the lowest of about 5,163 g with the fertilizer application of 800 kg.ha^{-1}. The control treatment and the high fertilizer level treatment produced similar plant fresh weight values of about 5,767 and 6,000 g, respectively. As the cassava fresh root yields were similar for fertilizer applications of 1,200 and 1,400 kg.ha^{-1} (Table 5), the results suggest that increasing the fertilizer application level from 1,200 to 1,400 kg.ha^{-1} only produced an increase in the fresh weight of the stem and leaves. Thus, applying fertilizer at the rate of 1,200 kg.ha^{-1} is the most appropriate level for cassava production at this location.

Kawano and Jennings (1983) reported that the harvest index of cassava is an important factor for yield not only under high but also under low yielding environments (poor soil fertility and a long dry season). In the current study, the cassava harvest index was greatly affected by different fertilizer levels as shown in Table 6. The highest harvest index of about 0.6 was observed with the fertilizer application of 1,200 kg.ha^{-1}, while the other application levels produced lower harvest index values, with the low fertilizer level and the control treatment having values of only 0.55 and

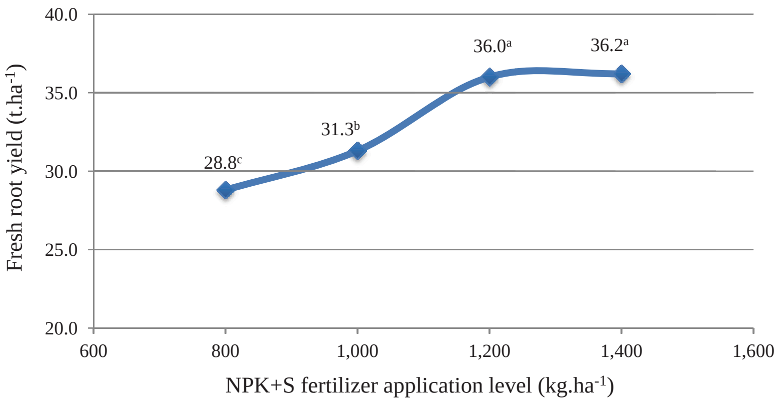

Figure 1 Cassava fresh root yield as affected by different fertilizer levels. Values with the same lowercase superscript letter are not significantly different ($P < 0.05$).

Table 6 Effects of fertilizer levels on plant fresh weight, harvest index, root dry matter and starch content.

NPK+S Fertilizer level (kg.ha^{-1})	Plant fresh weight (g)	Harvest index	Root dry matter (%)	Starch content (%)
800	5,163^{c}	0.55^{b}	38.4^{c}	27.4^{b}
1,000 (control)	5,767^{b}	0.56^{b}	38.7^{b}	27.5^{b}
1,200	6,000^{b}	0.60^{a}	38.9^{a}	27.8^{a}
1,400	6,380^{a}	0.57^{b}	38.9^{a}	27.8^{a}

^{a,b,c} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

0.56, respectively, whilst the extra-high fertilizer level also reduced the harvest index to 0.57. This result suggested that the appropriate fertilizer level would substantially increase the harvest index.

The root dry matter content was calculated from the weight of samples before and after drying in the oven. Table 6 shows the statistical analysis of the cassava root dry matter content under different fertilizer levels. The root dry matter content was highest for the fertilizer applied at 1,200 and 1,400 $kg.ha^{-1}$ with values of about 38.9%, followed by the control (38.7%), and finally by the treatment with 800 $kg.ha^{-1}$ of fertilizer (about 38.4%). This result indicated that the dry matter percentage of cassava roots was greatly affected by the fertilizer application level.

The root starch content was also significantly affected by different levels of fertilizer application (Table 6). The starch content was highest for the fertilizer applied at 1,200 and 1,400 $kg.ha^{-1}$ with values of about 27.8%. There were similar starch contents between the control treatment and the low fertilizer level (about 27.5 and 27.4 %, respectively). Thus, the cassava starch content under high fertility tended to be higher than that under low fertility. This result reveals that when increasing the fertilizer application to appropriate level, the root starch content of cassava would be increased, but then additional fertilizer would produce no further change in the root starch content as was also stated by Hy *et al.* (2000).

Effects of various cropping systems on cassava growth and development

As shown in Table 7, there were no considerable differences in the sprouting percentage among all treatments. The stem diameter of the control treatment was the lowest (2.1 cm), whilst the others treatments produced similar values , ranging from 2.4 to 2.6 cm. The result shows that cassava mono-cropping markedly affected stem diameter.

Table 7 and Figure 2 show the changes in plant height under different cropping systems with time (DAP). At harvest, the highest plant height of 220.6 cm was obtained from E6 and the lowest of 190.8 cm was recorded at E5. The differences in the plant height among E1, E3, E6 and E7 were not significant. Thus, this result also showed the significant effect of different cropping systems on the cassava plant height.

Effects of various cropping systems on cassava yield and yield components

The number of roots per plant is one of the most important cassava yield components.

Table 7 Cassava growth and development under various cropping systems.

Cropping system	Sprouting percentage (%)	Stem diameter (cm)	Plant height (cm)
E1	98.6	2.5^{a}	218.0^{ab}
E2	95.7	2.4^{a}	214.1^{bc}
E3	100	2.6^{a}	216.9^{abc}
E4	97.1	2.4^{a}	212.3^{c}
E5 (control)	95.7	2.1^{b}	190.8^{d}
E6	100	2.6^{a}	220.6^{a}
E7	98.6	2.6^{a}	218.4^{ab}

E1 = Cassava (C)+peanut (P)+*Paspalum atratum* hedgerows; E2 = C+*Paspalum atratum* hedgerows; E3 = C+P+*Pennisetum purpureum* hedgerows; E4 = C+*Pennisetum purpureum* hedgerows; E5 = C without hedgerows; E6 = C+P+*Tephrosia candida* hedgerows; E7 = C+*Tephrosia candida* hedgerows.

^{a,b,c,d} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

There were significant differences in the number of roots under various cropping systems (Table 8). E2 produced the maximum number of roots per plant of 14.0 while E5 observed the minimum of only 9.0.

As shown in Table 8, E6 obtained both the highest weight of roots per plant and weight of individual roots plant^{-1} of 3,530 and 359.9 g, respectively. E5 demonstrated the smallest weight of roots per plant of only 2,995 g, whilst E2 acquired the lowest weight of individual roots per plant of 243.3 g. There were no significant differences among the other treatments.

The results of the statistical analysis of the cassava fresh root yield under the various cropping systems are shown in Table 8. The treatment of

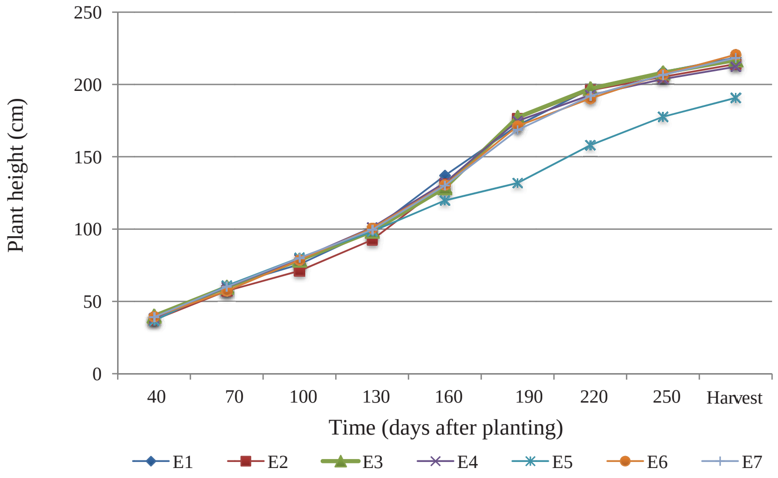

Figure 2 Plant height pattern of cassava under various cropping systems.
E1 = Cassava (C)+peanut (P)+*Paspalum atratum* hedgerows; E2 = C+*Paspalum atratum* hedgerows; E3 = C+P+*Pennisetum purpureum* hedgerows; E4 = C+*Pennisetum purpureum* hedgerows; E5 = C without hedgerows; E6 = C+P+*Tephrosia candida* hedgerows; E7 = C+*Tephrosia candida* hedgerows.

Table 8 Cassava yield and yield components under various cropping systems.

Cropping system	Number of roots per plant	Weight of roots per plant (g)	Weight of individual root per plant (g)	Fresh root yield (t.ha^{-1})
E1	12.3^{b}	3,400^{abc}	286.3^{cd}	34.0^{abc}
E2	14.0^{a}	3,344^{bc}	243.3^{d}	33.5^{bc}
E3	10.9^{bc}	3,434^{ab}	321.8^{abc}	34.4^{ab}
E4	11.4^{bc}	3,289^{c}	294.7^{bcd}	32.9^{c}
E5 (control)	9.0^{d}	2,995^{d}	338.7^{ab}	30.0^{d}
E6	10.1^{cd}	3,530^{a}	359.9^{a}	35.3^{a}
E7	10.4^{cd}	3,395^{abc}	335.0^{abc}	34.0^{abc}

E1 = Cassava (C)+peanut (P)+*Paspalum atratum* hedgerows; E2 = C+*Paspalum atratum* hedgerows; E3 = C+P+*Pennisetum purpureum* hedgerows; E4 = C+*Pennisetum purpureum* hedgerows; E5 = C without hedgerows; E6 = C+P+*Tephrosia candida* hedgerows; E7 = C+*Tephrosia candida* hedgerows.

^{a,b,c,d} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

cassava intercropped with peanut using *Tephrosia candida* as a hedgerow produced the highest fresh root yield of 35.3 $t.ha^{-1}$, while the mono-cropping treatment produced the lowest yield of only 30.0 $t.ha^{-1}$. This was due to the advantages conferred by the nitrogen nutrient when intercropping with peanut and by the retention of soil, fertilizers and water from the plots with a hedgerow as compared with cassava mono-cropping. Similarly, the treatments (E1, E3 and E6) involving intercropping with peanut gave higher yields of 34.0, 34.4, and 35.3 $t.ha^{-1}$, respectively, compared to the treatments (E2, E4 and E7) without intercropping with peanut of 33.5, 32.9, and 34.0 $t.ha^{-1}$, respectively. Moreover, the treatment using *Tephrosia candida* as a hedgerow also produced a higher yield compared to the treatments using *Paspalum atratum* and *Pennisetum purpureum*, with or without intercropping with peanut. Thus, the results suggest that intercropping with peanut and using hedgerows, especially *Tephrosia candida*, can significantly increase the cassava fresh root yield on sloping land. The results were also consistent with Leihner (2002) and Dang (2007).

Effects of various cropping systems on cassava harvest index, root dry matter and starch content

The total plant fresh weight of cassava under different cropping systems is shown in Table 9. E1 attained the maximum plant fresh weight of 6,016 g, while the minimum was 5,698 g in E5. However, there were no significant differences in the plant fresh weight among other treatments.

Table 9 shows the cassava harvest index was strongly affected by the various cropping systems. E6 had the greatest harvest index of 0.60, slightly higher than E3 and E7 (0.59), while the control had the smallest harvest index of only 0.53. The results suggest that intercropped cassava with peanut or using *Tephrosia candida* or *Pennisetum purpureum* in hedgerows produced the highest harvest index.

As shown in Table 9, there were no significant differences in the root dry matter under the various cropping systems. The root dry matter varied from 38.4% in E5 to 39.0% in E1.

The starch content of the various cassava cropping systems is provided in Table 9. The control treatment had the lowest starch content of 26.6%. Although E1, E6, and E7 had the highest

Table 9 Effects of various cassava cropping systems on plant fresh weight, harvest index, root dry matter and starch content.

Cropping system	Plant fresh weight (g)	Harvest index	Root dry matter (%)	Starch content (%)
E1	6,016^{a}	0.57^{bc}	39.0^{a}	27.6^{a}
E2	5,960^{ab}	0.56^{c}	38.8^{a}	27.3^{ab}
E3	5,800^{abc}	0.59^{ab}	38.7^{a}	27.4^{ab}
E4	5,841^{abc}	0.57^{bc}	38.6^{a}	27.1^{ab}
E5 (control)	5,698^{c}	0.53^{d}	38.4^{a}	26.6^{b}
E6	5,844^{abc}	0.60^{a}	38.9^{a}	27.9^{a}
E7	5,768^{bc}	0.59^{ab}	38.9^{a}	27.7^{a}

E1 = Cassava (C)+peanut (P)+*Paspalum atratum* hedgerows; E2 = C+*Paspalum atratum* hedgerows; E3 = C+P+*Pennisetum purpureum* hedgerows; E4 = C+*Pennisetum purpureum* hedgerows; E5 = C without hedgerows; E6 = C+P+*Tephrosia candida* hedgerows; E7 = C+*Tephrosia candida* hedgerows.

^{a,b,c,d} = Means within a column with the same lowercase superscript letter are not significantly different ($P < 0.05$).

starch content values of 27.6, 27.9, and 27.7%, respectively, there were no significant differences compared with the other treatments.

Effects of various cropping systems on dry soil eroded

Figure 3 shows that when cassava was intercropped with peanut, the amount of eroded soil was reduced by 63.2 to 80.2% compared to the farmer's traditional practice of mono-cropping. When hedgerows of *Paspalum atratum*, *Pennisetum purpureum*, or *Tephrosia candida* were added, erosion declined to only 19.8—68.9% of the control treatment. The treatments with *Tephrosia candida* hedgerows, with or without peanut, decreased the highest soil eroded by 70.8 and 80.2% compared to the control, followed by the treatments with *Paspalum atratum* with reductions of 40.6 and 66.0%, and finally the treatments with *Pennisetum purpureum* with reductions of 31.1 and 63.2%. Thus, the results suggested that at this location, cassava intercropped with peanut, using *Tephrosia candida* as hedgerows is the most effective system to reduced soil loss compared to the control with a comparative reduction of 80.2%.

CONCLUSION

Three experiments were conducted at Dong Mau commune, Van Yen district, Yen Bai province to enhance sustainable cassava production. The results indicated that the suitable plant density and the application level of NPK+S fertilizer for promising cassava variety KM21-12 was 12,500 plants.ha^{-1} and 1,200 kg.ha^{-1}, respectively. This density and fertilizer level gave the highest fresh root yield, harvest index, root dry matter and starch content.

Cassava intercropped with peanut, using *Tephrosia candida* as hedgerows, effectively reduced the soil eroded, as well as producing a high yield, harvest index and starch content.

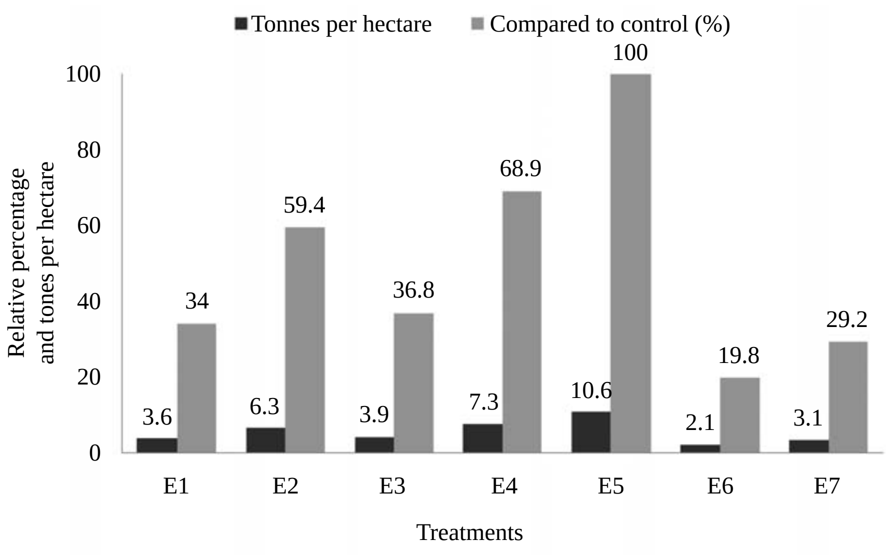

Figure 3 Dry soil eroded under various cassava cropping systems.
E1 = Cassava (C)+peanut (P)+*Paspalum atratum* hedgerows; E2 = C+*Paspalum atratu*m hedgerows; E3 = C+P+*Pennisetum purpureum* hedgerows; E4 = C+*Pennisetum purpureum* hedgerows; E5 = C without hedgerows; E6 = C+P+*Tephrosia candida* hedgerows; E7 = C+*Tephrosia candida* hedgerows.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Training and Research Innovation Grant (TRIG) project and the Hanoi University of Agriculture (HUA) for the Fellowship and also the Department of Agronomy, Faculty of Agriculture, Kasetsart University, Thailand for supporting the research.

LITERATURE CITED

Cock, J.H., D. Wholey and O.G. Casas. 1977. Effects of spacing on cassava. **Exp. Agr.** 13(3): 289–299.

Dang, N.T. 2007. Farmer participatory research (FPR) on soil erosion control and fertilizer use for cassava in Vietnam: 1999–2002, pp. 352–362. *In* R.H. Howeler, (ed). **Proceedings of the 7th Regional Workshop.** 28 October–1 November 2002. Bangkok, Thailand.

Edwards, D.G., C.J. Asher and G.L. Wilson. 1977. Mineral nutrition of cassava and adaption to low fertility conditions. *In* J. Cock, R. Macintyre and M. Graham, (eds.). **4th Symposium of the International Society for Tropical Root Crops.** Cali, Colombia.

Enyi, B.A.C. 1973. Growth rates of three cassava varieties (*Manihot esculenta* Crantz) under varying population densities. **J. Agr. Sci.** 81: 15–28.

Gardner, F.P., R.B. Pearce and R.L. Mitchell. 1985. **Physiology of Crop Plants.** Iowa State University Press, Ames, IA, USA. 327 pp.

Hy, N.H., P.V. Bien, N.T. Dang and T. Phien. 1996. Recent progress in cassava agronomic research in Vietnam, pp. 235–256. *In* R.H. Howeler, (ed.). **Proceedings of the 5th Regional Workshop.** 3–8 November 1996. Hainan, China.

Hy, N.H., N.T. Dang and P.V. Bien. 2000. Cassava agronomy research and adoption of improved practices in Vietnam, pp. 216–227. *In* R.H. Howeler and S.L. Tan, (eds.). **Proceedings of the 6th Regional Workshop.** 21–25 February 2000. Ho Chi Minh City, Vietnam.

Kawano, K. and P.R. Jennings. 1983. Tropical crop breeding – Achievements and challenges, pp. 81–99. *In* W.H. Smith, (ed.). **Symposium on Potential Productivity of Field Crops under Different Environment.** IRRI. Manila, the Philippines.

Kim, H., N.V. Bo, H. Long, N.T. Hien, H. Ceballos and R.H. Howeler. 2008. Current situation of cassava in Vietnam, pp. 100–112. *In* R.H. Howeler, (ed.). **Proceedings of the 8th Regional Workshop.** 20–24 October 2008**.** Vientiane. Lao PDR.

Lebot, V. 2009. **Tropical Root and Tuber Crops: Cassava, Sweet potato, Yams and Aroids.** CAB International. Wallingford, UK. 413 pp.

Leihner, D.E. 1979. Agronomic implications of cassava–legume intercropping systems, pp. 103–112. *In* E. Weber, B. Nestel and M. Campbell, (eds.). **Proceedings of an International Workshop.** 27 November–1 December 1978. Intercropping with Cassava. Trivandrum, India.

_____. 2002. Agronomy and cropping systems, pp. 91–113. *In* R.J. Hillocks, J.M. Thresh and A.C. Bellotti, (eds.). **Cassava, Biology, Production and Utilization.** CAB International. Wallingford, UK.

Lozano, J.C. 1976. **Field Problems in Cassava.** CIAT, Colombia. 205 pp.

Phien, T. and N.C. Vinh. 2007. Soil organic matter management for sustainable cassava production in Vietnam, pp. 234–250. *In* R.H. Howeler, (ed.). **Proceedings of the 7th Regional Workshop.** 28 October–1 November 2002. Bangkok, Thailand.

Sittibusaya, C., C. Tiraporn, A. Tongglum, U. Cenpukdee, V. Vichukit, S. Jantawat and R.H. Howeler. 1993. Recent progress in cassava agronomy research in Thailand, pp. 110–123. *In* R.H. Howeler, (ed.). **Proceedings of the 4th Regional Workshop.** 2–6 November 1993. Cassava Breeding, Agronomy Research and Technology Transfer in Asia. Kerala, India.

Spear, S.N., C.J. Asher and D.G. Edwards. 1978. Response of cassava, sunflower, and maize to potassium concentration in solution. I. Growth and plant potassium concentration. **Field Crop. Res.** 1: 363–373.

Tongglum, A., V. Vichukit, S. Jantawat, C. Sittibusaya, C. Tiraporn, S. Sinthuprama and R.H. Howeler. 1990. Recent progress in cassava agronomy research in Thailand, pp. 199–223. *In* R.H. Howeler, (ed.). **Proceedings of the 3rd Regional Workshop.** 22–27 October 1990. Malang, Indonesia.

Toro, J.C. and C. Atlee. 1980. Agronomic practice for cassava production, pp. 138–152. *In* C.J. Weber, J.C. Toro and M. Graham, (eds.). **Proceedings of a Workshop on Cassava Cultural Practices.** 18–21 March 1980. Salvador, Bahia, Brazil.

Wargiono, J. 1987. Agronomic practices in major cassava growing areas of Indonesia, pp. 183–204. Cassava Breeding and Agronomy Research in Asia. *In* R.H. Howeler and K. Kawano, (eds.). **Proceedings of a Regional Workshop.** 26–28 October 1987. Rayong, Thailand.

Yinong, T., L. Jun, Z. Weite and F. Baiping. 1993. Recent progress in cassava agronomy research in China, pp. 195–216. *In* R.H. Howeler, (ed.). **Proceedings of the 4th Regional Workshop.** 2–6 November 1993. Kerala, India.