SUSTAINABLE CASSAVA PRODUCTION ON SLOPING LANDS IN VIETNAM

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ABSTRACT

Cassava yields in Vietnam are low partially because the crop is grown mainly on sloping land with eroded and nutrient depleted soils, and with little or inappropriate inputs of fertilizers and/or manures. Moreover, many farmers harvest the stems, leaves and even the fallen leaves in addition to the roots, resulting in the removal of large amounts of N, K, Ca and Mg and a rapid depletion of the soil's nutrient supply. Although research has shown that the harvest of cassava roots does not remove more nutrients than the harvest of other crops (with the possible exception of K), when cassava stems and leaves are also removed from the field, nutrient removal, especially that of N, Ca and Mg, more than doubles compared with harvesting only the roots.

When grown on slopes, cassava cultivation can result in serious erosion due to the wide plant spacing used and the crop's slow initial growth. This leads to slow canopy formation, exposing the soil to rainfall splash and erosion. Erosion not only leads to loss of soil, with associated organic matter, nutrients and micro-organisms, but also a preferential loss of clay, organic matter and some nutrients, resulting in empoverishment of the remaining soil. Substantial amounts of nutrients are lost in eroded soil (mainly N and K) and runoff (mainly K).

Calculating the nutrient balance in cassava growing regions in Vietnam from the nutrient off-take in harvested cassava products and the nutrient additions in manure and chemical fertilizers, it was found that the N and K balances were both negative in three of the six regions, while the P balance was negative in one. In most areas farmers do not apply enough K and N, while in some areas they apply too much P, in the form of manure and SSP. These excessive applications of P are not only a waste of resources but may also cause pollution and eutrophication of waterways and lakes down stream.

Soil nutrient depletion can be reduced by returning plant tops and fallen leaves to the soil and by preventing runoff and erosion. Nutrients that are removed should be replaced through application of organic and inorganic fertilizers, or by green manuring, alley cropping, or intercropping, in which case the prunings or intercrop residues are reincorporated into the soil. The latter may lead to modest additions of N, and to recycling of P and K within the system.

Erosion can be prevented by planting cassava mainly on flat lands with high inputs to obtain high yields. When planted on slopes, the crop should be planted with minimum tillage and at rather close plant spacing, or in combination with intercrops like peanut. The use of good quality planting material, vigorous varieties and adequate applications of fertilizers or manures will enhance plant growth and formation of soil cover. Contour ridging, the planting of contour hedgerows, as well as application of straw mulch, will further reduce runoff and erosion.

Farmers are not likely to adopt soil conservation measures unless they are not too expensive or labor intensive in establishment and maintenance, and provide immediate benefits in terms of increased yields or useful products. The development and dissemination of more sustainable production practices can best be done with direct participation of farmers to ensure that the recommended practices are suitable for the local conditions and are acceptable in terms of costs and expected benefits.

INTRODUCTION

In Vietnam cassava (*Manihot esculenta* Crantz) is the fifth most important food crop in terms of area planted, after rice, maize, vegetables and sweetpotato. In 1998

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cassava was harvested in 238,700 ha, with a production of 1.98 million tonnes of fresh roots and a yield of 8.3 t/ha. The latter is among the lowest in Asia (**Table 1**). The low yield of cassava in Vietnam is due to the use of low-yielding varieties (mostly selected for good eating quality), the production of cassava on acid and low-fertility upland soils, and the limited or inappropriate use of manures and fertilizers.

Recently, new high-yielding varieties have been selected in Vietnam from clones introduced from Thailand, as well as from hybrid seed from CIAT/Colombia and Thailand. The release and multiplication of these new varieties has resulted in substantial increases in yield in those limited areas where these new varieties are now widely distributed, especially in the eastern region of South Vietnam. Additional increases in yield or income can be achieved through improved management practices, such as more appropriate nutrient management and erosion control, plant spacing and intercropping. This paper deals mainly with the aspect of nutrient management and erosion control on sloping land, with the objective of increasing yield and/or income for the farmers, while preserving the soil and water resources for future generations.

EFFECT OF CASSAVA ON SOIL PRODUCTIVITY

Of the total land area of 33 million ha in Vietnam, 75% is hilly or mountainous. About 21% of the total land area, or 6.9 million ha, is used for agriculture, of which 5.3 million ha for annual crops, while 42%, or 13.8 million ha, has been abandoned or is left in fallow. Thai Phien and Nguyen Tu Siem (1996), stated that "as a direct consequence of planting upland rice and cassava for food self sufficiency, more than one million ha have become eroded skeleton soils with no value for agriculture or for forestry". Similarly, ISRIC (1997) reports that of the 38.6 million ha of total land area in Vietnam, 8.6 million ha (22%) is suffering from various degrees of water erosion, while 5.0 million ha (13%) from fertility decline. For comparison, in Thailand 15% of the total land area is suffering from moderate levels of water erosion and 50% of light to moderate fertility decline. Thus, there is no doubt that soil erosion and fertility decline are serious problems in both Vietnam and Thailand.

Howeler (1992) estimated that 66% of cassava in Vietnam is grown on Ultisols, 17% on Inceptisols, 7% on Oxisols, 4% on Alfisols and the remaining 6% on Entisols and Vertisols. Most of the Ultisols and Inceptisols are characterized by a light texture, acid

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pH and low levels of organic matter (OM) and nutrients. According to a farm-level survey conducted in 1990/91 of over 1,100 households in 45 districts of all cassava growing regions of Vietnam (Pham Van Bien *et al.*, 1996), 59% of cassava is grown on sandy soils, 3.9% on silty soils, 11.7% on clayey soils and 25.3% on rocky soils. About 45% of cassava is grown on sloping land.

Cong Doan Sat and Deturck (1998) compared the physical and chemical properties of Haplic Acrisols in the eastern region of South Vietnam that had been under forest, rubber, sugarcane, cashew and cassava for many years. They reported that soils that had been under cassava had the lowest clay content, aggregate stability and water retention, as well as the second lowest infiltration rate, and third highest bulk density, indicating a physical degradation of the soil due to continuous cassava production. Moreover, cassava soils had also suffered chemical deterioration, as indicated by low levels of organic C, total N, CEC, and exchangeable K and Mg; available P levels in cassava soils were higher than under forest or cashew, but lower than under rubber or sugarcane, indicating that some source of P had been applied to cassava as well as to rubber and sugarcane (**Table 2**). Nguyen Tu Siem and Thai Phien (1993) reported a similar decline in soil OM, N, Ca and Mg, but no significant decline in available P during two years of cassava cropping, as compared to the original forest in Phu Quy in 1994.

The question remains whether cassava cultivation on these soils is the cause or the result of the physical and chemical degradation, i.e., does cassava cultivation cause soil degradation, or is cassava generally grown on those soils that are already degraded, due to its exceptional ability to still produce something on these soils while other crops would not? **Figure 1** shows that the first year after land clearing both upland rice and cassava produced high yields, but when grown continuously without fertilizer inputs, upland rice yields quickly decreased to zero in the fourth year, while cassava yields also decreased but more slowly, reaching 34% of the original yield in the fourth year. It is well known that cassava has an ability to grow well on poor and acid soils (Cock and Howeler, 1978; Howeler, 1991b). However, like any other crop, cassava absorbs nutrients from the soil and at harvest all or parts of these are removed from the field, resulting in nutrient depletion and fertility decline. In addition, soil/crop management, such as land preparation and weeding, can lead to soil compaction or to soil erosion, which results in soil loss and nutrient losses in eroded sediments and runoff.

A. Nutrient Removal by the Cassava Crop

Data reported in the literature on nutrient absorption and removal by cassava and other crops vary greatly, depending on the fertility of the soil, the yields obtained, and the plant parts removed in the harvest. **Table 3** shows the average removal by cassava roots, both per ha and per tonne of dry matter produced, as compared to that of other crops. Although the cassava yield of 35.7 t/ha of fresh roots is very high, the removal of N and P in those roots was similar or lower than those removed in the harvested products of other crops; when calculated per tonne of DM produced they are much lower than those of most other crops. K removal per ha was higher than for other crops, but K removal per tonne of DM produced was also similar or lower than that of other crops. Thus, it is clear that cassava does not remove more nutrients from the soil than other crops, with a possible exception of K.

Table 4 shows how nutrients are distributed at time of harvest among roots, tops (stems with attached leaves) and fallen leaves. If farmers remove from the field not only the roots but also stems, leaves and fallen leaves, they will remove substantial additional amounts of N, Ca and Mg, since 75% of N, 92% of Ca and 76% of Mg were found in the plant tops and fallen leaves, and only 25%, 8% and 24%, respectively, in the roots. In case of P, about equal parts were found in roots and tops, while for K about 60% was found in the roots and only 40% in tops and fallen leaves. Thus, if only roots are removed, the ratio of N, P, K removed (in terms of N, P_2O_5 and K_2O) is 1.8:1:3.8 or about 2:1:4, while if all plants parts are removed this will be 3.3:1:2.9 or about 3:1:3.

Table 4 indicates that nutrient removal is mainly a function of yield; however, the relationship is not linear since cassava grown at high fertility tends to have higher yields as well as higher nutrient concentrations in the roots than plants grown at low fertility. **Figures 2** and **3** show the relationship between N, P and K removal in the roots and in the whole plant, respectively, and fresh root yield (Howeler, 2001a), while **Table 5** shows the average removal in the roots per ha and per tonne of fresh or dry roots as calculated from many reports in the literature (Howeler, 2001a). These data indicate that if only cassava roots are harvested (as in Thailand) the crop removes mainly N and K and very little P, but when farmers harvest both the roots and the stems and leaves (as in Vietnam), the removal of all three nutrients more than doubles; in that case the removal of Ca and Mg also becomes significant, especially if fallen leaves are collected (**Table 4**). **Figure 2** shows that with an average yield of 15 t roots/ha, and the removal of all plant parts from the field, about 80 kg N, 9 kg P, and 50 kg K, would be removed. The amount of N lost corresponds reasonably well but the P and K losses are considerably lower than those reported by Thai Phien and Nguyen Cong Vinh (1998), i.e. losses of 62-153 kg N, 36-79 kg P and 56-122 kg K/ha.

Table 6 shows the amounts of nutrients applied in organic manures and chemical fertilizers in six agro-ecological regions of Vietnam, calculated from the average amounts of organic and chemical fertilizers used, according to the 1990/91 cassava survey conducted in 45 districts of 20 provinces (Pham Van Bien *et al*., 1996). Nutrient application was quite high in the Red River Delta and the North Central Coast, but very low in the Central Highlands. **Table 7** shows the yields obtained in each region and the nutrients removed in the harvested plant parts according to **Figure 3**, assuming that both roots and plant tops are removed. Without considering nutrient losses in runoff and erosion (see below), or losses due to leaching, volatilization or immobilization, the difference between nutrients applied and those lost in crop removal is the "nutrient balance" shown in **Table 7**. The balance for both N and K was negative in three of the six regions, while that for P was negative in only one region; the P balance was highly positive in the Red River Delta and in the North and South Central Coasts, mainly due to high applications of organic manures and simple superphosphate (SSP). From these rough calculations it is clear that cassava extracts more N and K from the soil than most Vietnamese farmers put back in the form of organic or inorganic fertilizers. This results in N and K depletion of those soils that have been used for a long time for cassava cultivation; the same is true for Mg (**Table 2**). This quickly leads to a reduction in yield (see **Figure 7** below). The opposite tends to occur for P. Cassava extracts relatively small amounts of P in the roots as well as the tops, while farmers in North Vietnam apply rather high doses of P in the form of pig manure and SSP. This is a waste of resources and may lead to P pollution of waterways and lakes. In case of N, the balance is positive in some but negative in other regions. Considering that large amounts of N are usually lost by leaching or volatilization, it is likely that the total balance is negative and that soils also become seriously depleted of N. This, however, can be partly offset by incorporation of residues of leguminous intercrops, such as peanut, or of prunings of hedgerow species, such as *Tephrosia candida*. The P and K in these residues must come from either the soil or from added manures or fertilizers; these should therefore not be considered as an "input" into the system, but merely a recycling of these nutrients within the system. The latter can be of value in case of deep rooted leguminous species, which can bring nutrients from deeper soil horizons back to the surface; it is doubtful that intercrops like peanut or black bean contribute much in this respect. The off-take of dry grain will generally result in a negative rather than a positive contribution to the nutrient status of the soil.

B. Erosion as a Result of Cassava Cultivation

Cassava is oftentimes blamed for causing severe erosion when grown on slopes. There is no doubt that cassava cultivation, like that of all annual food crops, causes more runoff and erosion than leaving the land in forest, in natural pastures or under perennial trees (**Table 8**). This is mainly due to the frequent loosening of soil during land preparation and weeding, as well as due to the lack of canopy and soil cover during the early stages of crop development. The question is whether cultivation of cassava results in more or less soil loss than that of other annual crops.

Compared with other crops cassava establishes a canopy cover only slowly (**Figure 4**), often requiring 3-4 months to reach full canopy cover (Nguyen Tu Siem and Thai Phien, 1993). Moreover, the cassava canopy cover is effective only in protecting the soil from rainfall-induced erosion, but is not effective in reducing runoff-induced erosion, which occurs near the soil surface, and which becomes increasingly important as the slope increases (Rose and Yu, 1998). This may lead to increased erosion. On the other hand, cassava does not need intensive land preparation and a smooth seed bed like many seeded crops, nor does it require more than one land preparation per year, compared with 2-3 times for short-cycle crops like most grain legumes, maize and sorghum. Moreover, once the canopy is established there is no more need for weeding, while the canopy is effective in reducing raindrop impact, and thus erosion.

Comparing erosion caused by several crops grown for four years on 7% slope on a sandy loam soil in Thailand, Putthacharoen *et al*. (1998) reported that erosion losses caused by cassava were 2-3 times higher than those caused by other annual crops, like maize, sorghum, peanut and mungbean, and 2-6 times higher than those caused by perennial crops like sugarcane and pineapple (**Table 9**). Similar trials conducted on 5% slope in Lampung, Indonesia, showed that annual erosion in fertilized cassava was similar to that of two consecutive crops of soybean, slightly higher than two crops of maize or one crop of upland rice followed by soybean, and significantly higher than two consecutive crops of peanut. The system of intercropping cassava with maize and upland rice followed by soybean also produced much less erosion than growing cassava in monoculture (Wargiono *et al*., 1998). In contrast, Howeler (1987) reported that in two erosion control trials at a high elevation in Popayan, Colombia, the cultivation of four consecutive crops of beans (*Phaseolus vulgaris*) caused four times more erosion than one 17-month crop of cassava, due to frequent land preparation and weeding required for beans. Thus, it may be concluded, that in most (but not all) cases cassava cultivation on slopes causes more erosion than that of other crops, mainly due to the wide plant spacing used and the slow initial growth of the crop, resulting in slow canopy development. This effect is exacerbated if there is excessive land preparation and weeding (as in some areas of north Vietnam), poor germination due to low-quality planting material, and slow initial growth due to lack of adequate fertilization.

C. Nutrient Losses in Eroded Sediments and Runoff

When soil particles are dislodged by the impact of raindrops or by the scouring action of overland flow, and move down-slope with runoff, the field not only loses the most fertile part of the soil, i.e. the topsoil, but also associated organic matter, manures, fertilizers and beneficial micro-organisms, such as mycorrhizal fungi. Moreover, clay particles, once dislodged, are quickly carried downslope, resulting in a preferential loss of clay and a lightening of soil texture. This may be the reason why soils used for a long time for cassava cultivation were found to be much lower in clay, organic C and CEC than those used for forest, rubber or cashew (**Table 2**). In addition, applied fertilizer particles can be dislodged and removed, or the water-soluble constituents can be lost with runoff water. In general, it was found that eroded sediments are much higher in nutrients than the soil in the original site. This enrichment is due to preferential losses of organic matter, clay, earthworm castings and plant debris laying on the soil, or by dissolved manures or fertilizer (Rupenthal *et al*., 1997). Thus, erosion does not only reduce the soil depth available for root growth and for uptake of nutrients and water, but it also leaves the remaining soil less fertile, while often exposing highly infertile subsoils. This has a detrimental effect on productivity, as can be seen in **Figure 5**, where cassava yields on eroded soil in Colombia were about half those on nearby non-eroded soil.

Little quantitative information is available on actual nutrient losses in sediments and runoff. **Table 10** shows data for two years of upland rice production on slopes of 25-35% near Luang Prabang, Laos, comparing the normal farmer's practice with an improved practice of growing rice in 5 m wide alleys between 1 m wide strips of double rows of vetiver grass (*Vetiveria zizanioides*) and mango trees. The latter practice markedly reduced runoff and erosion, especially in the second year after establishment. K losses were particularly high in both runoff and erosion during the first year of cropping, but decreased markedly in eroded soil in the second year, especially with alley cropping. N and P losses were always higher in the sediment than in runoff, but K losses were sometimes higher in the runoff. During two years of upland rice production using the farmer's practice, 74 kg N, 12 kg P and 101 kg K/ha were lost in eroded sediments and runoff; for the alley cropping treatment this was reduced to 20 kg N, 3 kg P and 48 kg K/ha. Thus, substantial amounts of nutrients, especially K, were lost in both eroded soil and runoff water.

Table 11 shows nutrient losses in eroded sediments from cassava plots with different treatments in Thailand and Colombia. The losses of P, K, Ca and Mg are in terms of available and exchangeable nutrients rather than total nutrients and are therefore much lower than those reported in **Table 10**. Nutrient losses in Colombia were much lower than in Thailand, because of lower erosion losses. Nevertheless, Ruppenthal *et al*. (1997) reported that in both Quilichao and Mondomo the sediments were enriched with Ca, Mg, K, P and sand compared with the original soil, with average enrichment ratios of 1.30, 1.08, 1.13, 1.11 and 1.16, respectively, while there was little enrichment of OM and N, and a slight empoverishment of silt and clay. The same authors reported that in cassava plots in Quilichao and Mondomo, on average 35% of lost P, 15% of K and 37% of Mg were found in the sediments and the remainder in the runoff. Thus, a considerable amount of nutrients were lost in runoff, especially K. This not only results in a serious loss of nutrients from the field, reducing soil productivity, but may also result in nutrient pollution and eutrophication of waterways and lakes downstream.

CROP/SOIL MANAGEMENT PRACTICES TO MAINTAIN OR IMPROVE SOIL PRODUCTIVITY

To maintain or improve the productivity of soils used for cassava cultivation, it is necessary to reduce nutrient losses by crop removal and erosion, and prevent physical deterioration through excessive land preparation (especially with heavy machinery), and loss of clay and organic matter through erosion. In addition, the nutrients and organic matter lost should be replaced by application of fertilizer or manures, or by incorporation of green manures or intercrop residues.

A. Fertility Maintenance

The decline in soil fertility due to cassava cultivation can be partially prevented by re-incorporation into the soil of all above-ground parts of the cassava plant, such as stems, leaves and fallen leaves, removing from the field only the roots. Long-term NPK trials conducted on a very poor soil in Khon Kaen, Thailand (Tongglum *et al.*, 2001) show that without fertilizer application but with incorporation of plant tops, yields of about 12 t/ha could be maintained during more than 20 years of continuous cropping, while yields decreased to 5-7 t/ha when plant tops were also removed from the field.

1. Chemical fertilizers

Nutrients removed in harvested products, in runoff and eroded sediments can be replaced by application of chemical fertilizers. Moreover, although cassava can grow on poor soils, the crop is highly responsive to fertilizer applications (FAO, 1980). While in most cases there is a yield response only to the application of N, P and K, in some cases, especially if plant tops are also removed, there may also be a yield response to the secondary (Ca, Mg, S) and micro-nutrients (especially Zn). Thai Phien and Nguyen Cong Vinh (1998) reported that during three consecutive cassava plantings on a shale-derived soil in north Vietnam, yields declined to less than 10 t/ha in the 2^{nd} and 3^{rd} cropping when no fertilizers were applied, but increased to over 20 t/ha when NPK fertilizers high in K were applied (**Figure 6**).

Numerous long-term fertility trials conducted in 11 locations in Asia (**Table 12**) indicate that after 4-10 years of continuous cassava cultivation, there were significant responses to application of N in 8, to K in 7 and to P in 4 of 11 locations. Thus, in most cassava growing soils in Asia, there is mainly a response to application of N and K, and only in a few areas is there also a response to P.

Figure 7 shows that after ten years of continuous cassava cultivation without fertilizer application at Thai Nguyen University in Thai Nguyen, north Vietnam, the yields of two varieties had decreased to only about 3 t/ha, while with adequate fertilization yields of 25 t/ha could be obtained. Application of K in the presence of N and P, increased the yields of KM 60 from about 2.7 to 26.2 t/ha. The response to N was also highly significant while that to P was significant only for the local variety Vinh Phu. **Figure 8** shows the trend in nutrient responses over the years. The marked yield decline during the first five years even in the presence of fertilizers, is mainly due to increasingly acute Mg deficiency. When Mg was uniformly applied as $MgSO_4.H_2O$ to all plots before the 6^{th} cropping cycle, yields increased again. During the first year there were already highly significant responses to K, N and P; the response to N and K increased during the first five years, while that to P remained nearly constant, increasing yields by about 20-30%. Soil exchangeable K remained far below the critical level even with annual K applications, while available P, even without P application, remained above the critical level for soil P.

The critical level of available P (Bray II) for cassava is only about 5 ppm, compared with 10-15 ppm for maize, common beans and soybeans (Howeler, 1990; Howeler, 2001b). The lack of a response to P application and the low critical level in the soil is due to a highly effective symbiosis between the fibrous roots of cassava and vesicular-arbuscular (VA) mycorrhizal fungi in the soil. The hyphae of the fungus grow in the root cortex and may extend as far as 1 cm from the root into the surrounding soil. Soluble P in this zone around each root can be absorbed by the fungus and transported via the hyphae into the cassava roots, thus increasing markedly the volume of soil from which the plant can absorb P. Cassava is highly mycotrophic, and without this mycorrhizal symbiosis cassava would not be able to survive and prosper on low-P soils (Howeler *et al*. 1982a, 1982b, 1987; Howeler and Sieverding, 1983; and Sieverding and Howeler, 1985).

Farmer participatory research (FPR) trials conducted in three provinces of north Vietnam during the past six years, also indicate a major response to application of K and N and a minor response (if any) to P. Net income was generally highest with an application ratio of 3:1:3 or 2.5:1:3 of N-P_2O_5-K_2O in the presence of 10 t/ha of farm yard manure (**Table 13**). This fertilizer regime has now been widely adopted by farmers in these three pilot sites of the project.

Since it is impossible to conduct fertilizer trials in all cassava growing regions in Vietnam, it is more practical to determine the need for specific nutrients from the diagnosis of nutrient deficiency symptoms (Asher *et al*, 1980; Lozano *et al*., 1981; and Howeler, 1985 and 1996), as well as from soil and plant tissue analyses (Howeler, 1996; Howeler, 2001b).

In the absence of laboratory facilities, a rough estimate of nutritional requirements can also be obtained from simple trials on farmers' fields using three rows each of the following treatments: $N_0P_0K_0$, $N_0P_1K_1$, $N_1P_0K_1$, $N_1P_1K_0$, and $N_1P_1K_1$, where N_0, P_0, K_0

indicate without N, P or K, and N_1, P_1, K_1 correspond to about 100 kg N, 40 P_2O_5 and 100 K_2O/ha, respectively, using urea, SSP and KCl as the nutrient sources; animal manures should not be applied in these trials. The yields of the center row of each treatment will give an indication of the relative importance of the three nutrients, after which more detailed trials can be conducted to determine the optimum amount(s) of the mosts important nutrient(s).

2. Organic manures

Especially in the Red River Delta and in the northern part of the Central Coast, farmers are accustomed to applying 4-10 t/ha of manure, mostly pig or buffalo manure, to cassava. The nutrient contents of these manures are seldom known and are highly variable (Howeler, 2001a). **Table 14** shows that on average chicken manure is relatively high in N, K, Ca and Mg, while pig manure is relatively high in P. Wood ash, water hyacinth and rice husks are all good sources of K, while wood ash is also very high in Ca and Mg.

Results from the cassava survey conducted in Vietnam in 1990/91 (Pham Van Bien *et* al, 1996) indicate that for the whole of Vietnam these manures may account for about 65% of N and K and 92% of all P applied to cassava. Manures are thus a major and indispensable source of nutrients for cassava, while also contributing organic matter and improving the physical conditions of the soil. These manure applications are particularly important when farmers remove all plant parts from the field, as they help restore soil organic matter and supply secondary and micronutrients. Still, **Table 13** indicates that the farmers' practice of high applications of FYM without N, P and K as chemical fertilizers did not result in maximum yields or profits. Highest yields and net income are probably obtained with modest (5-6 t/ha) applications of manure combined with about 60 kg N and 120 K_2O/ha, either without or with 30-60 kg P_2O_5/ha. Applications of Mg as fused Mg-phosphate are probably necessary in case no FYM is applied at all.

3. Green manures and alley cropping

Few experiments have been conducted in Vietnam to determine the effectiveness of planting and then incorporating a crop of green manure before planting cassava. In north Vietnam where farm size is small, few farmers will want to plant a non-productive crop for the sole purpose of improving soil fertility. However, in remote areas where land is abundant but fertilizers or manures are not available, this may be an attractive option. Moreover, the green manure may help to smother out *Imperata cylindrica* grass.

Experiments with various green manure species conducted in Thailand showed that incorporation of *Crotalaria juncea, Canavalia ensiformis, Mucuna* sp and pigeon pea (*Cajanus cajan*) increased cassava yields when no fertilizers were applied, but had no significant effect on yield in the presence of fertilizers (Howeler *et al*., 2001b). Similar results were obtained in Colombia (Howeler *et al*., 2001a). *Crotalaria juncea* was found to be the most effective specie in soils with pH>6.0, but in more acid soils *Canavalia ensiformis, Mucuna* and pigeon pea were more effective. In northern Thailand the use of rice bean (*Vigna umbellata*) was preferred by farmers because it provides good soil cover and the beans can be sold in the market (Pelletier, 1994).

Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. It is used to control erosion as well as to improve soil fertility when the prunings of the hedgerows are mulched or incorporated. Thai Phien *et al*. (1994) reported that *Tephrosia* hedgerows produced on average 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil, which may contribute 10-20 kg N/ha. This compares with 1.5-2.0 t/ha of dry residues of intercropped black bean supplying 35-40 kg N/ha, or 4-5 t/ha of dry residues of intercropped peanut supplying 50-70 kg N/ha. Only part of this N is added to the system through biological N fixation by the legumes.

4. Intercropping

Trials conducted for four years in Hung Loc Center in Dong Nai, south Vietnam, indicate that intercropping cassava with grain legumes, such as mungbean, soybean, cowpea, peanut, winged bean (*Psophocarpus tetragonolobus*) and sword bean (*Canavalia ensiformis*) decreased cassava yields about 10-20%, and that planting cassava in single rows at 1.0x1.0 m produced higher yields than planting in double rows. Intercropping with maize also reduced cassava yields about 20-25%. Profits were highest for cassava monoculture or intercropped with peanut (Nguyen Huu Hy *et al*., 1995).

Table 15 indicates that when cassava was grown on 9-12% slope in Tam Dao, Vinh Phu, intercropping with peanut and planting hedgerows of *Tephrosia candida*, reduced soil losses and runoff, especially when managed with high inputs of fertilizers. Intercropping and hedgerows reduced cassava yields, but the additional income from the peanut more than compensated for the lower income from cassava. Intercropping with peanut generally produced higher net income for the farmer than intercropping with other crops or monocropping (**Table 16)** (Le Sy Loi, 2000).

B. Erosion Control

Numerous erosion control trials conducted in both north and south Vietnam have shown that runoff and erosion losses can be markedly reduced by intercropping and planting of contour hedgerows (**Table 15)**. Intercropping with peanut was generally more effective in reducing erosion than intercropping with other crops (**Table 16**), due to the rapid formation of soil cover. Contour ridging and no- or reduced-tillage were also effective in reducing erosion, while adequate fertilization also helped to reduce erosion (Nguyen The Dang *et al.*, 1998). However, contour ridging, fertilization and intercropping require more work and usually imply higher production costs. Hedgerows also require more work in establishment and maintenance and may reduce yields by occupying 10-20% of the land. Thus, farmers have to consider the trade-off between immediate costs and benefits *versus* long-term benefits of less erosion and improved fertility.

TRANSFER OF TECHNOLOGIES

While many management practices to control erosion have been recommended by researchers and extension agents, few of these practices have actually been adopted by farmers. This is mainly because most of the recommended practices require either additional labor or money, and benefits are usually accrued over the long-term, while most poor cassava farmers are in desperate need of immediate income to feed their families.

Figure 9 shows the results of a modeling exercise to predict the long-term effect of planting contour hedgerows in a relatively eroded soil in the Philippines on the long-term yield of maize and on net present value (NPV). In this example the model predicts that when maize is grown in open fields without hedgerows, yields will decline markedly during the first years. With hedgerows yields will be lower initially, as hedgerows occupy space in the field, but maize yields with hedgerows will overtake those without hedgerows after two years and remain fairly constant at 2-3 t/ha for the next 25 years. **Figure 9B** indicates that the NPV for planting maize without hedgerows was higher than planting with hedgerows for the first five years. The NPV for the first two years was very low due to the high initial costs of establishing the hedgerows, the costs of maintenance and the lower maize yields obtained. Thus, the farmer will not receive economic benefits from planting hedgerows until after about five years. It is only after 10-15 years that farmers will reap substantial economic benefits from these soil erosion practices. But that is too long for most farmers with a short planning horizon, or with immediate needs for adequate income. This example shows the main dilemma in promoting soil conservation practices: most recommended practices were selected by researchers because they are effective in controlling erosion, but few consider whether poor farmers can actually bear the economic burden of adopting these practices. If they can not, governments may have to provide some incentives, since part of the benefits of better erosion control are reaped off-site by people living downstream or in the cities.

Another problem in the transfer of soil conservation technologies is that many soil erosion control trials were conducted on experiment stations under optimum and uniform conditions. These conditions seldom correspond with those faced by farmers living in mountainous areas with heterogeneous soils, topography and climates, and with economic opportunities that vary markedly from place to place depending on distance to roads and markets. Many practices that seemed very effective in controlling erosion, and may have economic benefits under the conditions of the experiment station, may be rejected by farmers simply because they are not effective or not appropriate under the farmer's specific biophysical or socio-economic conditions. For that reason it is more effective to present farmers with a range of options, from which they can select those that they consider useful, and let them try out some of these options on their own fields; this way farmers can observe and decide which is the most effective and useful practice for their own conditions. This farmer participatory research (FPR) methodology is particularly useful for developing and disseminating technologies like erosion control practices, that are highly site-specific and where there are many trade-offs between costs and benefits. Only farmers themselves can decide about the costs they can bear and the risks they can take now in order to obtain benefits sometime in the future.

Farmer participatory research has been conducted in three pilot sites in north Vietnam from 1995 to 1998 (Nguyen The Dang *et al.*, 1998), and has now expanded to about 20 sites in north, central and south Vietnam in 2001. **Table 17** shows an example of a FPR erosion control trial conducted by six farmers having adjacent plots on a uniform slope of 35-45%. During the third year of cropping, some erosion control practices, such as intercropping with peanut, application of fertilizers and contour hedgerows of vetiver grass or *Tephrosia candida*, reduced soil loss to about one third, while doubling gross and net income. These were the practices most farmers selected as most useful for their particular conditions. Farmers selected a combination of practices, like new varieties, better fertilization, intercropping etc. that increased income, in combination with contour hedgerows that mainly reduced erosion, so as to obtain both short-term and long-term benefits. **Table 18** indicates the agronomic practices farmers in the three pilot sites have tested, selected and are now adopting in their own fields.

CONCLUSIONS

Research conducted on experiment stations, on farmers' fields and with direct participation with farmers have shown that:

1. Cassava does not extract more nutrients from the soil than other crops, except when yields are very high and/or all plant parts are removed from the field.
2. When only roots are harvested, nutrients are removed in the ratio (in terms of $N-P_2O_5-K_2O$) of 2:1:4; when all plant parts including fallen leaves are harvested, nutrients are removed in the ratio of 3:1:3. In the latter case, large amounts of Ca and Mg are also removed.
3. Cultivation of cassava on slopes may cause more severe erosion than that of other annual crops due to its wide plant spacing and slow initial growth. It may cause less erosion than short-cycle crops (vegetables, beans) that are planted 2-3 times per year, and which require frequent land preparation and weeding.
4. Nutrient removal in eroded soil and runoff water can be substantial, especially K in runoff and sediments, and N in sediments, but nutrient losses from erosion are generally lower than those due to crop removal.
5. Soil nutrient depletion and exhaustion can be prevented by application of adequate amounts of chemical fertilizers, organic manures or compost, or by incorporation of cassava plant tops, green manures, intercrop residues or prunings of hedgerows.
6. Maintaining high soil fertility increases plant growth (and yield); the more rapid canopy development in turn protects the soil from rainfall splash and reduces erosion.
7. In most cassava soils in Asia, the crop responds mainly to application of K and N; only in a few locations the crop responds to application of P. In general, nutrients should be applied in a ratio of 2:1:2 or 3:1:3 of $N-P_2O_5-K_2O$.
8. Organic manures are useful sources of secondary and micro-nutrients; they contribute organic matter and improve soil physical conditions. For cassava, organic manures should be applied together with chemical fertilizers high in N and K.

9. Erosion in cassava fields can be prevented by growing cassava mainly in flat areas with high inputs; when grown on slopes, erosion can be reduced by minimum tillage, adequate fertilization, intercropping, vigorous varieties, mulching, contour ridging or planting contour barriers of grasses (vetiver) or leguminous shrubs (*Tephrosia candida*).
10. Farmers will adopt soil conserving production practices only if those practices are not too costly or labor intensive in establishment and maintenance, they are effective in reducing erosion, produce additional income and fit well into the current production practices.
11. Research and extension institutions, NGO's, the private sector and farmers must work together to develop and adopt suitable technologies, improve marketing channels etc. There must also be greater community involvement in the management and conservation of natural resources.

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Table 1. Cassava harvested area, production and yield in Asian countries in 2000.

Country	Area harvested ('000 ha)	Production ('000 t)	Yield (t/ha)
Cambodia	7.0	67	9.64
China	235.0	3,751	15.96
India	250.0	6,000	24.00
Indonesia	1,205.3	15,422	12.79
Laos	5.2	71	13.65
Malaysia	39.0	400	10.26
Myanmar	7.7	88	11.39
Philippines	210.0	1,787	8.51
Sri Lanka	29.5	260	8.82
Thailand	1,135.4	18.509	16.30
Vietnam	226.8	1,807	7.97
Total Asia	**3,351.1**	**48,163**	**14.37**

Source: *FAOSTAT, 2001.*

Table 2. Chemical properties of various horizons of Haplic Acrisols that have been under different land use in southeastern Vietnam.

	Forest	Rubber	Sugarcane	Cashew	Cassava	CV (%)
Organic C (%)	1.032 a	0.839 ab	0.796 ab	0.579 ab	0.496 b	44.7
Total N (%)	0.058 a	0.054 ab	0.040 abc	0.032 bc	0.022 c	36.7
Available P (Bray II)(ppm)						
-1st horizon	5.21 b	20.90 a	20.68 a	4.85 b	15.33 ab	37.5
-2nd horizon	2.48 b	7.03 a	7.92 a	3.19 b	5.31 ab	32.6
-3rd horizon	1.57 b	2.83 ab	3.82 a	1.08 ab	3.82 a	44.6
CEC (me/100g)	3.43 a	2.94 a	3.24 a	2.39 ab	1.53 b	27.1
Exch. K (me/100g)						
-1st horizon	0.132 a	0.127 a	0.051 b	0.070 ab	0.060 b	66.3
-2nd horizon	0.073 a	0.046 ab	0.022 b	0.031 ab	0.021 b	75.1
Exch. Mg (me/100g)	0.145 a	0.157 a	0.055 ab	0.046 ab	0.036 b	89.1

Values are average of 6-10 profiles per cropping system. Within rows data followed by the same letter are not significantly different at 5% level by Tukey's Studentized Range Test.
Source: *Cong Doan Sat and Deturck, 1998.*

Table 3. Average nutrient removal by cassava and various other crops, expressed in both kg/ha and kg/t harvested product, as reported in the literature.

	Yield (t/ha)		(kg/ha)			(kg/t DM produced)		
Crop/plant part	fresh	dry[1)]	N	P	K	N	P	K
Cassava/fresh roots	35.7	13.53	55	13.2	112	4.5	0.83	6.6
Sweet potato/fresh roots	25.2	5.05	61	13.3	97	12.0	2.63	19.2
Maize/dry grain	6.5	5.56	96	17.4	26	17.3	3.13	4.7
Rice/dry grain	4.6	3.97	60	7.5	13	17.1	2.40	4.1
Wheat/dry grain	2.7	2.32	56	12.0	13	24.1	5.17	5.6
Sorghum/dry grain	3.6	3.10	134	29.0	29	43.3	9.40	9.4
Beans[2)]/dry grain	1.1	0.94	37	3.6	22	39.6	3.83	23.4
Soya/dry grain	1.0	0.86	60	15.3	67	69.8	17.79	77.9
Groundnut/dry pod	1.5	1.29	105	6.5	35	81.4	5.04	27.1
Sugarcane/fresh cane	75.2	19.55	43	20.2	96	2.3	0.91	4.4
Tobacco/dry leaves	2.5	2.10	52	6.1	105	24.8	2.90	50.0

[1)]Assuming cassava to have 38% DM, grain 86%, sweet potato 20%, sugarcane 26%, dry tobacco leaves 84%.
[2)]*Phaseolus vulgaris*
Source: Howeler, 1991a.

Table 4. Dry matter and nutrient distribution in 12-month-old cassava cv. M Ven 77, grown with and without fertilization in Carimagua, Colombia.

	(t ha^{-1})	kg ha^{-1}										
	DM	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Unfertilized												
-Top	5.11	69.1	7.4	33.6	37.4	16.2	8.2	0.07	0.03	0.45	0.33	0.26
-Roots	10.75	30.3	7.5	54.9	5.4	6.5	3.3	0.08	0.02	0.38	0.02	0.10
-Fallen leaves	1.55	23.7	1.5	4.0	24.7	4.0	2.5	0.04	0.01	-	0.37	0.18
Total	**17.41**	**123.1**	**16.4**	**92.5**	**67.5**	**26.7**	**14.0**	**0.19**	**0.06**	**-**	**0.72**	**0.54**
Fertilized												
-Tops	6.91	99.9	11.7	74.3	55.0	15.3	9.6	0.08	0.03	0.78	0.57	0.30
-Roots	13.97	67.3	16.8	102.1	15.5	8.4	7.0	0.07	0.03	0.90	0.06	0.17
-Fallen leaves	1.86	30.5	2.0	7.1	31.9	4.7	2.6	0.05	0.02	-	0.46	0.19
Total	**22.74**	**197.7**	**30.5**	**183.5**	**102.4**	**28.4**	**19.3**	**0.20**	**0.08**	**-**	**1.09**	**0.66**

Source: *Howeler, 1985a.*

Table 5. Average fresh and dry root yield, as well as the amount of nutrients removed when cassava roots or the whole plant is harvested based on data from the literature[1).]

Plant part	Yield (t ha^{-1}) fresh	dry	Nutrient removal	N	P	K	Ca	Mg
Roots	28.87	11.43	kg ha^{-1}	67.1	11.2	88.1	13.5	7.9
Whole plant		18.99		179.5	22.7	156.1	81.8	25.8
Roots	28.87	11.43	kg t^{-1} fresh roots	2.32	0.39	3.05	0.47	0.27
Whole plant		18.99		6.22	0.79	5.41	2.83	0.89
Roots	28.87	11.43	kg t^{-1} dry roots	5.87	0.98	7.71	1.18	0.69
Whole plant		18.99		15.70	1.99	13.66	7.16	2.26

[1)]Data are average of 15 data sets which have yields reported in dry weight.
***Sourc**e: Howeler, 2001b.*

Table 6. Nutrient application for cassava production in various regions of Vietnam according to farm level surveys of 1, 117 households in 20 provinces in 1990/91.

	Organic	Chemical (kg/ha)					N applied[1] (kg/ha)					P[2] applied (kg/ha)				K[2] applied (kg/ha)			
	(kg/ha)	Urea	SA	SSP	KCl	NPK	Organic	Urea	SA	NPK	Total	Organic	SSP	NPK	Total	Organic	KCl	NPK	Total
Total Vietnam	**3,400**	**27**	**19**	**30**	**24**	**3**	**31.3**	**12.1**	**3.9**	**0.4**	**47.7**	**28.9**	**2.2**	**0.2**	**31.3**	**22.8**	**12.0**	**0.4**	**35.2**
North Vietnam	*4,426*	*21*	*0*	*61*	*35*	*0*	*40.7*	*9.4*	*0*	*0*	*50.1*	*37.6*	*4.5*	*0*	*42.1*	*29.7*	*17.5*	*0*	*47.2*
-North Mountainous Region	2,389	15	0	37	15	0	22.0	6.7	0	0	28.7	20.3	2.7	0	23.0	16.0	7.5	0	23.5
-Red River Delta	7,452	40	0	79	93	0	68.6	18.0	0	0	86.6	63.3	5.8	0	69.1	49.9	46.5	0	96.4
-North Central Coast.	7,288	22	0	112	36	0	67.0	9.9	0	0	76.9	61.9	8.3	0	70.2	48.8	18.0	0	66.8
South Vietnam	*2,543*	*31*	*36*	*4*	*15*	*5*	*23.4*	*13.9*	*7.4*	*0.7*	*45.4*	*21.6*	*0.3*	*0.3*	*22.2*	*17.0*	*7.5*	*0.6*	*25.1*
-South Central Coast.	4,690	33	55	2	20	1	43.1	14.8	11.3	0.1	69.3	39.8	0.1	0.1	40.0	31.4	10.0	0.1	41.5
-Central Highlands.	172	8	0	0	0	0	1.6	3.6	0	0	5.2	1.4	0	0	1.4	1.2	0	0	1.2
-Southeastern Region	850	40	27	9	16	14	7.8	18.0	5.5	2.1	33.4	7.2	0.7	0.9	8.8	5.7	8.0	1.8	15.5

[1]Assuming urea to contain 45% N, ammonium sulfate 20.5% N, NPK 15% each of N, P_2O_5 and K_2O, SSP 17% P_2O_5 and KCl 60% K_2O, and that "organic" refers to wet pig manure, which may have a composition (wet weight basis) of: 50% moisture, 0.92% N , 0.85% P and 0.67% K

[2]P and K in elemental form.

Source: *adapted from Pham Van Bien et al., 1996.*

Table 7. Nutrient balance as a result of nutrient removal and application in the production of cassava in various regions of Vietnam in 1991/92.

	Cassava root yield ($t\ ha^{-1}$)	Nutrient removal ($kg\ ha^{-1}$)[1]			Nutrients applied ($kg\ ha^{-1}$)[2]			Nutrient balance ($kg\ ha^{-1}$)[3]		
		N	P[4]	K[4]	N	P[4]	K[4]	N	P[4]	K[4]
Total Vietnam	**12.36**	**62**	**7.0**	**40**	**48**	**31.3**	**35**	**-14**	**24.3**	**-5**
North Vietnam	*14.54*	*80*	*8.8*	*49*	*50*	*42.1*	*47*	*-30*	*33.3*	*-2*
-North Mountainous Region	16.26	85	10.0	51	29	23.0	23	-56	13.0	-28
-Red River Delta	11.47	58	6.5	39	87	69.1	96	29	62.6	57
-North Central Coast	12.45	65	7.1	41	77	70.2	67	12	63.1	26
South Vietnam	*10.61*	*57*	*6.0*	*36*	*45*	*22.2*	*25*	*-12*	*16.2*	*-11*
-South Central Coast	9.95	48	5.2	32	69	40.0	41	21	34.8	9
-Central Highlands	8.54	43	4.8	29	5	1.4	1	-38	-3.4	-28
-Southeastern Region	12.37	63	7.0	40	33	8.8	15	-30	1.8	-25

[1] Assuming all plant parts are removed from the field and nutrient removal is read off the curves presented in Figure 3.
[2] Nutrients applied as organic manures and chemical fertilizers (see Table 11).
[3] Nutrient balance = nutrients applied – nutrients removed in harvested products.
[4] P and K in elemental form.
Source: *Howeler, 2001a.*

Table 8. Amount of soil erosion on sloping land, as influenced by different land use systems in Vietnam.

Land use system	Eroded soil (t/ha/year)
Cassava (monoculture)	145.1
Tea (10 years old)	33.3
Planted pine forest	28.7
Natural grass	12.0

Source: *Nguyen Dinh Kiem, 1989.*

Table 9. Total dry soil loss by erosion (t/ha) due to the cultivation of eight crops during four years on 7% slope with sandy loam soil in Sri Racha, Thailand from 1989 to 1993.

	No. of crop cycles	First period (22 months)	Second period (28 months)	Total (50 months)
Cassava for root production	4	142.8 a	168.5 a	311.3
Cassava for forage production	2	68.8 b	138.5 ab	207.3
Maize	5	28.5 d	35.5 cd	64.0
Sorghum	5	42.9 c	46.1 cd	89.0
Peanut	5	37.6 cd	36.2 cd	73.8
Mungbean	6	70.9 b	55.3 cd	126.2
Pineapple[1)]	2	31.4 cd	21.3 d	52.7
Sugarcane[1)]	2	-	94.0 bc	-
F-test		**	**	
cv (%)		11.4	42.7	

[1)]second cycle is ratoon crop; sugarcane only during second 28-month period
Source: *Putthacharoen et al., 1998.*

Table 10. Effect of soil/crop management on runoff and soil loss by erosion, as well as the nutrients lost in runoff and eroded sediments during two years of cropping upland rice in Luang Prabang, Laos in 1994 and 1995.

	Farmer's practice		Alley cropping[1)]	
	1994	1995	1994	1995
Runoff (m^3 ha^{-1})	**1,475**	**2,119**	**1,296**	**765**
Nutrients lost in runoff (kg ha^{-1}):				
N	0.71	2.35	0.49	0.71
P	0.084	0.85	0.085	0.33
K	7.87	26.12	6.69	7.89
Dry soil loss (t ha^{-1})	**4.88**	**9.21**	**3.56**	**1.76**
Nutrients[2)]lost in eroded soil (kg ha^{-1}):				
N	17.09	53.92	11.61	7.61
P	1.94	9.28	1.32	1.50
K	43.54	23.96	31.19	2.66

[1)]using vetiver grass double hedgerows (1 m width) with mango trees; upland rice in 5 m wide alleys between double hedgerows
[2)]Values correspond to total N, P and K
Source: *Phommasack et al., 1995,1996.*

Table 11. Nutrients in sediments eroded from cassava plots with various treatments in Thailand and Colombia.

Location and treatments	Dry soil loss (t ha^{-1} $year^{-1}$)	kg ha^{-1} $year^{-1}$ N[1)]	P[2)]	K[2)]	Mg[2)]
Cassava on 7% slope in Sri Racha, Thailand[3)]	71.4	37.1	2.18	5.15	5.35
Cassava on 5% slope in Pluak Daeng, Thailand[4)]	53.2	22.3	1.25	3.27	-
Cassava planted on 7-13% slope in Quilichao, Colombia[5)]	5.1	11.5	0.16	0.45	0.45
Cassava with leguminous cover crops in Quilichao, Colombia[5)]	10.6	24.0	0.24	0.97	0.81
Cassava with grass hedgerows in Quilichao, Colombia[5)]	2.7	5.8	0.06	0.22	0.24
Cassava planted on 12-20% slope in Mondomo, Colombia[5)]	5.2	13.3	1.09	0.45	0.36
Cassava with leguminous cover crops in Mondomo, Colombia[5)]	2.7	6.5	0.04	0.24	0.20
Cassava with grass hedgerows in Mondomo, Colombia[5)]	1.5	3.5	0.02	0.13	0.10

[1)]Total N
[2)]Available P, and exchangeable K and Mg
[3)]***Source:*** *Putthacharoen et al., 1998.*
[4)]***Source:*** *Tongglum et al., 2001.*
[5)]***Source:*** *Ruppenthal et al., 1997.*

Table 12. Response of cassava to annual application of N, P or K after several years of continuous cropping in long-term fertility trials conducted in various locations in Asia.

Country-location		Years of cropping	Response to N	Response to P	Response to K
China	-Guangzhou	4	**[1]	**	**
	-Nanning	8	**	**	NS
	-Danzhou	6	**	NS	*
Indonesia	-Umas Jaya	10	NS	NS	NS
	-Malang	8	**	NS	**
	-Lampung	6	**	*	**
	-Yogyakarta	4	NS	NS	NS
Philippines	-Leyte	6	NS	NS	NS
	-Bohol	4	**	NS	**
Vietnam	-Thai Nguyen	8	**	**	**
	-Hung Loc	8	**	NS	**

[1] NS = no significant response
* = significant response ($P<0.05$)
** = highly significant response ($P<0.01$)

***Source:** CIAT, 1998.*

Table 13. Average results of five FPR fertilizer trials conducted by farmers in Kieu Tung village of Thanh Hoa district, Vinh Phu province, Vietnam in 1996.

Treatments	Yield (t/ha) cassava	Gross income[1] (mil. dong/ha)	Fertilizer costs[1] (mil. dong/ha)	Net income (mil. dong/ha)
1. 10 t/ha of FYM	15.93	7.96	1.00	6.96
2. 10 t/ha of FYM; 60N + 60P_2O_5 + 120K_2O	19.34	9.67	2.19	7.48
3. 10 t/ha of FYM; 60N + 60P_2O_5 + 80K_2O	18.67	9.33	2.05	7.28
4. 10 t/ha of FYM; 60N + 40P_2O_5 + 120K_2O	21.89	10.94	2.07	8.87

[1]Prices:
- cassava fresh roots: d 500/kg
- FYM: 100/kg
- Urea (45%N): 3000/kg
- SSP (17%P_2O_5): 1000/kg
- KCl (60%K_2O): 2200/kg

***Source:** Thai Phien et al., 1997.*

Table 14. Average nutrient contents of various manures, composts and wood ash.

Source of manure	% Moisture	(% of dry matter) N	P	K	Ca	Mg	S
Cattle manure	68.2	1.85	0.81	1.69	1.54	0.62	0.29
Pig manure	60.0	2.04	1.38	1.38	-	-	-
Chicken manure	43.0	2.91	1.37	1.54	4.56	0.83	-
Sheep manure	-	3.00	0.62	2.68	1.72	0.86	0.43
Human manure	-	1.20	0.06	0.21	-	-	-
City/rural compost	-	1.16	0.37	0.90	-	-	-
Rice straw compost	73.7	1.07	0.19	0.69	-	-	-
Peanut stems + leaves compost	58.6	0.81	0.10	0.38	-	-	-
Water hyacinth	-	2.00	1.00	2.30	-	-	-
Wood ash	-	-	0.87	4.17	23.2	2.10	0.40

Source: *Howeler, 2001a.*

Table 15. Effect of various cassava-based cropping systems on runoff, soil loss by erosion as well as crop yields and gross income obtained when cassava, cv. Vinh Phu, was planted on 9-12% slope in Tam Dao, Vinh Phu in 1994.

Cropping systems	Runoff (m^3/ha)	Dry soil loss (t/ha)	Cassava yield (t/ha)	Peanut yield (kg/ha)	Gross income[1)] ('000d/ha)
Bare land	14,539	6.9	-	-	-
Cassava monoculture	12,678	6.9	10.8	0	4,860
C+peanut with low input	12,233	6.1	9.1	498	6,585
C+peanut+hedgerows+low input	12,031	4.8	7.6	450	5,670
C+peanut+hedgerows+high input	11,473	2.8	7.9	466	5,885
C+peanut+mixed hedgerows+high input	10,674	3.7	6.9	479	5,500

[1)] Prices: cassava d 450/kg fresh roots
peanut 5000/kg dry pods

Source: *Huynh Duc Nhan et al., 1995*

Table 16. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, as well as on dry soil loss due to erosion when grown on 10% slope at Agro-forestry College of Thai Nguyen Univ., Thai Nguyen, Vietnam in 1997.

Intercropping treatments	Yield (t/ha)		Gross income[1)]	Costs fert. +seed[1)]	Net income	Dry soil loss (t/ha)
	cassava	intercrop	←	(mil. d/ha)	→	
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C + peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C + soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C + mungbean	20.83	0.27	10.49	7.84	2.65	28.61
5. C + black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C + cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

[1)]Prices:

cassava:	d 400/kg fresh roots		
peanut:	5000/kg dry pods	peanut seeds:	d 7000/kg dry pod
soybean:	6000/kg dry grain	soybean seeds:	7000/kg dry grain
mungbean:	8000/kg dry grain	mungbean seeds:	8000/kg dry grain
black bean:	7000/kg dry grain	black bean seeds:	7000/kg dry grain
cuoc bean:	5000/kg dry grain	cuoc bean seeds:	5000/kg dry grain

Source: *Le Sy Loi, 2000.*

Table 17. Effect of various crop management treatments on the yield of cassava and intercropped peanut, as well as the gross and net income and soil loss due to erosion in an FPR erosion control trial conducted by six farmers on about 40% slope in Kieu Tung village of Thanh Ba district, Phu Tho province, Vietnam in 1997.

Treatments[1)]	Dry soil loss (t/ha)	Yield (t/ha)		Gross income[2)]	Production costs	Net income	Farmers' ranking
		cassava	peanut	<------------(mil.dong/ha)------------>			
1. C monoculture, no fertilizers, no hedgerows (TP)	106.1	19.17	-	9.58	3.72	5.86	6
2. Cassava+peanut, no fertilizers, no hedgerows	103.9	13.08	0.70	10.04	5.13	4.91	5
3. C+P, with fertilizers, no hedgerows	64.8	19.23	0.97	14.47	5.95	8.52	-
4. C+P, with fertilizers, *Tephrosia* hedgerows	40.1	14.67	0.85	11.58	5.95	5.63	3
5. C+P, with fertilizers, pineapple hedgerows	32.2	19.39	0.97	14.55	5.95	8.60	2
6. C+P, with fertilizers, vetiver hedgerows	32.0	23.71	0.85	16.10	5.95	10.15	1
7. C monoculture, with fertilizers, *Tephrosia* hedgerows	32.5	23.33	-	11.66	4.54	7.12	4

[1)]Fertilizers=60 N+40 P_2O_5+120 K_2O; all plots received 10 t pig manure/ha
TP=farmer traditional practice

[2)]Prices: cassava: d 500/kg fresh roots
peanut: 5,000/kg dry pods
1US $ = approx. 13,000 dong

Source: *Thai Phien, 1997.*

Table 18. Technology components selected and adopted by participating farmers from their FPR trials conducted from 1994 to 1998 in three pilot sites in north Vietnam.

District Province	Pho Yen Thai Nguyen	Thanh Ba Phu Tho	Luong Son Hoa Binh
Varieties	KM 98-7*** KM 60** KM 95-3*	SM17-17-40** Vinh Phu (TP)** CM 4955-7*	KM 98-7*** KM 95-3** KM 94*
Fertilizer practices	FYM 10 t/ha (TP) +80N+40P_2O_5 +80K_2O**	FYM 10 t/ha (TP) +60N+60P_2O_5 +120K_2O**	FYM 5 t/ha (TP) +40N+40P_2O_5 80K_2O**
Intercropping	Monoculture (TP) C+peanut***	Monoculture (TP) C+peanut***	Monoculture (TP) C+taro (TP) C+peanut***
Soil conservation	*Tephrosia* barriers*** vetiver barriers*	*Tephrosia* barriers*** vetiver barriers* pineapple barriers*	*Tephrosia* barriers*** vetiver barrier* mulch of straw (TP)*

[1)] * = some adoption
** = considerable adoption
*** = widespread adoption
TP = traditional practice; FYM = farm-yard manure

Source: *Howeler (unpublished).*

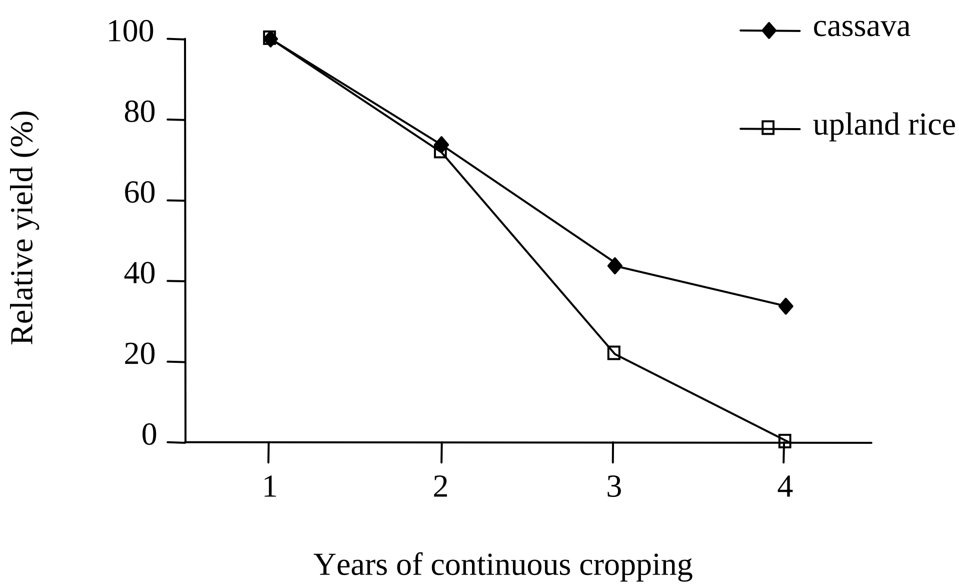

Figure 1. Yield reduction of upland rice and cassava due to fertility decline as a result of continuous cropping without fertilizer application. 100% corresponds to 18.9 t/ha of fresh cassava roots and 2.55 t/ha of rice.
***Source:** adapted from Nguyen Tu Siem, 1992.*

Figure 2. Relation between the N, P and K contents of cassava roots and fresh root yield, as reported in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t ha^{-1}.
Source: *Howeler, 2001 b*

Figure 3. Relation between the amounts of N, P and K in the whole cassava plant at time of harvest and the fresh root yield, as reported in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t ha.$^{-1}$
Source: *Howeler, 2001 b.*

Figure 4. Percent soil cover during establishment of various crops and cropping systems.
Source: *Aina et al., 1979.*

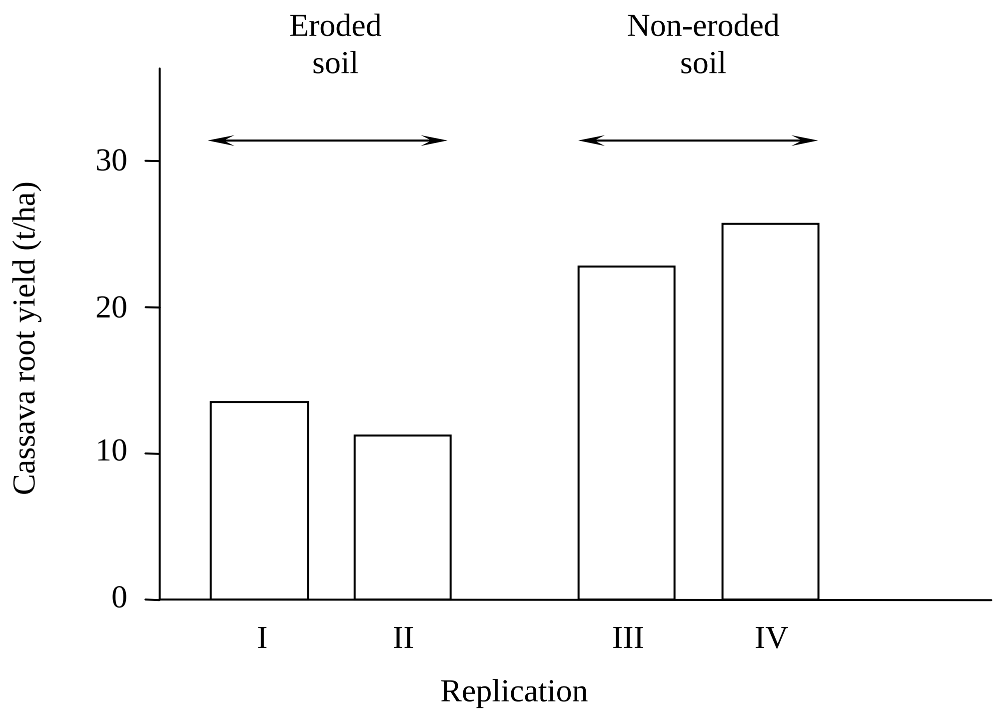

Figure5. The average yield of 18 cassava varieties planted in two replications on an eroded slope and two replications on an adjacent non-eroded flat area in 1983/84 in Mondomo, Cauca, Colombia.
Source: *Howeler, 1986.*

Figure 6. Effect of fertilizer application on cassava yield during three years of continuous cropping on a soil derived from shale in north Vietnam.
Source: *Thai Phien and Nguyen Cong Vinh, 1998.*

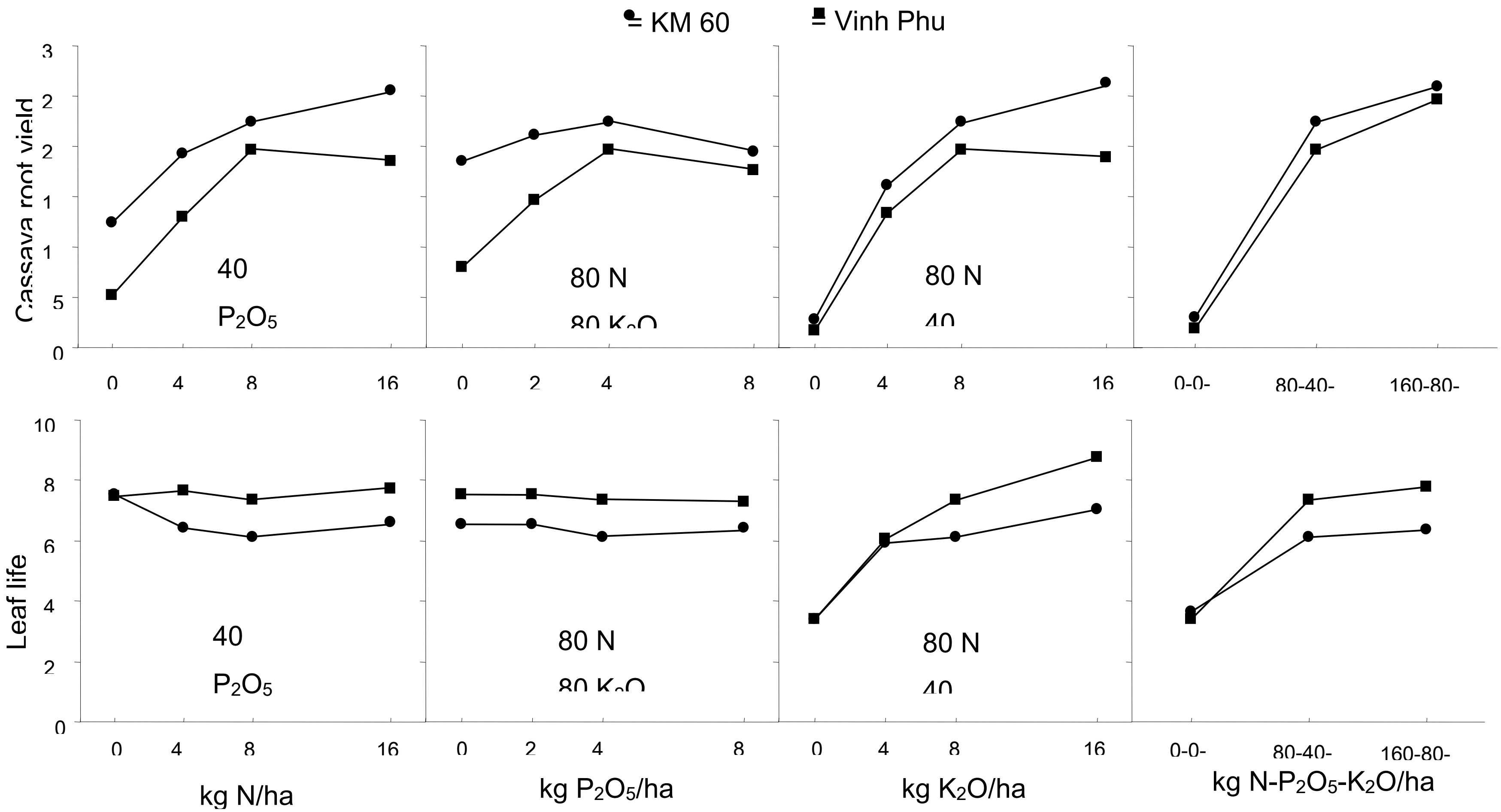

Figure 7. Effect of the annual application of various levels of N, P and K fertilizers on the fresh root yield and on leaf life at 3 MAP of two cassava cultivars grown at Thai Nguyen University, Thai Nguyen, Vietnam, in 1999 (10th year).

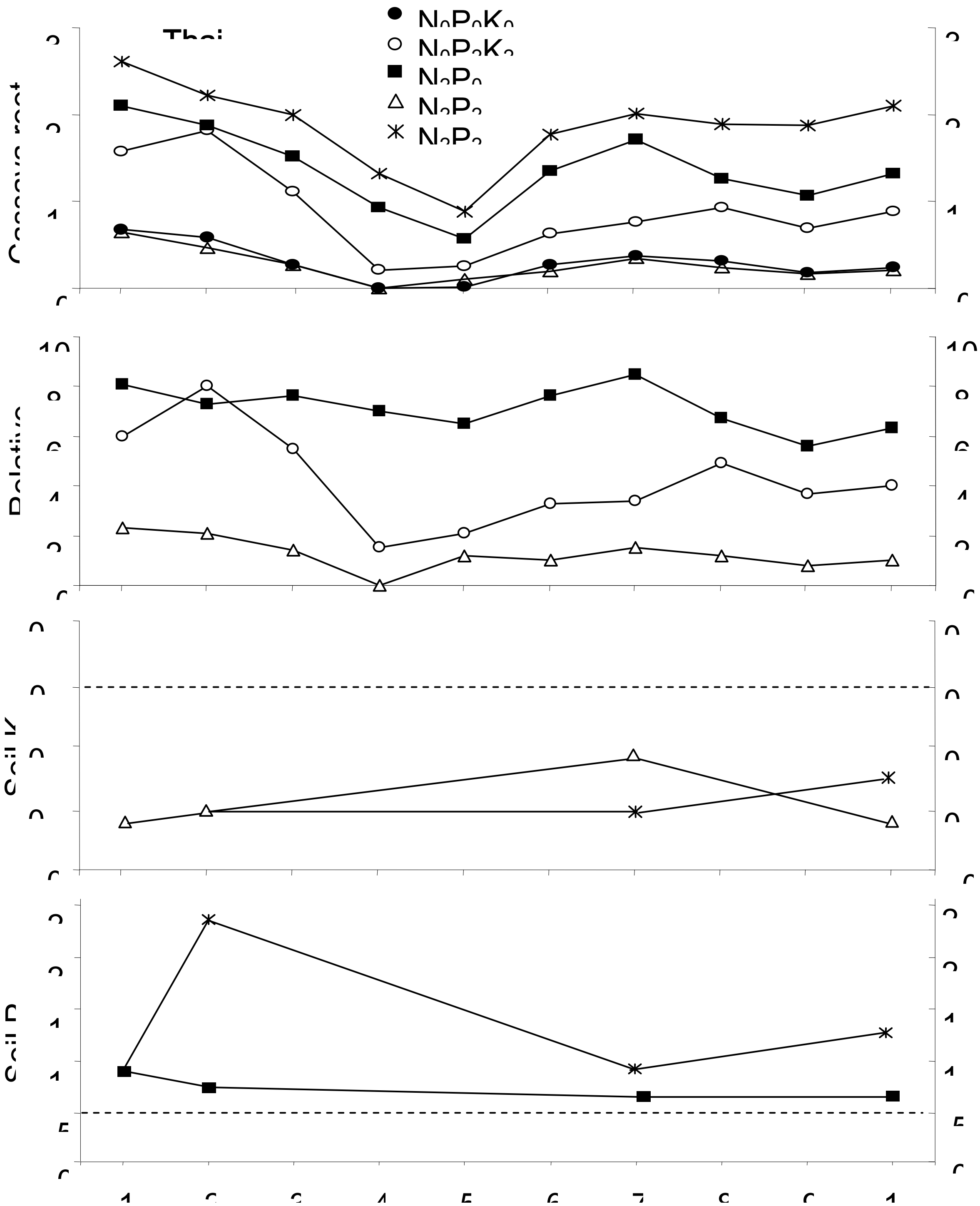

Figure 8. Effect of annual applications of N, P and K on cassava root yield, relative yield (yield without the nutrient over the highest yield with the nutrient) and the exchangeable K and available P (Bray 2) content of the soil during ten years of continuous cropping in Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam Data ar aveaged over two varieties.
Source: *Nguyen Huu Hy et al., 2001.*

Figure 9. The effect of planting maize with and without contour hedgerows in Tranca, Laguna, Philippines. On maize yields (A) and on net present value (B) during 25 years of cropping as predicted by the APSIM model, using a 25% discount rate.
Source: *Aina et al., 1978.*