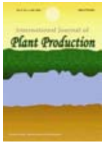

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Nutrient balances for cassava cultivation in Kampong Cham province in Northeast Cambodia

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Abstract

In Cambodia, cassava is mostly grown with little or no fertilizer inputs, but the magnitudes of nutrient balances are not known. This study was conducted to assess nutrient balances for cassava cultivation in Kampong Cham province in Northeast Cambodia. Forty five households in four cassava production zones were interviewed in relation to their cultural practices and crop residue management, upon which sources of nutrient inputs and outputs were based. Chemical fertilizer, manure, planting materials and rainfall were the defined inputs, while cassava roots and stumps were the outputs. Crop cutting was undertaken in the cassava fields of the 45 households to obtain weights of roots and other plant parts. Nutrient balances were calculated for the individual fields based on nutrient contents of the component sources obtained from the literatures. The results showed negative balances for all the nutrients evaluated. The imbalances were most serious for N, K and Ca with the averages of -64.45 kg N, -52.83 kg K and -10.83 kg Ca ha^{-1}, but were less serious for P and Mg with the averages of -2.85 kg P and -7.20 kg Mg ha^{-1}. These negative balances were the consequence of low nutrient inputs in current practices where only a few farmers applied low rates of chemical fertilizer or manure. Continued use of current practices will threaten the sustainability of cassava production in Cambodia. For long term productivity of the crop, the application of organic manures together with lime and chemical fertilizers high in N and K is recommended.

Keywords: Soil nutrients; Agricultural sustainability; Soil fertility management; Cassava fertilization; Long-term productivity.

Introduction

Cassava (*Manihot esculenta* Crantz) is currently the most important upland crop of Cambodia. The crop has been grown in the country for several decades, but prior to the 1970s it was grown in small areas mainly as a food for local consumption. Cassava cultivation is popular among farmers in the Northeast and Eastern Regions of Cambodia, especially by the people who live in upland areas. Some farmers in the lowlands also plant the crop around their homes for domestic consumption (MAFF, 2003). During the period of civil war between 1975 and 1979, cassava played an important role as a food crop, as there was generally insufficient rice production to meet local food needs (Sopheap, 2008). Over the past decade, cassava production in Cambodia has undergone a dramatic change, in response to increases in demand for domestic consumption and for export, and relatively high prices. The area planted to cassava has increased markedly from 15,380 ha in 2000 to 157,000 ha in 2009, with production increasing from 147,763 tons in 2000 to 3,497,000 tons in 2009; crop yields have also shown a significant increase, from an average of 9.61 t ha^{-1} in 2000 to 22.27 t ha^{-1} in 2009 (FAOSTAT, 2011). In terms of total production, cassava has now become the second most important crop in Cambodia, after rice. Its role has also changed from being primarily a food crop to becoming an industrial crop with multiple end-uses, including being an animal feed, a source of starch, a sweetener and processed food, and for ethanol production. The crop has become an important source of cash income for resource-poor farmers of Cambodia (Sopheap, 2008). Market opportunities in Vietnam, Thailand and elsewhere are the major driving force for these changes (Seng et al., 2009).

Most cassava in Cambodia is cultivated with little or no fertilizer inputs (Sopheap, 2008). The current high average cassava yield for Cambodia (22.27 t ha^{-1} in 2009) has come mainly from the expansion of the crop into new production areas where the soils are relatively fertile, coupled with the introduction of high yielding varieties, particularly KM 94 (a variety introduced from Vietnam, which is originally a Thai variety KU 50 and also known locally as *Malay*). In areas where cassava has been grown continuously for many years, crop yields are rather low. It has been well recognized that cassava can extract large amounts of nutrients from the soil and can cause serious soil erosion when grown on sloping land without proper management practices (Howeler, 2001). The amount of nutrients removed from the soil depends on the yield level obtained. For a fresh root yield level of 15 t ha^{-1}, the nutrients removed in the root harvest has been estimated at 30 kg N, 3.5 kg P and 20 kg K ha^{-1} (Howeler, 1981). At the root yield level of 35.7 t ha^{-1}, the nutrients removed were found to be 55 kg N, 13.2 kg P and 112 kg K ha^{-1} (Howeler, 1991). Howeler (2002) reviewed the results of 15 experiments reported in the literature on nutrient removal by cassava roots, with fresh root yields ranging from 6 to 65 t ha^{-1}. He found that the quantities of nutrients removed varied with the yield levels, ranging from 13-162 kg N, 0.9-28.2 kg P and 4-137 kg K ha^{-1}. Thus, like other crops, continuous planting of cassava without fertilization will result in a decline in soil fertility and an associated reduction in crop yields (Howeler, 2000). Nutrient depletion and yield decline have been shown in several areas where cassava has been grown for many years (Chan, 1980; Howeler, 1992; Nguyen, 1992; Sittibusaya, 1993; Howeler, 2000; Tongglum et al., 2001). This can also be expected in new cassava producing areas of Cambodia if the current fertilizer management practices are continued. Thus, sustainability will be an important issue for cassava production in Cambodia in the future.

A quantitative knowledge of the depletion of plant nutrients from soils will help to provide an understanding of the stage of soil degradation, and will help with the development of better soil nutrient management strategies (Roy et al., 2003). Soil nutrient balance, the difference between nutrient inputs to and nutrient outputs off a system (Janssen, 1999), has been used as an indicator of soil quality changes in agricultural systems (Bindraban et al., 2000). A positive balance (inputs > outputs), sometimes designated as a nutrient surplus or excess, points to enrichment, while a negative balance (inputs < outputs), sometimes designated as deficit, points to depletion of the system (Stoorvogel and Smaling, 1990). Nutrient balance analysis has been used as a tool for assessing the sustainability of land use systems (Patanothai, 1998; Smaling et al., 1999). Nutrient balances can serve as indicators for the magnitude of losses of nutrients, and help to identify the causes of such losses (Phong et al., 2010). A number of studies on nutrient balances have been conducted in different countries around the world, including Africa and Europe (Smaling et al., 1999; Janssen, 1999; Oenema and Heinen, 1999), Asia (Patanothai, 1998; Vien, 1998; Manaligod and Cuevas, 1998; Polthanee et al., 1998) and America (Jordan, 1985). These studies have provided useful information, not only for the improvement of the soil fertility management, but also for determining the most appropriate management strategies for different soil types and land use systems in those countries.

It has been well recognized that different production systems may bring about different forms of nutrient imbalance, which can potentially result in different types of problems (Stoorvogel and Smaling, 1990). In high input agricultural systems such as in Europe, nutrient balances are often positive, leading to pollution of ground and surface water. On the contrary, in low input agricultural systems such as those found in many African countries, the nutrient balances are generally negative, resulting in the depletion of soil nutrient stocks and seriously threatening future agricultural production (Stoorvogel and Smaling, 1990). Studies in Sub-Saharan Africa have revealed alarming rates of nutrient depletion (Stoorvogel, 2007). Negative nutrient balances have been found in several crop production systems in Southeast Asia (Patanothai, 1998). For cassava cultivation, Howeler (2001) has undertaken studies on nutrient balances in Vietnam and Thailand. The study in Vietnam covered six agro-ecological regions with varying rates of fertilizer application and crop yields. Positive balances were found for N, P and K in the Red River Delta (positive balances of 29, 62.6 and 57 kg ha^{-1} for N, P and K, respectively) and in the North and South Central Coasts, where farmers apply large amounts of manure. In contrast, negative balances were shown for all three nutrients in the Central Highlands (-38, -3.4 and -28 kg ha^{-1} for N, P and K, respectively) where farmers apply very little manure and almost no chemical fertilizer. In the case of Thailand where farmers normally apply the 15-15-15 compound ($N:P_2O_5:K_2O$) fertilizer to cassava at an average rate of 70 kg ha^{-1}, assuming an average yield of 15 t ha^{-1} and that only roots are removed, the nutrient balances were estimated at -19.5 kg N, 1.1 kg P, and -11.3 kg K ha^{-1}.

Under current management practices, cassava production in Cambodia is considered a low input system, and negative balances of nutrients are anticipated. However, the magnitude of depletion of soil nutrients is not known. The objective of this study was to assess the nutrient balances for cassava cultivation in upland areas of Kampong Cham province in Northeast Cambodia. The knowledge of the status of the soil nutrient balances is regarded as potentially useful for devising strategies for more sustainable cultivation of cassava in Cambodia.

Materials and Methods

Selection of study site

Kampong Cham province, located in Northeast Cambodia (11^{o} 56' 16" N latitude, 105^{o} 41' 28" E longitude, 31-38 m asl), 124 km from the capital city Phnom Penh, was selected as the area for the study. This province was chosen because it has the largest planted area and the largest production of cassava in the country (MAFF, 2008); it also has a long history of cassava production. Annual rainfall in the province ranges from 1,200-1,900 mm. There are two distinct soil types - a red soil called *Labansiek* (Eutric Nitisol) and a black soil called *Kampong Siem* (Gleyic Phaeozem) (FAO-ISRIC-ISSS, 1998); each has two soil sub-types, gravel and non-gravel. The red soil is light in texture, while the black soil has a higher clay content; both soils are generally low in fertility (White et al., 1997).

Initially, a preliminary survey was conducted in the province to obtain general information on the areas grown to cassava, farmers' cassava cultivation practices, crop residue management and yield levels. Secondary data were also collected on climate, topography, soil type and history of cassava production. Based on the information collected in the preliminary survey and secondary data, the cassava production areas in Kampong Cham were divided into four agro-ecological zones (Figure 1). Zones I and II are located in Tbong Khmum district, Zone III is located in Dambe district and Zone IV is located in Memout and Ponea Kreak districts.

Zone I has both gravel and non-gravel red soils, while Zone II has non-gravel black soil. The landscape in both Zones I and II is gently undulating. Cassava has been grown in these two zones continuously without fertilizer application for about 25 years. Zone III soils comprise both gravel and non-gravel black soils, and cassava is grown on gravel soils. The landscape in this zone is gently undulating. Zone IV is located in the districts of Memout and Ponea Kreak on the eastern side of the Mekong River. Cassava has been grown in this zone for about ten years. The main soil type is a non-gravel red soil. The landscape is gently undulating and cassava yields are normally higher than in the other three zones.

A village with a large area of cassava cultivation from each zone was selected for detailed study. The selected villages were Vihear Loung and Tmor Pich in Tbong Khmum district (Zones I and II, respectively), Kok Srok in Dambe district (Zone III), and Kondol Chrom in Ponea Kreak district (Zone IV).

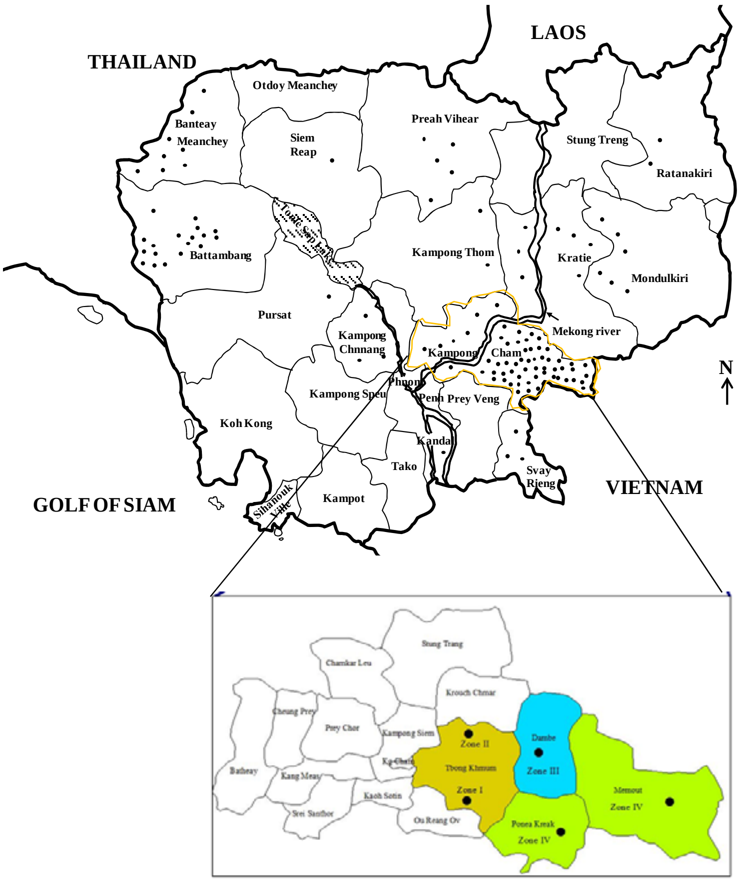

Figure 1. Distribution of cassava growing areas in Cambodia in 2007 (each dot represents 1,000 ha), and locations of Kampong Cham province and cassava production zones in the province.

Determination of the sources of nutrient inputs and outputs

The assessment of nutrient balances for cassava production in Kampong Cham province was done by conducting nutrient balance analyses for the individual cassava fields of the sample households in the four cassava production zones. The concept and methodologies for analyzing soil nutrient balances were those described by Bindraban et al. (2000), Roy et al. (2003) and Phong et al. (2010). Conceptually, there are six inputs and five outputs of nutrients in a crop production system. The inputs include: (1) chemical fertilizers, (2) manure, (3) atmospheric deposition, (4) biological nitrogen fixation, (5) sedimentation and irrigation, and (6) planting material. The outputs include: (1) harvest product, (2) removed crop residue, (3) leaching, (4) gaseous loss and (5) erosion.

To determine the sources and amounts of nutrient inputs and outputs in relation to cassava cultivation in the study area, a farm survey was conducted employing a semi-structured interview, combined with a field visit to collect information on farmers' practices in cassava production for the individual sample households, particularly in relation to fertilizer use and crop residue management. Crop cutting was used to determine the fresh weights of roots and other plant parts for each field. The farm survey and crop cutting were conducted during the period December 2009 to February 2010. Initially, it was planned to analyze 12 fields within each zone, one field for each household. However, early harvesting of the cassava crop by some farmers resulted in the crop cuts for yield measurement being able to be done for only 10 fields in Zone 2 and 11 fields in Zone 4; while 12 fields were done in Zones 1 and 3 as planned. A total of 45 households were covered by the survey and crop cutting, with the number of farmers in each village representing 70-80% of the cassava growing households in each village. Prior to the survey, the commune and village leaders were approached to get permission to conduct the survey, and to obtain secondary information on cassava growers in the village, together with their past yield records. Farmers were stratified-randomly selected to provide representative samples of households which had obtained high and low cassava yields in the past, with the condition that they were willing to be interviewed and allow crop cutting in their cassava fields.

In upland areas of Kampong Cham province cassava is generally planted early in the wet season, starting from early April until the end of June, and harvesting is usually done between December and February. Planting involves putting planting stakes in furrows (horizontal planting) at a specific spacing which can vary among the farmers, and then covering the stakes with soil. Some farmers may apply chemical fertilizers or manure after planting, but many do not. Weeding is done 1-3 times, and the weed biomass is usually left in the field. At harvest, the plants are uprooted and roots are cut from the base of the plant and then taken from the field as the harvest product. The stumps are also usually cut from the plants, with some being taken from the field for use as firewood, while the rest are left in the field but later removed to facilitate plowing before the next planting. Stalks that are of good size are sometimes cut and stored for use as planting material for the next season. However, when planting material is not needed, these stalks are also left in the field. The remaining residues that include plant tops, stems, leaves and small branches, are left in the field to be later incorporated into the soil by tractor during land preparation for the next planting. These crop residues and weeds form part of the nutrients recycled back into the soil.

Based on these farmers' practices, the nutrient inputs were identified as: (1) chemical fertilizers, (2) manure, (3) planting materials and (4) deposition from rain (wet deposition). Deposition from dust (dry deposition) was expected to be small, as there was very little burning in the area; biological fixation was also regarded as being small, as few leguminous weeds were observed in the cassava fields. No sedimentation was anticipated, as the cassava fields are in the uplands. Therefore, in this study, dry deposition, biological nitrogen fixation and sedimentation were excluded from the sources of nutrient inputs. Likewise, leaching, gaseous losses and erosion, were not considered as outputs, as their measurement would be difficult and costly, although some loss of nutrients by these pathways was anticipated. Soil erosion and related potential nutrient loss, was expected to be small, as the study areas where cassava was grown had gently undulating land with less than 3% slope. Thus, the harvested product (cassava roots) and crop residues removed (i.e. the stumps) were the only two sources of nutrient outputs included in the nutrient balance analyses.

Measurement of individual input and output parameters

The nutrient inputs in this study included chemical fertilizer, organic manure (cattle manure), planting material (stakes) and deposition from rain. For chemical fertilizer, the type and amount applied to each cassava field were obtained from the farmer interview. The amounts of individual nutrient elements (N, P and K) applied per ha were then calculated from the nutrient composition of the specified fertilizer and the application rate. The amount of manure applied to each field was also obtained from the farmer interview. The manure used was mainly wet cattle manure. Based on Howeler (2001), when averaged over 10 data sources cited in the literature, wet cattle manure has an average moisture content of 68.2% (31.8% DM) and contains 1.85, 0.81, 1.69, 1.54 and 0.62% N, P, K, Ca and Mg, respectively, on a dry weight basis. These figures were used for estimating the inputs of the individual nutrient elements in the form of cattle manure to each cassava field.

The input in the form of planting material was determined by first calculating the number of planting stakes used per ha, based on the information of plant spacing provided by individual farmers during the interview phase. The derived number was then multiplied by the average weight of a stake to get the fresh weight of planting stakes used per ha, which was then converted into dry weight. The inputs of individual nutrient elements were then calculated from the stake nutrient content of the elements estimated on a dry weight basis. The average weight of the stake used was 150 gm. This figure was derived from weighing sample stakes that were made from 10 stalks by cutting the stalks into pieces which approximated the normal length of cassava planting stakes (about 30 cm). The dry matter percentage of planting material and its nutrient contents were obtained from different sources that were reported in the literatures, as reviewed by Howeler (1991). Dry matter percentage of plant top parts, averaged over two sources in the literature, was 31%, while the nutrient content on a dry weight basis, averaged over nine sources, was 1.87, 0.16, 0.79, 1.04 and 0.26% for N, P, K, Ca and Mg, respectively. These estimates were used in calculating the input of individual nutrients from the planting stakes.

The nutrient inputs from rain was based on estimates from Poltanee et al. (1998), which were derived from actual measurement of rainfall in Khon Kaen province in Northeast Thailand throughout 1992, and related weekly analysis of the nutrient content of the rainfall. Total rainfall in Khon Kaen in that year was 793 mm, with concentrations of nutrients averaging 0.225, 0.123 and 0.163 ppm for N, P and K, respectively. This amounted to 1.78 kg N, 0.97 kg P and 1.29 kg K ha^{-1} y^{-1}.

Two major sources of nutrient outputs were considered in this study - the harvested products (i.e. cassava roots), and removed crop residue in the form of stumps. Fresh weight yields of both were obtained from crop cutting in individual farmers' fields in the four zones covered by the study. For each field, four plots, each of 5×5 m^2, were harvested. Roots and stumps were separated from other plant parts (stems and leaves), and the fresh weights of roots, stumps and the other plant parts were measured. The dry matter percentage of fresh roots was based on the average of two data sources given by Howeler (1991). The nutrient content of fresh roots was also taken from Howeler (1991), using the averages of nine data sources in which cassava yields were in the same range as those obtained in this study. On this basis, the cassava roots in the study area were assumed to have a 38% dry matter content, and average contents of 0.79% N, 0.09% P, 0.63% K, 0.11% Ca and 0.08% Mg, on a dry weight basis. The dry matter percentage and content of individual elements of the stumps was assumed to be the same as those of the planting stakes (i.e., 31% dry matter and 1.87% N, 0.16% P, 0.79% K, 1.04% Ca and 0.26% Mg on a dry weight basis) (Howeler, 1991). These dry matter and nutrient content estimates were used in calculating the quantities of outputs of individual nutrients in the roots and stumps that were removed from the fields.

Nutrient balances analysis

The balances for N, P, K, Ca and Mg were calculated for each field, based on the differences between nutrient inputs and nutrient outputs. Variations among the fields were examined and comparisons among zones were also made on the nutrient balances.

Results

Average nutrient balances over all four zones

Sources of nutrient inputs that were considered in this study included mineral fertilizer, organic manure, planting material, and wet deposition. The inputs of nutrients from chemical fertilizer were rather small, as only 10 out of 45 sampled households (22%) in the four cassava production zones in Kampong Cham province applied chemical fertilizer to their cassava fields, and with low application rates. The fertilizer applied was diammonium phosphate (18-46-0), with an average application rate of 23.67 kg ha^{-1}, giving the nutrient inputs of only 4.96 kg N and 4.29 kg P ha^{-1} (Table 1). Cattle manure also provided little nutrient inputs as it was applied by only three households (7%) in all four zones, with a low average application rate of only 402.5 kg ha^{-1}. The nutrients supplied through the cattle manure were 2.38 kg N, 1.04 kg P, 2.16 kg K, 1.97 kg Ca and 0.37 kg Mg ha^{-1}. The nutrient inputs from wet deposition were also small, being only 1.78 kg N, 0.97 kg P and 1.29 kg K ha^{-1}. Among the four input sources, the planting material (cassava stakes) provided the largest quantities of nutrient inputs into the system, with the averages over all four zones being 13.65 kg N, 1.17 kg P, 5.77 kg K, 7.59 kg Ca and 1.9 kg Mg ha^{-1}. In total, the nutrient inputs amounted to 20.99 kg N, 6.49 kg P, 7.93 kg K, 9.56 kg Ca, and 2.27 kg Mg ha $^{-1}$ (Table 1).

Table 1. Average nutrient inputs, outputs, balance and recycled nutrients, for cassava cultivation over four production zones in Kampong Cham province in Northeast Cambodia.

Input /Output	Quantity (kg ha^{-1})	Nutrient (kg ha^{-1})				
		N	P	K	Ca	Mg
Chemical fertilizer	24	4.96	4.29	-	-	-
Organic fertilizer	403	2.38	1.04	2.16	1.97	0.37
Planting material	2,355	13.65	1.17	5.77	7.59	1.90
Rainfall	-	1.78	0.97	1.29	-	-
Total input	-	20.99	6.49	7.93	9.56	2.27
Cassava roots	21,703	65.15	7.42	51.96	9.07	6.60
Cassava stumps	3,494	20.28	1.92	8.80	11.32	2.87
Total output	-	85.44	9.34	60.76	20.39	9.47
Balance	-	-64.45	-2.85	-52.83	-10.83	-7.20
Recycled (stems & leaves)[±]	10,703	62.05	5.31	26.21	34.51	8.63

[±] Stems and leaves were retained in the field, thus, were considered recycled the nutrients back to the field.

Only two sources of nutrient output were considered - the harvested product (cassava roots) and the crop residue which was removed (stumps). Average fresh root yield of cassava over the four zones was 21.7 t ha^{-1}. The amounts of nutrients removed in the form of root yield were 65.15 kg N, 7.42 kg P, 51.96 kg K, 9.07 kg Ca and 6.60 kg Mg ha^{-1}. On average, 3.5 t ha^{-1} of stumps were removed from the fields, resulting in the removal of 20.28 kg N, 1.92 kg P, 8.80 kg K, 11.32 kg Ca and 2.87 kg Mg ha^{-1}. Total nutrients removed by both sources amounted to 85.44 kg N, 9.34 kg P, 60.76 kg K, 20.39 kg Ca and 9.47 kg Mg ha^{-1} (Table 1).

As the quantities of nutrient outputs were much greater than the inputs, the balances for all nutrients were negative and considerable, being -64.45 kg N, -2.85 kg P, -52.83 kg K, -10.83 kg Ca and -7.20 kg Mg ha^{-1} (Table 1). It was noted that the quantity of nutrients in stems and leaves that were recycled back into the soils were quite considerable, averaging 62.05 kg N, 5.31 kg P, 26.21 kg K, 34.51 kg Ca and 8.63 kg Mg ha^{-1} (Table 1).

Variations among zones in nutrient balances

Negative balances were shown for all nutrients in all four cassava production zones in Kampong Cham province. However, the magnitudes of the balances for the individual nutrients varied to some extent among the four zones. Zones 2 and 3 appeared to have greater negative balances than Zones 1 and 4 for all nutrients except P, for which Zones 3 and 4 had greater negative balances than Zones 1 and 2 (Table 2). Among the three major nutrients (N, P and K), the magnitude of the negative balances for N and K were large, ranging from -53.33 to -78.60 kg ha^{-1} for N and -43.44 to -60.85 kg ha^{-1} for K; the balances for P were much smaller, ranging from -1.67 to -7.83 kg ha^{-1}. For Ca and Mg, although the negative balances were much lower than those for N and K, being -8.00 to -16.45 kg ha^{-1} for Ca and -5.80 to -8.62 kg ha^{-1} for Mg, these amounts were considered significant as these are secondary nutrients.

Differences in nutrient inputs among the four zones were also observed. Zones 1 and 2 had greater levels of inputs than Zones 3 and 4 for all the nutrients (Table 2). This reflected the fact that some households in Zones 1 and 2 applied chemical fertilizer or manure to their cassava fields, but no households in Zones 3 and 4 fertilized their cassava crops. Although the average rates of fertilizer and manure application in Zones 1 and 2 were low, being 18 and 29 kg ha^{-1} for chemical fertilizer (18-46-0) and 525 and 280 kg ha^{-1} for cattle manure, respectively, they still provided some nutrient inputs, resulting in the levels of nutrient inputs for Zones 1 and 2 being greater than for Zones 3 and 4, where the nutrient inputs came only from the planting material and wet deposition from rainfall.

The levels of nutrient outputs in the four zones did not show the same trends as nutrient inputs, but closely reflected crop yields in the respective zones. Average crop yield in Zone 2 was the highest (25.6 t ha^{-1}), followed by Zone 3 (22.6 t ha^{-1}), Zone 1 (20.4 t ha^{-1}), and Zone 4 (18.2 t ha^{-1}). The amounts of nutrient outputs, thus, were highest for Zone 2, followed by Zones 3, 1 and 4, sequentially. However, the amounts of nutrients removed by the outputs in Zones 1 and 2 were offset to some extent by inputs from chemical fertilizer and manure, making the nutrient balances in Zone 2 slightly lower than those for Zone 3 (Table 2).

Table 2. Average nutrient inputs, outputs and balance, for cassava cultivation in the individual zones in Kampong Cham province in Northeast Cambodia.

Input /Output	Quantity (kg ha^{-1})	Nutrient (kg ha^{-1})				
		N	P	K	Ca	Mg
Zone 1						
Chemical fertilizer	18	3.30	3.68	-	-	-
Organic fertilizer	525	3.09	1.35	2.82	2.57	0.48
Planting material	2,258	13.09	1.12	5.53	7.28	1.82
Rainfall	-	1.78	0.97	1.29	0.00	0.00
Total input	-	21.26	7.12	9.64	9.85	2.30
Cassava roots	20,405	61.26	6.98	48.85	8.53	6.20
Stumps	3,646	21.11	1.81	8.92	11.74	2.94
Total output	-	82.37	8.78	57.77	20.27	9.14
Balance	-	-61.11	-1.67	-48.13	-10.42	-6.83
Zone 2						
Chemical fertilizer	29	6.62	4.90	-	-	-
Organic fertilizer	280	1.67	0.72	1.51	1.37	0.26
Planting material	2,822	16.36	1.40	6.91	9.10	2.27
Rainfall	-	1.78	0.97	1.29	0.00	0.00
Total input	-	26.43	7.99	9.71	10.47	2.53
Cassava roots	25,615	76.90	8.76	61.32	10.71	7.79
Stumps	3,770	21.85	1.87	9.23	12.15	3.04
Total output	-	98.75	10.63	70.56	22.86	10.83
Balance	-	-72.32	-2.64	-60.85	-12.39	-8.29
Zone 3						
Chemical fertilizer	-	-	-	-	-	-
Organic fertilizer	-	-	-	-	-	-
Planting material	1,528	8.86	0.76	3.74	4.92	1.23
Rainfall	-	1.78	0.97	1.29	0.00	0.00
Total input	-	10.64	1.73	5.03	4.92	1.23
Cassava roots	22,571	67.76	7.72	54.03	9.43	6.86
Stumps	3,704	21.47	1.84	9.07	11.94	2.99
Total output	-	89.23	9.56	63.11	21.38	9.85
Balance	-	-78.60	-7.83	-58.08	-16.45	-8.62
Zone 4						
Chemical fertilizer	-	-	-	-	-	-
Organic fertilizer	-	-	-	-	-	-
Planting material	2,812	16.30	1.39	6.89	9.06	2.27
Rainfall	-	1.78	0.97	1.29	-	-
Total input	-	18.08	2.36	8.18	9.06	2.27
Cassava roots	18,223	54.70	6.23	43.63	7.62	5.54
Stumps	2,856	16.70	2.17	7.99	9.45	2.53
Total output	-	71.41	8.40	51.61	17.07	8.07
Balance	-	-53.33	-6.04	-43.44	-8.00	-5.80

Distributions of nutrient inputs, outputs and balances, for individual fields

Substantial variations among fields were observed for nutrient inputs, outputs and balances, for all nutrients except P, in all four cassava production zones in Kampong Cham province (Figure 2). The variation among fields in the level of inputs for individual nutrients was greater for Zones 1 and 2 than for Zones 3 and 4. This difference reflected the fact that for Zones 1 and 2, there were differences among fields in the amounts of chemical fertilizer and manure applied, coupled with differences in plant spacing (therefore, differences in the amount of planting material used), while for Zones 3 and 4, the differences reflected only variability in plant spacing, as the fields in these two zones were not fertilized. The fields that showed the highest levels of nutrient inputs were those that received high rates of cattle manure. The low variation for P in Zones 3 and 4 would have reflected the low P content in the cassava planting stakes.

Variations in the levels of outputs of individual nutrients (Figure 2) closely reflected the variation in crop yield among the fields, which ranged from 14.5 to 25.0 t ha^{-1} for Zone 1; 18.4 to 37.2 t ha^{-1} for Zone 2; 14.5 to 29.7 t ha^{-1} for Zone 3; and 12.7 to 23.0 t ha^{-1} for Zone 4. The low variation in P outputs in all four zones could be explained by the low P content of cassava roots (0.16% of dry wt.).

The distribution of N balances for the individual fields (Figure 2c) reveals that most fields in all four zones had negative balances of more than -40 kg N ha^{-1}, while only 10% of the fields in Zone 2 and 36% of the fields in Zone 4 had negative balances of less than -40 kg N ha^{-1}. A significant number of fields even had sizable negative balances of N (> -80 kg N ha^{-1}); these fields constituted 17, 30 and 50% of the fields in Zones 1, 2 and 3, respectively. Overall, the negative N balances were quite significant.

For P, most of the fields in Zones 1 and 2 and all the fields in Zones 3 and 4 only had small negative balances (< -40 kg P ha^{-1}) (Figure 2f), while 42% of the fields in Zone 1 and 10% of the fields in Zone 2 had small positive balances for P. Thus, overall, P losses were rather small.

In contrast to P, a higher proportion of fields had significant negative K balances (> -40 kg K ha^{-1}) than those with less serious negative balances (< -40 kg k ha^{-1}) (Figure 2i). The fields with significant negative K balances accounted for 58, 60, 55 and 83% of fields in Zones 1, 2, 3 and 4, respectively. Overall, K losses were also important.

The distribution of Ca balances (Figure 2l) was generally similar to those for K, with the proportion of fields with significant negative balances (> -10 kg Ca ha^{-1}) being in the majority in Zones 1, 2 and 3, accounting for 66, 50 and 92% of the fields in these three zones, respectively. An exception existed in Zone 4, where only 27% of fields had sizeable negative Ca balances. Overall, Ca losses were less serious in Zone 4, moderate in Zones 1 and 2, but more serious in Zone 3.

Only 27% of the fields in Zone 2 and 17% of the fields in Zone 3, had sizable negative Mg balances (> -10 kg Mg ha^{-1}). The rest of the fields had smaller negative balances (Figure 2o). Mg losses were, therefore, considered minor.

Overall, the majority of the fields in all four zones had considerable negative balances for N, K and Ca, with the losses being most serious in Zone 3.

An in-depth examination of the data relating to individual fields reveals that the fields that had small negative balances for most of the nutrient elements, or even positive balances for P, were those that received an application of chemical fertilizers (18-46-0) at the rates between 50 to 120 kg ha^{-1}, or cattle manure at rates between 2,800 to 3,500 kg ha^{-1}. Although the yield increases from fertilizer or manure application (which would increase nutrient outputs) could not be assessed, the negative nutrient balances appear to have been offset to some extent by the application of chemical fertilizer or manure.

Discussion

This study aimed to assess the nutrient balances for cassava cultivation in upland areas in Kampong Cham province in Northeast Cambodia. The results show clear negative balances for all the nutrient elements that were considered (N, P, K, Ca and Mg), indicating that these nutrients are being lost from the soil under the current cassava cropping practices. Serious losses were shown for N, K and Ca, both in terms of large average amounts being lost (-64.45 kg N, -52.83 kg K and -10.83 kg Ca ha^{-1}) and the frequency of fields with large negative balances. The losses for P and Mg were less, averaging -2.85 kg P and -7.20 kg Mg ha^{-1}, with most fields having small negative balances for these two nutrients. Some fields with manure or chemical fertilizer application had small positive balances for P. Similar trends were shown for the four cassava production zones in Kampong Cham that were studied, but the magnitude of the balances for the individual nutrients varied to some extent among zones. Zones 2 and 3 had greater negative balances than Zones 1 and 4 for all the nutrients except P.

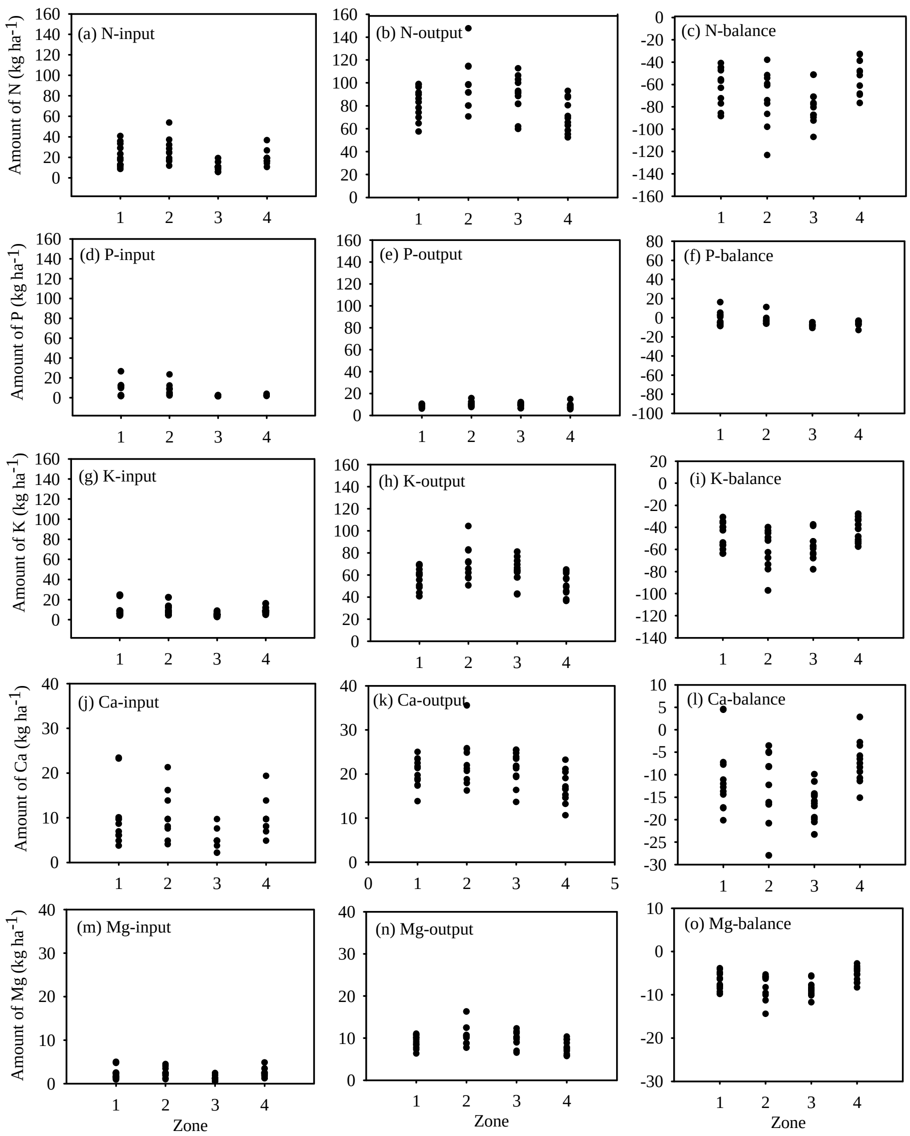

Figure 2. Distribution of inputs, outputs and balances for N, P, K, Ca and Mg among fields in the four cassava production zones in Kampong Cham province in Northeast Cambodia.

Nutrient losses from cassava production on the Cambodian soils covered by this study were considerably greater than those reported for the Central Highlands of Vietnam (-38, -3.4 and -28 kg ha^{-1} for N, P and K, respectively) where farmers apply very little manure and almost no chemical fertilizer to cassava, and also much greater than the losses reported in Thailand (-19.5 kg N, 1.1 kg P, and -11.3 kg K ha^{-1}) where farmers apply the 15-15-15 (N-P_2O_5-K_2O) compound fertilizer to cassava at a rate of 70 kg ha^{-1}, with a yield level of 15 t ha^{-1} (Howeler, 2001). This result is probably related to the higher root yield of cassava in the Kampong Cham province in this study (21.7 t ha^{-1}), and the fact that some of the nutrient losses in cassava growing areas of Thailand are compensated for by fertilizer inputs.

The negative nutrient balances for cassava production in Kampong Cham province are the consequence of low inputs in current cassava cultivation practices in the province. Only a few farmers in Zones 1 and 2, which are representative of old cassava production areas, apply chemical fertilizer or manure to their cassava crops, and even for these farmers, the application rates are low. None of the farmers in the other two zones, which are representative of newer areas of cassava cultivation, fertilize their cassava crops. The most significant source of nutrient inputs into current cassava production is in the form of nutrients in planting material, averaging 13.65 kg N, 1.17 kg P, 5.77 kg K, 7.59 kg Ca and 1.90 kg Mg ha^{-1}. Rainfall contributed only small amounts of N, P and K, averaging 1.78, 0.97 and 1.29 kg ha^{-1}, respectively. Nutrient outputs were mainly from cassava roots, and to a lesser extent, cassava stumps which are removed from the field. The amount of nutrients removed through these components is dependent on crop yields. The average amounts of nutrients removed in the form of cassava stumps were 20.28 kg N, 1.92 kg P, 8.80 kg K, 11.32 kg Ca and 2.87 kg Mg ha^{-1}. The levels of nutrient removal in the form of stumps will be largely compensated for by inputs in the form of planting stakes and rainfall. Thus, nutrient balances in cassava production can be roughly estimated by nutrient outputs in the form of harvested roots minus nutrient inputs from application of chemical fertilizer and manure. With low levels of fertilizer inputs but relatively high crop yields, negative nutrient balances would prevail.

The above analysis, however, did not take into account nutrient losses through erosion, leaching and volatilization. As shown by Phong et al. (2011), leaching and gaseous losses of nutrients are a function of the fertilizers applied. Currently, cassava production in Kampong Cham is a low-input system where little fertilizer or manure are applied. Nutrient losses from these two sources would, therefore, be unimportant. Nutrient losses through erosion could be significant in sloping areas (Howeler, 2001). However, the cassava fields in the study areas in Kampong Cham province are either flat or only gently sloping; nutrient losses through erosion under these growing conditions would be minor.

In this study, the average nutrients in stems and leaves that were recycled back to the soils were estimated at 62.05 kg N, 5.31 kg P, 26.21 kg K, 34.51 kg Ca and 8.63 kg Mg ha^{-1}. These amounts are quite significant when compared with other sources of nutrient inputs or nutrient output. If these crop residues are removed from the field, the consequence would be substantially greater negative balances for all the nutrients presented in Table 1. The practice of keeping or returning the plant residues should therefore be maintained. Evidence from long-term NPK trials conducted on a very poor soil in Khon Kaen province in Thailand has shown that, without fertilizer application but with incorporation of plant tops, yields of about 12 t/ha could be maintained for more than 15 years of continuous cropping, but when the tops were removed from the field, yields declined to between 5 and 7 t/ha (Howeler, 1995). In some fields, however, the stalks are used for planting, and are thus removed from the fields. This is unavoidable since planting material is needed for the next crop. In these fields, nutrient losses would be substantially greater than for fields where the planting material is not needed. Quite often, the planting stakes used are from cassava plants in the same fields. In this situation, the nutrients from planting stakes are not brought in as input, but are recycled nutrients. This would make the negative nutrient balances even greater than those indicated in Tables 1 and 2, with the averages of all the sites being increased to -76.32, -3.04, -57.31, -18.42 and -9.1 kg ha^{-1} for N, P, K, Ca and Mg, respectively.

It was also noted that the fertilizer most commonly used by farmers in the study area was diammonium phosphate (18-46-0) which contains a high concentration of P but no K, while the nutrient balance analyses showed small negative balances for P but considerable negative balances for K. The type of fertilizer should, therefore, be considered in the development of appropriate fertilizer recommendations for cassava production in Kampong Cham.

Conclusions

The results of this study clearly show that, under the current low-input practices, cassava fields in Kampong Cham province of Northeast Cambodia are losing nutrients that are essential for plant growth, particularly N, K and Ca. If such practices are continued for an extended period, soil fertility will decline and future crop yields will also decrease. Cassava production in Cambodia is, therefore, unsustainable under continuing use of the current low-input practices. To sustain production of the crop, appropriate strategies to avoid soil nutrient depletion will need to be adopted. Soil nutrient depletion and exhaustion can be prevented by the application of adequate amounts of chemical fertilizers, organic manures or compost, and by the incorporation of plant tops, green manures or prunings of hedgerows (Howeler and Phien, 2000). The high negatively balances for N and K suggest that chemical fertilizers high in these two elements should be used. Lime should also be applied to compensate for the loss of Ca. Organic manures can provide secondary nutrients and micro-nutrients, and help improve soil physical properties. If available, the organic manures should be applied together with lime and chemical fertilizers high in N and K for long-term productivity of cassava cropping systems.

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