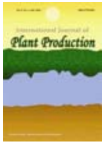

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Unveiling constraints to cassava production in Cambodia: An analysis from farmers' yield variations

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Abstract

Cassava (*Manihot esculenta* Crantz) is currently the most important upland crop of Cambodia, but information on yield variations and causal factors which is important for efficiently targeting efforts to increase production is still lacking. The objectives of this study were to determine the yield variations and causal factors for cassava production in Kampong Cham province in Cambodia. Forty five households in four production zones were selected for the study. A farm survey employing semi-structured interviews, combined with field visits, were used for the collection of information on farmers' practices in cassava cultivation, while crop cutting was done to provide estimates of cassava yields. The data were analyzed for yield variations, yield gaps and causal factors. The results showed large variations in yield among farmers' fields, ranging from 12.7 to 37.2 t ha^{-1}. The fields were divided into five yield categories, with the mean yields of the lower four categories ranging from 76.0 to 34.2% of the maximum yields, with corresponding yield gaps ranging from 8.9 to 24.4 t ha^{-1}. The main yield constraints identified were soil nutrient deficits, short crop duration and weed competition. The highest yielding fields had no production constraints, but the number and/or the level of constraints increased in fields with lower crop yields. However, for different fields with similar yield levels, the main production constraints sometimes differed. The results clearly indicated that there are opportunities for yield improvement and narrowing of yield gaps through the adoption of field specific improved technologies and management practices.

Keywords: Yield gap; Yield limiting factors; Cassava cultivation; Production constraints; Crop management.

Introduction

In Cambodia, cassava (*Manihot esculenta* Crantz) is currently the second most important crop after rice. Production of the crop has greatly increased during the past 10 years due to a combination of increased demand for both domestic consumption and for export, and associated high prices. The area planted to cassava has expanded dramatically from 15,380 ha in 2000 to 157,000 ha in 2009, while annual production has increased from 147,763 t in 2002 to 3.5 million t in 2009. Average cassava crop yield has also increased significantly from 9.61 t ha^{-1} in 2000 to 22.27 t ha^{-1} in 2009 (FAOSTAT, 2011). Much of this improvement reflects the expansion into new production areas where soils are relatively fertile, combined with the adoption of new higher yielding varieties. Cassava has now become an important cash crop for resource-poor farmers in Cambodia (Sopheap, 2008). Although the current national average yield of cassava in Cambodia is relatively high (22.27 t ha^{-1} in 2009) when compared to other countries (13.37 t ha^{-1} for Colombia, 13.40 t ha^{-1} for Myanmar, 16.82 t ha^{-1} for Vietnam, and 18.75 t ha^{-1} for Indonesia) (FAOSTAT, 2011), in areas where cassava has been grown for many years, such as in parts of Kampong Cham province in Northeast Cambodia, crop yields are relatively low. Improved management practices are needed to raise crop yield in these areas, and to sustain or even improve the yield levels in new production areas.

In reality, like other crops, cassava cropping is always subject to a number of constraints which keep its yield lower than its potential. This difference between actual farmer yield and potential yield is generally referred to as the ‘yield gap’ (Gomez, 1977; Tran, 2004; Fermont et al., 2009; Lobell et al., 2009). Information on the magnitude of yield gap and associated causal factors is important for efficiently targeting efforts to increase production (Lobell et al., 2009). There is, however, considerable variation in the literature in the way yield gap is defined, in the type of data used to represent potential yield and farmer yield, and in the procedures used to obtain these yields. Three categories of yield gap are generally recognized: (i) the gap between the theoretical potential yield and the highest research station yield; (ii) the gap between the highest research station yield and the highest farm yield; and (iii) the gap between the highest farm yield and the average farm yield (Tran, 2004; Lobell et al., 2009). The first category is the yield gap that scientists aim for in varietal improvement. The second category usually reflects the differences in environmental conditions between research stations and farmers’ fields which are non-transferable. The third category reflects physical and biological production constraints, e.g., soil fertility, water, crop variety, insect pests, diseases and weeds, together with socio-economic constraints, e.g., production costs, credit availability, inputs, labor and knowledge (Tran, 2004). This third category of yield gap is of special interest for practical purposes, as it has the potential to be reduced through improvements in crop management or access to inputs.

For a given area, there is always some variation in crop yields among farmers' fields due to inherent spatial variability in certain biophysical constraints and differences in farmers' management practices. Spatial variability of soil properties, particularly soil nutrients, has also been shown even in the same field as a consequence of variation in farmer managements (Ayoubi et al., 2007). Yield variations of over two folds within a small area have frequently been reported (Calvino and Sandras, 2002; Sandras et al., 2002; Lobell et al., 2007; Tittonell et al., 2008). This between-field yield variation often manifests in the form of a significant gap between the average yield for a given area and that achieved from the highest-yielding field. Narrowing this gap plays a critical role in raising production of the crop in the area (Lobell et al., 2005). Although yield gap analyses have been conducted for a number of crops in several countries (De Datta et al., 1978; Langsigan et al., 1996; Pingali et al., 1997; Aggarwal et al., 2000; Timsina et al., 2004), many of these studies have disregarded the inherent variability among farmers' fields. An improved understanding of the factors which most limit yields in farmers' fields (and, as importantly, those that do not) is needed to identify opportunities for improving farmer incomes, as well as to reduce the potential environmental impacts of agriculture (Lobell et al., 2005). The analysis of yield variations among fields could potentially identify the limiting constraints, if yield data and associated information on specific soil and management factors likely to affect yields are available (Lobell et al., 2009). Surveys of farmer practices, supplemented by measurements of soil properties and crop performance, have the potential to provide a valuable means of assessing yield constraints in farmers' fields (Calvino and Sandras, 2002; Sandras et al., 2002; Inthavong et al., 2011).

Factors causing yield gaps, however, vary among locations. A number of studies have shown that factors that either support or hamper grain production are locally or regionally specific (Timsina and Conner, 2001; Keys and McConnell, 2005; Reidsma et al., 2007). Neumann et al. (2010) pointed out that minimizing the yield gap requires an understanding of the nature and strength of regional-specific constraints; therefore, yield constraints need to be assessed separately to provide a basis for increasing actual yields in a specific region. Thus, despite the importance and prevalence of yield gaps, its precise cause in many regions is not well know, due, in part, to a lack of data on spatial variations in crop yields and yield controlling factors (White et al., 2002). This is also true for the case of cassava production in Cambodia. This study was, therefore, conducted to measure the variations and gaps in cassava yield among farmers' fields in different production zones in Kampong Cham province in Northeast Cambodia, together with the associated causal factors.

Materials and Methods

The study area

This study was carried out in Kampong Cham province in Northeast Cambodia (11^{o} 56' 16" N latitude, 105^{o} 41' 28" E longitude, 31-38 m above sea level). This province was chosen because it has the largest area of cassava in the country and a long history of cassava cultivation. In 2007 cassava was planted on approximately 62,000 ha, accounting for more than 50% of the total cassava area in the country (108,000 ha) (MAFF, 2008). This province is also representative of the relatively diverse range of environments and management practices of the cassava-based cropping systems in Cambodia. Annual rainfall in the province ranges from 1,200-1,900 mm. Two soil types are found in the area - a red soil called *Labansiek* (Eutric Nitisol) and a black soil called *Kampong Siem* (Gleyic Phaeozem) (FAO-ISRIC-ISSS, 1998); each has two sub-types, gravel and non-gravel. The red soil is light in texture, while the black soil has higher clay content. Both soils are relatively low in fertility (Hin et al., 2005).

Based on soil type, agro-ecological setting and history of cassava cultivation obtained from a 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 Ponhea Krek 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 the gravel soils. The landscape in this zone is also gently undulating.

Zone IV also has both gravel and non-gravel red soils and gently undulating landscape. Cassava has been grown in this zone for about ten years, and cassava yields are normally lower than in the other three zones. A village with a large area of cassava cultivation was selected in each zone for the 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 Ponhea Krek district (Zone IV).

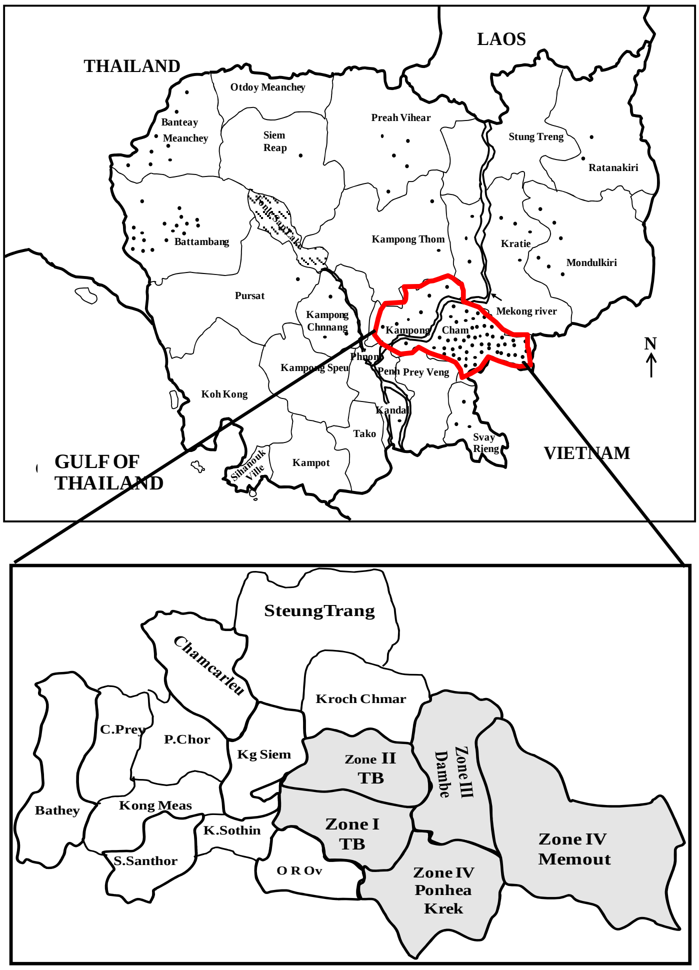

Figure 1. Distribution of cassava growing areas in Cambodia in 2007 (each dot represents 1,000 ha), and locations of Kampong Cham province and cassava production zones in the province.

Data collection and analysis

Data were collected on management practices, soil properties and crop yields in cassava fields of the sample households in each selected village. Additional data on daily rainfall, maximum and minimum temperatures and humidity for the study period (2009-2010) were also obtained from the Kampong Cham Provincial Department of Meteorology and Water Resources. A farm survey employing a semi-structured interview, combined with a field visit, was used in collecting information on farmers' cassava practices for the individual sample households. Crop sampling was used to measure cassava yield for each field, while soil samples were taken for laboratory analysis. The farm survey, soil sampling and crop cutting were conducted during the period of December 2009 to February 2010. Initially, it was planned to collect data for 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 restricted to only 10 fields in Zone 2 and 11 fields in Zone 4. However, in Zones 1 and 3, 12 fields were sampled 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 the 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 recorded high and low cassava yields in the past. Farmer collaborators had to indicate a willingness to be interviewed and allow the sampling of their cassava crops.

Information obtained from the farmer interview included - the variety of cassava used, planting date, type and amounts of chemical fertilizer and/or manure applied, number of weedings done on the crop sampled field, and number of years that the household has cultivated cassava. As the farmers could not always remember the exact dates of planting, but could remember whether they planted early, middle or late in the month, early planting was equated for 5^{th} (e.g. 5 April), mid-month planting was equated for 15^{th} (e.g. 15 April) and late planting was equated with 25^{th} (e.g. 25 April). Farmers were also asked to give a fertility rating for the soils in the cassava fields in which crop sampling was done, using the scores of 1-3, where 1=good fertility, 2=medium fertility, and 3=low fertility.

Crop sampling was done for 45 fields, one field for each sample household. In each field, four plots, each 5×5 m^2, were harvested. The roots were separated from other plant parts and their fresh weights were measured. Prior to harvesting of each plot, plant counts were made, and any insect or disease damage was recorded. Weed density was also scored on a scale of 1-3, where 1=low, 2=moderate, and 3=high weed density. After harvesting, 0-20 cm soil samples were taken from four locations in each field, using a soil augur; the four soil samples from each field were mixed and a composite sample of 200-300 g was taken, sun-dried for 2-3 days, and then taken for analysis in a soils test laboratory at the Khon Kaen Regional Office of the Thailand Department of Land Development. The samples were analyzed for pH (1:1 H_2O), total N (Kjeldahl method), available P (Bray II), exchangeable K (Ammonium acetate 1M pH 7.0), exchangeable Al (KCl/AAS), and percentages of sand, silt and clay.

The data collected on biomass and root yields were analyzed for nutrient balances, and the results were presented in a separate report (Sopheap et al., 2012). In this study, cassava yields from sample farmers' fields were examined for their distribution, and were classified into five groups - high, moderately high, moderate, moderately low and low. Yield gaps from the highest yielding field were determined for the individual groups. To determine the factors causing the yield gaps, the relationships between yield and possible influencing factors, and between these factors themselves, were first examined using correlations. The factors examined included - soil quality score, soil type, planting date, crop duration, weed density score, number of weedings, plant population, and years of farmer's experience in growing cassava. A stepwise regression analysis was then used to determine the relative importance of these effects on cassava yield, and to identify the significant factors that should be included in the model. Simple regressions were also done for those factors that appeared to have significant relationships with yield. For fertilizer or manure application and weed score, which are discrete variables, analysis of variance was used to determine their effects on yield. Soil analysis results for each field were compared with the critical values for cassava obtained from the literature (Howeler, 2002) to determine the deficit nutrients for particular fields. Finally, selected fields for the individual yield groups were compared for the levels of factors that showed a significant influence on yield, to elucidate the factors that caused the yield gaps at different yield levels.

Results and Discussion

Distribution of cassava farm yields and yield gaps at different yield levels

Fresh weight yields of cassava from crop cutting for the 45 fields of the sample households showed great variation, ranging from 12.8 to 37.2 t ha^{-1}, with an average of 21.3 t ha^{-1}. The yield gap between the maximum and the average yield was 15.9 t ha^{-1}, while the gap between the average and the minimum yield was 8.6 t ha^{-1}, giving a total gap between the maximum and minimum yield of 24.4 t ha^{-1}, twice the value of the minimum yield itself (Table 1). Fermont et al. (2009) also found large differences in cassava yields among farms in Kenya and Uganda, with the differences between the high and the low yielding fields being 5.9 and 9.7 t ha^{-1}, respectively. In the present study, yield values were more or less normally distributed, with the moderate yielding group having the highest frequencies and declining towards both the higher and the lower ends (Table 1). Mean yields of the moderately high to the low yielding groups ranged from 76.0-34.2% of the highest yielding field, with the yield gaps increasing from 8.9 to 24.4 t ha^{-1}, respectively. Distributions of yields in the different zones showed similar patterns, with Zone 2 having the highest average yield, followed by Zone 3, Zone 1 and Zone 4, respectively (Figure 2). The highest yielding field was in Zone 2, and its yield of 37.2 t ha^{-1} was substantially higher than those for other fields, including that for the second highest yielding field (30.5 t ha^{-1}), and even higher than the highest yield obtained under experimental conditions in Cambodia (36 t ha^{-1}) (Sopheap et al., 2008). This field is located near a rubber plantation, which is normally fertilized at a high rate, and, as per the farmer interview, presumably received nutrient inflow from the rubber plantation during periods of rainfall. The highest yield obtained from this study, therefore, could be considered as being close to the potential farm yield in the study area under rainfed conditions.

Table 1. Distribution of fresh weight yields of cassava from sample farmers' fields, and yield gaps for the different yield groups from the maximum yield category.

Yield group	Mean (t ha^{-1})	Range (t ha^{-1})	No. of fields	Percent of maximum yield	Yield gap[1] (t ha^{-1})
High	37.2	>30.9	1	100.0	-
Moderately high	28.3	26.0-30.9	7	76.0	8.9
Moderate	22.4	20.0-25.9	22	60.2	14.8
Moderately low	16.8	14.0-19.9	13	45.2	20.4
Low	12.8	<14.0	2	34.2	24.4

[1] Difference between the maximum yield and mean yield of the group.

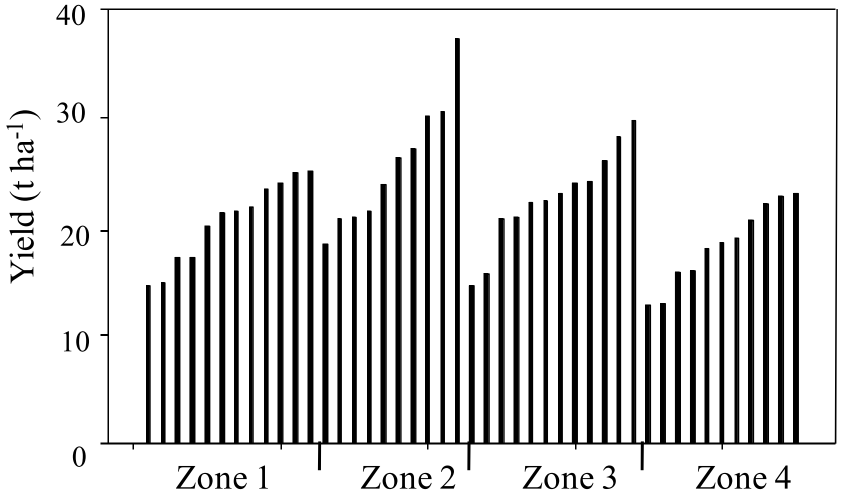

Figure 2. Distribution of farmers' cassava yields in different production zones in Kampong Cham province (Mean±SE: Zone 1=20.4±1.08, Zone 2=25.6±1.84, Zone 3=22.6±1.29, Zone 4=18.2±1.11).

Factors affecting cassava yield in Kampong Cham province

Correlation analyses among yield and possible influencing factors show high and significant correlations (r) between cassava yield and soil quality score (-0.73, P<0.01), planting date (-0.50, P<0.01), crop duration (0.66, P<0.01), weed density score (-0.58, P<0.01) and number of weedings (0.62, P<0.01) (Table 2), suggesting that each of these factors might influence cassava yield in the study area. However, there were also strong relationships among pairs of the related yield influencing factors, e.g., planting date and crop duration (r= -0.74, P<0.01), and weed density score and number of weedings (r= -0.69, P<0.01). Significant correlations were also found between unrelated factors, e.g., soil quality score with planting date, crop duration, weed density and number of weedings; planting date and crop duration with weed density score and number of weedings (Table 2). These relationships indicated that the effects of the above factors on cassava yield in the present study are complexly confounded. No relationship was observed between yield and plant population, years of farmer's experience in growing cassava, and soil type, indicating that these factors did not contribute to the yield variations in the current study.

Fertilizer and manure application was not included in the correlation computations because the data did not allow a meaningful correlation analysis as few farmers applied manure and only a small number of farmers applied chemical fertilizers at low rates. All the sampled fields were grown to the cassava variety KM 94, locally called Malay, which was introduced from Vietnam and was originally the Thai variety KU 50. Therefore, variety was not the cause of yield variation in the present study.

Table 2. Correlations between cassava yield and factors influencing yield.

Parameter	Yield	Soil quality score	Planting date	Crop duration	Weed density score	Number of weedings	Plant population	Years grown	Soil type
Yield	1.00								
Soil quality score[1]	-0.73**	1.00							
Planting date (days)[2]	-0.50**	0.52**	1.00						
Crop duration (days)	0.66**	-0.56**	-0.74**	1.00					
Weed density score[3]	-0.58**	0.57**	0.61**	-0.40**	1.00				
Number of weedings	0.62**	-0.58**	-0.56**	0.47**	-0.69**	1.00			
Plant population	-0.15	0.31*	-0.02	0.10	0.17	-0.08	1.00		
Years of cassava growing[4]	0.05	0.14	0.22	0.01	0.18	0.07	0.03	1.00	
Soil type[5]	0.20	-0.16	-0.13	0.42**	-0.48**	-0.11	-0.06	0.19	1.00

[1] Score of 1 to 3, where 1=good, 2=moderate and 3=poor.
[2] Days starting from 1 January.
[3] Score of 1 to 3, where 1=low, 2=medium and 3=high density.
[4] Years of farmer's experience in growing cassava.
[5] 1=sandy, 2=loamy, 3=clayey loam, 4=clayey and 5=rocky.
*, ** Significant at P≤0.05 and P≤0.01, respectively.

A stepwise sequential regression analysis of yield on soil quality score, planting date, crop duration, weed density score, number of weedings, plant population, years of farmer's experience in growing cassava and soil type was carried out to assess the relative importance of these factors in affecting yield. The results showed that only soil quality score and crop duration were significant factors included in the reduced model. Soil quality score was identified as the most important factor, accounting for 54% of yield variability (R^2=0.54). Crop duration was selected as the second parameter in the sequential fit; its inclusion in the model accounted for a further 9% of the yield variability (R^2=0.09). These two factors together accounted for 63% of total yield variability (R^2=0.63) (Table 3).

Table 3. Sequential regression analysis for cassava yield in relation to soil quality score and crop duration.

Variable	DF	SS	MS	F	R^2
Soil quality score (SQ) and crop duration (CD)	2	708.4	354.2	35.6**	0.63
SQ alone	1	602.9	602.9	60.5**	0.54
CD after SQ	1	105.5	105.5	10.6**	0.09
Residual	42	418.3	9.9		

** Significant at P≤0.01.

Figure 3 illustrates the influence of soil quality as scored by farmers on cassava yield in their fields. Lower yields were found to be associated with lower soil quality. Clearly, the farmers were well aware of the quality of their soils. This result indicates that soil fertility is a major constraint affecting cassava yields in Kampong Cham province.

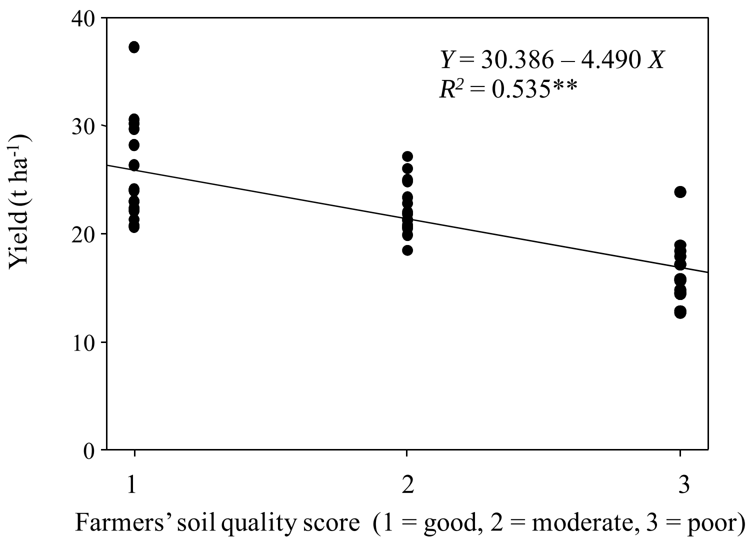

Figure 3. Relationship between actual cassava yield and farmers' soil quality score.

Although the average yield in fields that received chemical fertilizer (25.9 t ha^{-1}, average of 10 fields) appeared to be higher than for the non-fertilized fields (20.3 t ha^{-1}, average of 32 fields), the difference could not be accounted for by fertilizer application alone, as there were confounding effects of other factors, particularly crop duration. In addition, the average yield from fields that received manure (20.8 t ha^{-1}, average for 3 fields) did not differ from that of the non-fertilized fields, presumably due to confounding effects of other yield limiting factors. Nevertheless, the significantly higher yield (37.2 t ha^{-1}) obtained from the field located near the rubber plantation, which presumably received an inflow of nutrients from the rubber field, provides additional evidence of the soil fertility constraint in the area.

Further direct evidence of a nutritional constraint to cassava yields in Kampong Cham came from the soil analysis data. Comparisons of the soil analysis values for total N (Kjeldahl method), available P (Bray II) and exchangeable K (Ammonium acetate 1 M pH 7.0) against the corresponding critical values (Howeler, 2002), indicated that 39 of the 45 fields (87%) were deficient in one or more of the three nutrient elements, while 6 fields (13%) were not deficient in any nutrient. The majority of the fields (21 fields, 47%) were deficient in P, while five fields (11%) were deficient in K and one field (2%) was deficient in N. The number of fields that were deficient in two nutrient elements ranged from 1 to 6 (2 to 13%), and three fields (7%) were deficient in all three nutrient elements (Table 4). Apparently, most of the fields in all four zones were deficient in one or more of the major nutrient elements. This could be accounted for by the continuation of the current management practices in which very little fertilizer or manure was applied over the past years, as the nutrient balance analysis of these fields indicated significant negative balances for N, P and K of the current cultivation practices (Sopheap et al., 2012). Clearly, soil nutrient status is an important factor contributing to the cassava yield variation in Kampong Cham province. This result is consistent with the general conditions of cassava production reported for other countries (Howeler, 1992; Howeler, 2002; Fermont et al., 2009).

Table 4. Number of fields that showed deficits[1] in different nutrient elements.

Zone	Total no. of fields	Deficit in N, P and K	Deficit in N and P	Deficit in N and K	Deficit in P and K	Deficit in only N	Deficit in only P	Deficit in only K	Non-deficit
Zone 1	12	2	1	1	3	1	2	2	0
Zone 2	10	0	0	0	0	0	8	0	2
Zone 3	12	1	0	0	2	0	8	0	1
Zone 4	11	0	0	1	1	0	3	3	3
Total	45	3	1	2	6	1	21	5	6
Percent	100	6.7	2.2	4.4	13.3	2.2	46.7	11.1	13.3

[1] Critical value below which a deficit is defined: Total N=0.16%, available P=6 mg kg^{-1}, exchangeable K=0.15 meq $100g^{-1}$. Source: Howeler (2002).

The influence of crop duration on cassava yield in Kampong Cham province is shown in Figure 4. Clearly, the longer is the crop duration the higher the crop yield. Crop duration, in turn, is highly correlated with planting date, with later plantings being associated with shorter crop duration. This was because of a wider spread of planting dates than for harvest dates as the sampled cassava fields were planted during the early-rainy season, from early April until the end of June, and were harvested during the period from early December until late January (Figure 5). The effect of crop duration on yield was, therefore, confounded with the effect of planting date and could not be separated. However, regression analysis did indicate that crop duration was more important than planting date in influencing yield, and this was supported by crop physiology reasoning. Crop duration was, therefore, taken to be a significant factor affecting cassava yield in the present study.

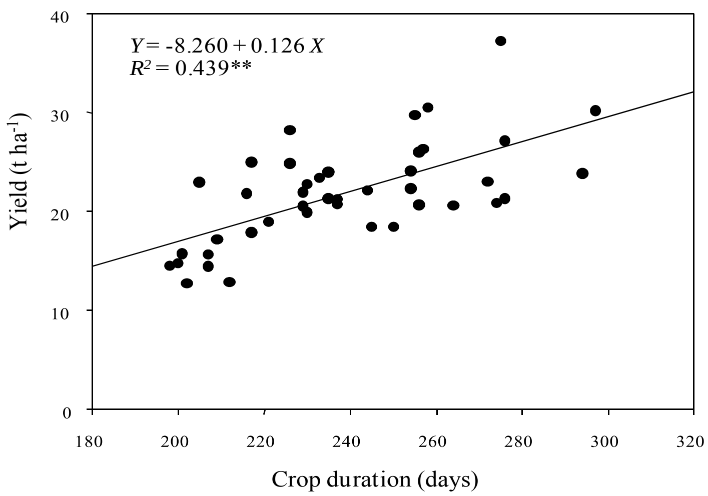

Figure 4. Relationship between actual cassava yield and crop duration.

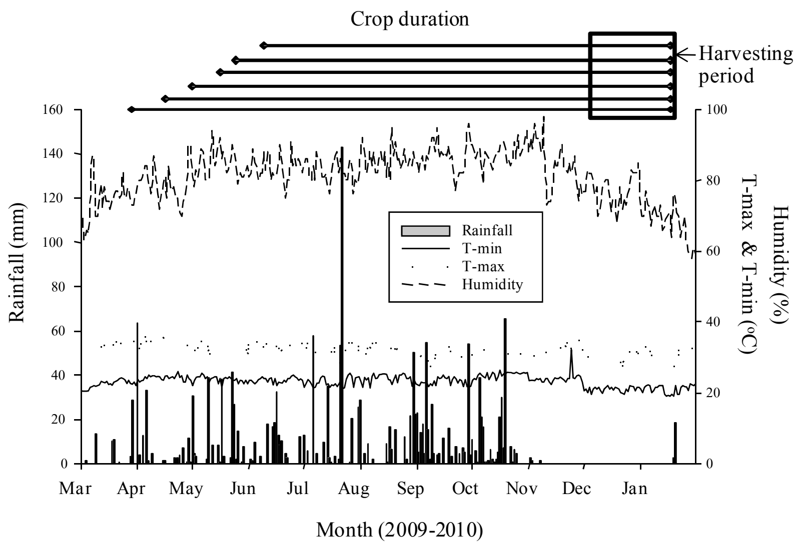

Figure 5. Crop durations for different planting dates.

Although the sequential regression analysis did not identify weed density as a significant factor for yield variation, comparisons among mean yields indicated some effect of weed density on cassava yield. On average, there was no difference in cassava yields between the low weed density and the medium weed density fields, with means for crop yield being 23.6 and 23.0 t ha^{-1}, respectively. Yield, however, was significantly lower (14.8 t ha^{-1}) at the high weed density (Figure 6). Weed density was highly correlated with the number of weedings, i.e., more weedings were associated with lower weed density. It was, therefore, concluded that weed density is another yield influencing factor in the present study.

Although cassava in the study areas was grown under rainfed conditions, the annual rainfall of 1,752 mm was well distributed throughout the rainy season (Figure 5), and drought was not anticipated to be the major production constraint in the present study. It is acknowledged that irrigation can potentially give higher yields than under rainfed conditions; however, irrigated cassava cultivation is not a practical option for farmers in the study area. No serious insect and disease damage to the crop was observed in sampled farmers' fields. Therefore, insects and disease were not regarded as constraints for cassava production in Kampong Cham at the time of the study.

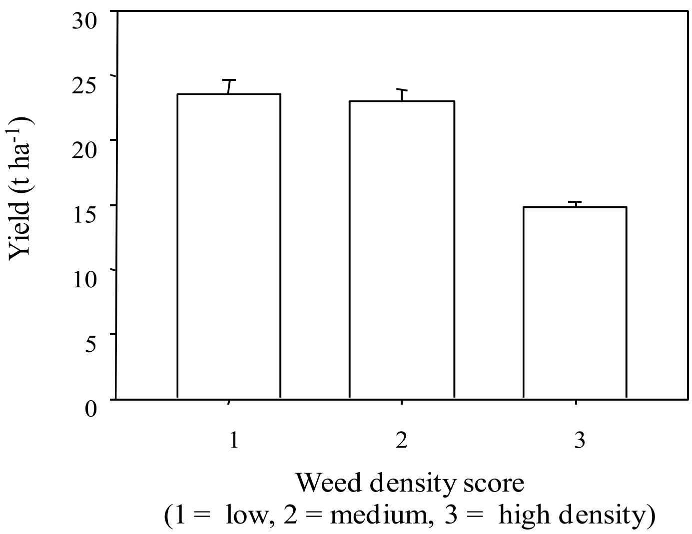

Figure 6. Mean for cassava yield (with standard error) for different weed density scores.

Factors causing cassava yield gaps at different yield levels

Table 5 shows a selection of fields in the different yield groups, giving their yield values and factors identified as yield influencing factors. It can be seen that the field with the highest yield (37.2 t ha^{-1}) had all the yield influencing factors in the favorable category, i.e., good quality soil, long crop duration, fertilized and low weed density. To the contrary, all fields in the lowest yielding group had all these potentially yield influencing factors in the unfavorable category, i.e., poor quality soil, short crop duration, unfertilized and high weed density. Those in the moderately high yielding group had one or two factors in the low or moderate categories, but these factors differed for the different fields. For example, the field with 30.2 t ha^{-1} yield had medium weed density, while the field with 28.2 t ha^{-1} yield had moderately long crop duration and was unfertilized. The number of constraining factors and/or level of constraint increased in lower yielding fields, while the constraining factors also varied among the different fields. Thus, a field in the medium yielding group might have two serious constraining factors, e.g. the field with 23.8 t ha^{-1} yield, or have three factors at medium constraint levels e.g. the field with 22.8 t ha^{-1} yield, while a field in the moderately low yielding group might have three constraining factors, e.g., the field with 17.2 t ha^{-1} yield, or four factors, some of which were at medium levels, e.g. the field with the 18.4 t ha^{-1} yield. Fermont et al. (2009) also found that many cassava fields in Africa were affected by multiple and interacting production constraints, and suggested that these constraints should be addressed simultaneously if significant productivity improvements are to be achieved.

Table 5. Cassava yield and factors influencing yield for selected fields in the different yield groups.

Category	Yield[1] (t ha^{-1})	Factor influencing yield			
		Soil quality	Crop duration[2]	Fertilizer application	Weed density
Very high	37.2	Good	Long	Yes	Low
High	30.2	Good	Long	Yes	Medium
	28.2	Good	Moderately long	No	Low
	26.3	Good	Moderately long	Yes	Medium
Moderately high	23.8	Poor	Long	Yes	Medium
	22.8	Moderate	Moderately short	No	Medium
	21.8	Moderate	Moderately short	Yes	Low
Moderately Low	18.4	Poor	Moderately long	No	Medium
	17.2	Poor	Short	Yes	Medium
	15.7	Poor	Short	No	High
Low	12.9	Poor	Short	No	High
	12.7	Poor	Short	No	High

[1] Fresh weight yield.

[2] Short=198-222 days, moderately short=223-247 days, moderately long=248-272 days, long=273-297 days.

The results of this study indicated that substantial improvement in cassava yields in Kampong Cham province can potentially be achieved by removing or alleviating the prevailing constraints, as low to moderate yielding fields accounted for 82% of the fields covered by the study. Soils nutrient deficits could be removed by appropriate nutrient management treatments, while early planting could extend crop duration, and weed populations could be controlled by more frequent weeding or other appropriate measures. However, as different fields often have different constraints, different technologies or improved management practices are needed in improving cassava yields in individual fields.

Conclusions

The results of this study reveal substantial variations in cassava yields in Kampong Cham province in Northeast Cambodia. The maximum yield obtained (37.2 t ha^{-1}) was considered to be representative of the maximum potential farm yield under rainfed conditions. However, large yield gaps relative to the maximum yield were shown for most fields, with the potential for doubling the yield in more than 50% of the fields. The main yield constraints identified were-soil nutrient deficits, short crop duration and high weed density. The highest yielding field exhibited none of these constraints, while declining crop yields were associated with increasing numbers of constraints, but the constraints sometimes differed for different fields at the same yield level. The lowest yielding fields had all three factors as constraints. Different technologies or improved management practices are needed to improve crop yields for the individual fields. Thus, strategies need to be devised to target technologies that are appropriate for individual fields.

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