Improving the sustainability, productivity, and livelihood impacts of smallholder cassava production

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ABSTRACT

Cassava is grown in SE Asia as food, feed for animals, and as a source of starch for processing into a myriad of products for a wide range of uses. As the importance of cassava as a feedstock for processing has increased, and as cassava root and starch prices have increased, so the importance of cassava in income generation and in poverty alleviation has increased. Cassava grows quite well under conditions of low soil fertility and water availability and grows in difficult environments. The ability of cassava to grow in poor soils and erratic rainfall makes it a favourable crop for the poor and, at the same time, a crop that responds well to improved management. The development of improved varieties has increased the potential yields by smallholders. On-farm research with farmers in Cambodia and Laos has shown that new varieties plus improved soil fertility management, through inorganic and organic fertilizers, intercropping, and erosion control, produce significant returns on investment. Intercropping provides further benefit by improving food security and increasing income. Improved postharvest handling, for on-farm feeding systems or for feedstock for the processing industries, has resulted in further income and flexibility for smallholders and a simple harvesting tool has increased labour productivity. While the new varieties have been adopted widely and approximately doubled average root and starch yields, many of the other improvements in production, which have great potential benefits for sustainability and profitability, have not been adopted as widely. The prospects for much greater technology transfer are huge, as is the potential for more South-South learning and exchange.

Keywords: cassava, improved management, sustainable production, livelihoods

INTRODUCTION

Cassava has been grown in Asia for at least two centuries, with the majority of early production being for direct human consumption. By the 1960s, agricultural statistics record that there were more than 2 million ha of cassava grown across Asia (FAOSTAT, 2013), with 70% of this area being in Indonesia, where the vast majority was used for food, snacks, or other products for human consumption. Through the 1970s and 80s there was a rapid increase in the area under production, primarily in Thailand. This rapid expansion was driven by the export trade to Europe for animal feed. By the end of the 1980s Thailand had the largest area in the region under cassava, with about 1.5 million ha of the total 4 million in Asia, and between them Thailand and Indonesia accounted for about 75% of the total area. The trade in dried cassava chips for animal feed in Europe began to collapse in the early 1990s and the area under cassava in Asia declined, particularly in Thailand. Since the late 1990s the market has recovered, although now driven by increased demand for cassava in a wider range of food, feed, pharmaceutical, industrial, and energy sectors and for markets outside Europe, particularly in East Asia, and most particularly in China.

While some cassava in the region is grown in plantations by large companies, the vast majority of the 4 million ha grown in Asia is grown by smallholders, involving an estimated 8 million farming households. Cassava is a water and nutrient efficient crop that can be grown more easily than many other crops on poorer soils and in less reliable rainfall areas. This makes cassava an attractive crop for poorer smallholder farmers. Although well suited to low input agriculture in more marginal areas, cassava responds well to improved soil fertility, water regimes, and management.

The increase in production in Asia during the 1970s and 80s, particularly in Thailand, was driven primarily by an increase in the area grown. In the 1980s, CIAT, which holds the world collection of cassava and cassava wild relatives in trust, started a breeding program to improve cassava yields and starch content in Southeast Asia based on the well-adapted landraces and selections grown in Thailand at the time. Through collaborative work with Thai breeders, new varieties began to be released from the early 1990s, which resulted in a steady increase in yield by more than 50%. The same or related materials were evaluated and released in Vietnam, and during the first decade of this century Vietnam experienced a more than four-fold increase in production, based on a doubling or more of both the area grown to cassava and the yield, as new varieties were adopted.

As new markets have developed and demand has expanded there have been significant impacts of cassava as a crop that can improve the livelihoods of the poor. As production increased, so did processing, first to process dried chips and then to produce starch, modified starch products, bioethanol, and other products. It has been estimated that the increased benefit to farmers attributed to the increases in yield from improved cassava varieties totaled more than US$12 billion in the last two decades across the Greater Mekong Subregion (GMS) (Ebata, 2011). With trends for increasing demand and prices, these prospects remain very high, and not just for Thailand and Vietnam. The areas grown to cassava have increased in other countries in the region. Most particularly in Cambodia, where the area has increased more than ten-fold over the last decade, but also in Myanmar and the Lao PDR. Even in Indonesia, where the area has declined over the last 50 years by about 10%, the production has almost doubled with improvements in management and varieties.

It is estimated that 50% of the cassava grown in Asia and perhaps 80% in the GMS countries is with varieties produced at CIAT, in collaborative breeding programs in Southeast Asia, or using breeding material from CIAT. The adoption of new high yielding and high starch varieties has been widespread, however, adoption of improved management has been much less.

With any improvements in crop genetics, there are usually equivalent improvements in production that can be gained through better management of the crop. Long term trials on research stations, as well as shorter term studies on farmers fields in Thailand and Vietnam, have shown that improved soil fertility, erosion control, and other activities, such as intercropping, combined with labour-saving procedures and improved links to markets can increase yields, profit, and sustainability. Evidence suggests that most of the increases in cassava yield and income have resulted from improved varieties and comparatively little from the adoption of improved management, so there is scope for further improvement.

RESULTS IN SATNET COUNTRIES

While the initial applied research for development on cassava in Southeast Asia and the initial increases in yields and production were in Thailand and then Vietnam, there was no reason to believe that the same advances in production could not occur in other Southeast Asia countries. Through a series of on-station trials and participatory on-farm evaluations this has been shown to be the case in Cambodia and Lao PDR, and to a lesser extent in Myanmar. CIAT has worked to evaluate cassava production systems with researchers from the Provincial Department of Agriculture, Forestry and Fisheries, the Cambodia Agriculture Research and Development Institute (CARDI), and the Royal University of Agriculture (RUA) in Cambodia, and researchers from the National Agriculture and Forestry Research Institute (NAFRI) in the Lao PDR.

Varieties

New varieties and breeding lines were tested in various agro-ecological zones to evaluate their suitability to specific environments. Using a Farmer Participatory Research (FPR) methodology, cassava varieties were tested by farmers on their own fields at the same time as longer-term experiments were conducted on-station. Across the more than 20 on-farm and FPR-trials conducted in Cambodia during 2005-2012, varieties such as KU 50 and Huay Bong 60 from Thailand and SC8 and SC9 from China consistently out-yielded local varieties (Table 1). In these trials, fresh root yields varied between 15 and 55 t/ha and fresh top yields between 10 and 20 t/ha, depending on variety, soil fertility, climate and management. Similarly, across the more than 50 trials, mainly on-farm FPR trials, conducted in Lao PDR during 2005-2012 several varieties, such as Rayong 72 and KU 50 from Thailand and KM 98-1 and KM 140 from Vietnam, consistently out-yielded local varieties. In this situation, the fresh root yields varied between 10 and 45 t/ha and fresh top yields between 7 and 20 t/ha, depending on variety, soil fertility, climate, and management.

Table 1. Results of cassava variety trials conducted in Kampong Cham province of Cambodia averaged for the production seasons of 2010/11 and 2011/12

Variety	Fresh root yield (t/ha)	Starch content (%)	Starch yield (t/ha)
KU 50	55	27.8	15.3
Hauy Bong 60	54	29.2	15.7
SC 8	51	26.0	12.4
SC 9	42	27.3	10.8
SC 5	40	28.4	10.2
Rayong 1	40	25.2	9.9
Rayong 90	37	31.4	11.1
KM 98-1	36	31.7	10.7
Rayong 60	35	28.2	9.5
Rayong 9	35	31.4	10.7
OMR 36-31-1	34	28.9	9.6
Rayong 7	30	30.4	8.8
Batrang	30	26.9	7.4
Rayong 72	30	31.4	9.2
SC 201	30	23.0	6.9
Nanzhi 199	29	29.5	8.5
Nep	25	25.3	6.1
GR 891	25	27.9	6.4
Rayong 5	18	31.4	5.7
Damlong Kor (Local)	11	22.4	3.6

The involvement of farmers, extension workers, and development projects in the evaluation of new varieties has increased our understanding of the suitability of varieties at the same time as helping in the extension process to adopt these higher yielding and higher starch content varieties. Adoption has been widespread in both countries, with these varieties becoming the varieties of choice, especially for new plantings, where planting material is available. The adoption of these improved varieties is an essential entry point to improved livelihoods, but also to further modify cassava production systems to make them as sustainable, resilient, and profitable as possible.

Balanced soil fertility management

Although cassava grows quite well on relatively infertile acid upland soils, has an efficient nutrient acquisition capacity, especially for phosphorus, and recycles a substantial amount of nutrient uptake in leaf drop, like most crops it responds well to improved soil fertility. The net removal of nutrients per kg of product, in this case roots, is relatively low compared to many other crops, although considering the large amount of roots that can be removed from the field, the removal of nutrients, particularly of K, is significant (Table 2). Again, like all crops, if the nutrients removed are not replaced the soil fertility will decline and there will be a net decline in top growth, in root growth and quality, and in the quality of the stem, and thus in the following crop grown from these stems.

Table 2 Average nutrient removal (kg/t DM & kg/ha) in the harvested products of various crops

	Yield (t/ha)		Nutrients removed					
			kg/t Dry Matter			kg/ha		
Crop (plant part)	Fresh	Dry	N	P	K	N	P	K
Sorghum (dry grain)	3.6	3.10	43.3	9.40	9.4	134	29.0	29
Cassava (fresh roots)	35.7	13.53	4.5	0.83	6.6	55	13.2	112
Sweet potato (fresh roots)	25.2	5.05	12.0	2.63	19.2	61	13.3	97
Tobacco (dry leaves)	2.5	2.10	24.8	2.90	50.0	52	6.1	105
Sugarcane (fresh cane)	75.2	19.55	2.3	0.91	4.4	43	20.2	96
Soybean (dry grain)	1.0	0.86	69.8	17.79	77.9	60	15.3	76
Groundnut (dry pod)	1.5	1.29	81.4	5.04	27.1	105	6.5	35
Maize (dry grain)	6.5	5.56	17.3	3.13	4.7	96	17.4	26
Rice (dry grain)	4.6	3.97	17.1	2.4	4.1	60	7.5	13
Wheat (dry grain)	2.7	2.32	24.1	5.17	5.6	56	12.0	13
Beans (dry grain)	1.1	0.94	39.6	3.83	23.4	37	3.6	22

Source: Howeler 1991 Assuming Dry Matter: Cassava 38%, Grain 86%, Sweet potato 20%, Sugarcane 26%, Tobacco 84%

The need for soil fertility improvement and the rate of fertility decline will depend on the inherent soil fertility and on the cropping history. As much of the land used for cassava is relatively infertile and often cropped repeatedly, the need for soil fertility management is expected and generally the returns on investment in inorganic and organic fertilizers are high.

In the short-term, on newly cropped soils, there are often no significant responses to the application of chemical fertilizers, or the response is mainly to N and P if the soil is inherently very infertile. The response to fertilizers tends to increase over time due to the depletion of soil nutrients in the harvested roots. In most cases K, which is removed in large quantities in the roots (Table 2), becomes the most limiting nutrient such that after several years of continuous cassava production yields will decline unless K is applied. N may be removed in large quantities if leaves and stems are also taken from the field. Roots contain relatively small amounts of P, so P removal from the soil in the root harvest is therefore much lower than that of N or K. In some soils, however, such as some in parts of Lao PDR, where the soils are extremely P-deficient, there is virtually no yield of cassava (or other crops) without applications of phosphorus.

Long-term soil fertility management trials in a number of sites have shown that stable yields can be maintained for decades with the right fertility management. Smallholder farmers have been involved in evaluating soil fertility management practices on their own farms. Such participatory approaches help to better understand the site-specific responses to fertility management and start the process of extension and adoption of improved management by farmers. The example from Xieng Khouang (Table 3) shows the importance of K and, for these soils, the relative importance of P. While the higher applications often produce better yields, high imbalanced applications can result in reduced yields. In terms of cost effectiveness some of the mid level application rates are clearly the more profitable, with the best combination vary as the sale price of roots and the purchase price of different fertilizers vary.

Table 3 Average response to fertilizer applications in two trials in Xieng Khouang, Lao PDR from 2005 to 2009

Nutrient Treatments (kg/ha)			Average Root Yield t/ha (*rank*)					
N	P_2O_5	K_2O	KU 50		Local		Average	
100	200	200	43.9	*1*	29.1	*3*	36.5	*1*
50	100	200	41.0	*3*	29.9	*2*	35.5	*2*
50	200	100	37.3	*5*	32.1	*1*	34.7	*3*
100	100	100	35.9	*6*	21.6	*7*	28.8	*7*
50	100	100	33.8	*8*	19.6	*9*	26.7	*8*
25	100	100	42.8	*2*	26.6	*5*	34.7	*3*
0	100	100	38.0	*4*	21.0	*8*	29.5	*6*
50	50	100	35.9	*6*	27.2	*4*	31.6	*5*
50	100	50	28.4	*9*	21.7	*6*	25.1	*9*
50	0	100	16.4	*10*	6.2	*11*	11.3	*11*
50	100	0	12.5	*12*	8.6	*10*	10.6	*10*
0	0	0	13.2	*11*	3.6	*12*	8.4	*12*
		Average	31.6		20.6		26.1	

Erosion control

Cassava has the reputation of causing serious soil degradation due to excessive uptake of nutrients leading to soil nutrient depletion, but this is a common misconception. Cassava is often grown by poor farmers trying to make a living on poor and degraded soils with no or little inputs as cassava is one of the few crops that will grow on these soils. As with other crops, continued cultivation can have a detrimental effect on the chemical and physical properties of soils, however, there is good evidence that with improved management of the crop high yields can be maintained for many years.

Cassava in Southeast Asia is often grown on land with rolling topography or, in some countries, on rather steep land in mountainous areas. In both cases, there can be a high risk of soil erosion. The slope of the land, the length of the slope, the soil type, the degree of ground cover, and the intensity of rainfall all affect the erosion process. Even on gently sloping land, cassava cultivation may result in serious erosion if the soil is light textured, if there is little ground cover at times of high rainfall intensity, and if there is no proper soil erosion control.

Erosion results in deteriorating soil physical and chemical characteristics, which in turn affects the productive capacity of the soil. Shallow soils or those having unfavorable subsoil are most affected, and highly demanding crops like maize and soybean are more susceptible to yield declines than less demanding crops like cassava.

Simple cultural practices can significantly reduce the potential soil erosion during intensive rainfall events. For instance, the detachment of soil particles, the first step in soil erosion, can be reduced by protecting the soil surface through closer plant spacing, mulching, minimum tillage, intercropping, or applying fertilizer to increase plant growth and speed up canopy closure. The risk of detachment varies with soil type and quality, as well as rainfall intensity, and is inversely related to clay content and soil organic matter content. Similarly, potential erosion can be reduced by reducing the removal of detached particles in runoff by shortening the length of the slope. This can be achieved by providing restrictions to water movement on the contours across the slope by using vegetative barriers, such as strip cropping, hedgerows of grasses, legumes, and/or trees, intercropping, and unploughed strips, or providing physical barriers such as contour ploughing, contour ridges, and other physical barriers such as rocks, tree trunks, or even walls. The strength of these barriers needs to increase with increasing slope and the spacing of barriers down the slope needs to decrease with increasing slope. Some of these barriers have the additional impact of reducing the slope as they lead to the formation of terraces.

The choice of erosion control measures is not only based on their effectiveness (and thus the prevention of soil loss, fertilizer lose, runoff, and yield decline), but also on the cost of implementation in terms of labour, materials, maintenance, and replacement, as well as production losses or even production gains. Planting contour hedgerows of vetiver grass, *Paspalum atratum* grass or *Tephrosia candida* shrubs have been found to be quite effective in reducing erosion and increasing yields by natural terrace formation and by preventing the loss of the fertile top soil, of applied fertilizers, and of water. Also, they are popular as they only take up a small area, so have a minimal impact on the area for cassava. In addition, *Paspalum* is a good animal feed and *Tephrosia* can contribute to soil fertility improvement. Other measures, such as strip cropping and intercropping can be popular, even if they decrease the area grown to cassava or yield of cassava through competition, because they provide additional production and income. In addition to these immediate direct and indirect benefits from the different erosion control methods, the longer term benefits need to be considered, as erosion and runoff are reduced and the long-term sustainability of the systems are improved.

When grown on slopes without proper soil management, production of cassava in Laos was found to result in greater soil losses by erosion than other crops. Of the methods for reducing erosion that were evaluated, the most effective in terms of reducing soil loss were the use of various live barriers (hedgerows) and intercropping with peanut (Table 4).

Table 4 Comparison of soil erosion control measures in cassava-based systems in Xieng Khouang Province, Lao PDR (2007/8 to 2008/9)

Treatments: Hedgerows, intercropping, and fertilizer	Stakes / hill	Hill spacing	Dry soil loss (t/ha)
Hedgerow of *Paspalum atratum* with fertilizers and lime	1 stake/hill	*0.9 x 0.9 m*	7.0^{a}
Hedgerow of *Tephrosia candida* with fertilizers and lime	1 stake/hill	*0.9 x 0.9 m*	7.8^{a}
Contour ridging, with fertilizers and lime, no hedgerows	1 stake/hill	0.9 x 0.9 m	8.5^{a}
Hedgerow of Vetiver grass with fertilizers and lime	1 stake/hill	0.9 x 0.9 m	8.8^{a}
Peanut intercrop (2 rows), fertilizers and lime and no hedgerows	1 stake/hill	0.9 x 0.9 m	9.4^{a}
Closer plant spacing with fertilizers and lime, no hedgerow	1 stake/hill	0.7 x 0.7 m	9.6^{a}
Hedgerow of pineapple, with fertilizers and lime	1 stake/hill	0.9 x 0.9 m	11.1^{ab}
No ridging, fertilizers and lime and no hedgerows	1 stake/hill	0.9 x 0.9 m	12.3^{b}
Traditional practice: no fertilizer or lime, no hedgerows, no ridging	2 stakes/hill	0.9 x 0.9 m	19.4^{c}
Up-down ridging, with fertilizers and lime, and no hedgerows	1 stake/hill	0.9 x 0.9 m	32.7^{d}
LSD (5%)			4.0

Intercropping

In addition to being an important method for reducing erosion in cassava fields, by protecting the soil surface and slowing the movement of water down the slope, intercropping has many other advantages for smallholder farmers. Intercropping provides biophysical diversity of crops, and thus can reduce the risk of complete crop failure, some economic resilience against market variability, and additional food or income at different times of the year. It may also improve use of available farm land and labor and, especially in the case of legumes, may contribute positively to soil fertility.

The biophysical productivity of intercropping systems depends on a number of factors, particularly the choice of the right crop combination in terms of plant type and/or growth habit, and the management of interspecific competition through the choice of planting patterns, planting times, and the management of soil fertility and soil moisture (Aye and Howeler, 2012). As a longer season crop that establishes quite slowly, cassava is well suited to intercropping with a range of shorter season crops. In terms of economic benefits, the yield, price, and ease of marketing of the intercropped species, in combination with the yield and price of cassava, will be the major deciding factor in the choice of which crop to use. The use of high-value short-term intercrop species not only helps with income and cash flow but can also justify inputs such as fertilizer that benefit both the intercrop and the cassava.

In a study in Lao PDR (Table 5), different legume crops were evaluated, with different levels of competition or benefit to the cassava, and with different yields of the legume. Given the relative yields and prices, peanut was the preferred intercrop species in this instance.

Table 5 Comparison of intercropping options near Vientiane, Lao PDR in 2006/2007

Treatment	Cassava root yield (t/ha)	Intercrop grain yield (t/ha)
Cassava (monocrop)	23.7	-
Cassava with soybean	25.5	0.18
Cassava with peanut	25.0	0.64
Cassava with mung bean	22.8	0.32
Cassava with rice bean	20.5	0.13

Harvesting cassava

Cassava can be harvested at any time because it does not have a specific maturity and ripening stage. Generally, farmers harvest cassava at 10-11 months after planting, depending upon the climatic and soil fertility conditions, as well as marketing opportunities and price. Some smallholder farmers may not harvest all their cassava at one time, but instead harvest the plants or even the roots one-by-one for their own home consumption and for animal feeding.

The optimum time to harvest cassava varies between varieties. If farmers harvest a variety of cassava earlier than its optimum period, they are likely to get a reduced yield, and if they harvest later than the optimum, the starch and dry matter content may be low. Importantly, cassava should not be harvested after the onset of rains that follow a dry period, because at that time the starch content in the roots declines noticeably as the plants remobilize starch to drive the development of new leaves. Farmers can check the starch content in the roots by scratching a finger nail across the cut surface of a root. When a milky liquid oozes out, the starch content is high enough for harvesting.

Cassava can be left to grow for more than one season, resulting in further increases in yield of roots and starch, although care needs to be taken to avoid periods of starch remobilization and growing for too long, which leads to increased fiber content, but this is usually after 24 months or more. While extending the growing season of the crop does lead to a long period without income, if the cash flow can be managed, the benefits of higher yield, some reduction in labour costs per unit of roots, and reduced risk of erosion, through less frequent disturbance of the soil, can be beneficial. There is also the potential to manage both planting and harvesting to better suit the feedstock demands of the processing industry and so perhaps benefit in price by matching supply to the demand of processors.

Cassava is harvested by pulling the roots out of the ground, which can be time consuming and hard work, especially with unfavorable soil moisture conditions at the time of harvest or in heavy textured soils. Normally, farmers use very simple tools such as hoes, spades or digging sticks. The development of a simple harvesting tool, based on the principle of a lever, has facilitated harvesting. This simple yet innovative tool can be manufatured easily with a sale price of US$2-3. It helps alleviate back pain and fatigue, reducing the drudgery of harvesting, especially for women, and results in a doubling or more of labour productivity (Table 6).

Table 6 Comparison of labour savings with two methods for harvesting cassava systems

Soil type	Harvesting Method and Labour Use (man-day/ha)		Labour-saving
	Manual	Harvesting tool	
Clay loam	14-20	6-10	8-10
Loamy	10-16	4-8	6-8
Sandy loam	8-12	4-6	4-6

Farmer may also use various animal drawn or tractor-mounted tools to lift the roots to facilitate harvesting, and fully mechanized equipment can be considered in large-scale plantations when labor is scarce or expensive.

Improved postharvest handling, for on-farm feeding systems or for supplying feedstock for the processing industries, has resulted in further income and flexibility for smallholders. Simple equipment to chop roots and leaves can facilitate these processes and further increase labour productivity.

CONCLUSION

The current and projected demand for cassava indicates that cassava remains a good option for livelihood improvement for smallholder farmers in Southeast Asia. To maximize the livelihood benefits, maximize the biophysical and economic resilience, and maintain sustainable production in these systems requires good management. The adoption of improved varieties is an excellent entry point to greater livelihood improvement through cassava production, but this needs to be combined with good crop management in terms of soil fertility management, avoidance of soil degradation, intercropping for economic and crop management benefit, the adoption of labour-saving procedures, and the efficient links to markets. Much is known about all of these components so the challenge is to develop a greater knowledge of the site-specificity of the management approaches and to develop efficient and accurate ways for smallholder farmers to access this knowledge, primarily through extension services and service providers.

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