

## **15. Economic prospects for root and tuber crop utilization for starch and animal feed in Asia**

Keith O. Fuglie

### **Abstract**

In Asia, the role of tropical root and tuber crops is changing from being food staples to sources of raw materials for processed food products and animal feed. The growing utilization of root and tuber crops in these expanding markets depends critically on price competitiveness relative to other commodities, especially maize. In this paper, price relationships among commodities in Asia are examined to assess the potential of cassava and sweetpotato in starch and feed markets. For starch, cassava is competitive in Southeast Asia. Sweetpotato is competitive in selected starch markets in China, but faces increasing competition from maize. Crop breeding to increase starch yield from cassava and sweetpotato will improve their competitiveness in these markets. In feed markets, millers are likely to prefer maize over root and tuber crops due in part to the higher cost of protein supplements when using root and tuber crops. Sweetpotato is a viable feed option for small farmers who grow their own feed so long as the protein rich-riich foliage can be effectively incorporated along with starchy roots in feed rations.

### **Introduction**

It is a well-known “law” of economics that as income rises the per capita consumption of starchy food staples falls. What was observed in Europe and North America in the 19<sup>th</sup> and early 20<sup>th</sup> Centuries is taking place in Asia in the late 20<sup>th</sup> and early 21<sup>st</sup> Centuries. In western countries, white potatoes gave way to wheat as the preferred staple once consumers could afford the more expensive cereal grain. In Asia, the tropical root crops (cassava and sweetpotato) along with coarse gains (maize, sorghum, and millet) are similarly giving way to rice and wheat as incomes rise.

This trend toward declining per capita consumption does not, however, imply a declining importance of tropical root and tuber crops in Asian agriculture. Rather, what is taking place is a rapid transition in utilization of these commodities. Instead of being consumed directly, tropical root and tuber crops are being converted into high-valued foods such as meat (through use as animal feed) and processed products like starch noodles. Per capita consumption of these products is on the rise, and as a consequence the future prospects of market demand for tropical root and tuber crops are promising. In China, much of this transition has already occurred: Huang et al. (2002) estimated that by 1997, 74 percent of sweetpotato production was already being used for animal feed or starch. In Thailand, Boonjit (1999) estimated that in 1997 around 60 percent of Thailand’s cassava production was exported for use in animal feed and up to 40 percent was destined for starch extraction. These trends are expected to continue in China and elsewhere in Asia. Scott, Rosegrant and Ringler (2000) projected that between 1993 and 2020 the total market demand in China for cassava and sweetpotato would grow faster than the growth in demand for the main food staple, rice. For Southeast Asia, this study projected faster growth for sweetpotato than rice, with cassava

slightly lower than rice (Table 1). Most of the projected growth in demand for cassava and sweetpotato was expected to occur in the markets for animal feed and starch.<sup>1</sup>

For an agricultural commodity to become an important raw material for animal feed or starch-based products requires that its supply be dependable and its price competitive with alternatives. For many value-added uses, root and tuber crops must compete against maize, rice, wheat, and other sources of raw materials. In addition, root and tuber crops, due to their high water content and perishability, may require additional conditioning (e.g., chipping and drying) to put them into forms that are more easily storable and transportable. But past experiences in Asia suggest that root and tuber crops can in many cases compete effectively with cereals in these markets. The development of cassava-based livestock feeds in Thailand and Indonesia in the 1980s, and sweetpotato-based food processing in China in the 1980s and 1990s, illustrate the potential for these crops to fulfill demands for value-added products. The same characteristic that makes root and tuber crops an important food staple for low income consumers gives them potential for value-added processing: *they are versatile and inexpensive sources of food energy (carbohydrates)*.

My purpose in this paper is to analyze the underlying reasons driving the increased utilization of tropical root and tuber crops in Asia. Utilization of cassava and sweetpotato for food, feed, and starch is likely to vary significantly within the region. It will depend on a number of factors, such as the rate of global and regional economic growth, choices in government policy, and, most importantly, the comparative cost of commodities. In the next section I show the present relative cost of carbohydrates (e.g., starch) from various commodities in different Asian countries. I also examine what would happen to market utilization if the costs of starch from root and tuber crops could be reduced through the efforts of plant breeders to raise starch yield. In the third section I extend the analysis to markets for animal feed. I use a linear programming model to assess least-cost sources of pig feed rations (pigs are the most important animal commodity in non-Muslim countries of East and Southeast Asia). Deriving least-cost feed rations requires consideration of the cost of not only carbohydrates but also protein, the two major ingredients of balanced feed rations. The final section summarizes the major findings of the paper.

### **Relative Prices of Carbohydrates from Agricultural Commodities**

To derive estimates of the relative cost of carbohydrates (starch) from different crop commodities, I use FAO producer prices data from 1980 to 1995 and standard starch conversion rates. Included in the analysis are sweetpotato, cassava, white potato, maize, and wheat for several countries. To eliminate the effects of inflation on prices, the price of each commodity is divided by the price of maize in a country for a given year. Thus, all commodity prices are expressed relative to the price of maize, and then the 16-year average price is calculated. Using the average relative price over a long period of time avoids the influence of yearly fluctuations and gives a clearer picture of long-run relative costs.

One limitation of this approach is that prices are only reported for commodities produced in a country. Thus, the results don't tell us whether imported cassava can effectively compete against maize or wheat starch in Japan, since cassava is not grown by Japanese farmers. Furthermore, these prices are national averages, and do not take into account

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<sup>1</sup> See Fuglie and Oates (2002) for an analysis of the growing demand for starch in Asia for manufacturing food and non-food products. See Delgado et al. (1999) for demand projections for global livestock products and animal feed.

regional differences in relative prices. In China, for example, the price of sweetpotatoes relative to maize is higher in the coastal provinces than in interior provinces such as Sichuan. However, the results appear to reflect current utilization patterns well. Thus, they capture the key economic forces shaping commodity utilization for starch in East and Southeast Asia.

Commodity prices relative to maize are shown in Table 2a. For example, the price Thai farmers received for a ton of cassava (fresh weight) was only 0.29 (or 29 percent), on average, the price they received for maize. Potato prices in Indonesia were 1.79, or 79 percent higher than maize prices, and 297 percent higher than cassava prices (to find this, I divide the potato price by the cassava price and subtract 1.00). From Table 2a one is not able to compare prices across countries since the price of maize differs from country to country. Inter-country differences in crop prices reflect shipping costs, tariffs and other constraints to trade.

Assuming that processing costs of starch are the same for each commodity, the relative price of starch is calculated by dividing the commodity price from Table 2a by the ratio of commodity's starch conversion rate to the starch conversion rate of maize (Table 2b). The starch conversion rates are assumed to be 65 percent for cereals (maize, wheat, and rice), 30 percent for cassava, and 20 percent for potatoes and 20 percent for sweetpotatoes. Plant breeding efforts currently underway should raise the starch content of sweetpotato to 30 percent in the near future (Ma, Li and Mok, 1999). The effect of an increase in starch content of sweetpotato to 30 percent is also considered in Table 2a.

The relative costs of starch derived from wheat and rice are the same as those reported in Table 2a, since the conversion rates are identical. But for root and tuber crops, the relative cost of starch is higher because starch conversion rates are lower: it takes a greater amount of the commodity as fresh weight to yield the same amount of starch compared with cereals. For example, even though 1 ton of fresh sweetpotato only costs 63 percent of a ton of maize in Indonesia, sweetpotato starch is more than double the cost of maize starch. This is because it takes 3.25 tons of sweetpotatoes to produce as much starch as 1 ton of maize, given these extraction rates.

One limitation of this analysis is that it does not consider by-products from starch production. Maize, wheat, and rice produce valuable by-products, such as protein-rich gluten, when starch is extracted. When valuable by-products are produced during processing, the raw material cost of the commodity can be reduced. In the manufacture of wheat starch, for example, gluten and other by-products can provide as much as 45 percent of total value, compared with 55 percent from starch. The implication of by-products from starch production is that the relative starch prices reported in Table 2b will tend to be biased upward for cereals and biased downward for roots and tubers, since cereals generally produce more valuable by-products.

### **Starch from Root and Tuber Crops in Asia**

What the results suggest is that cassava has considerable potential as a source of starch in Southeast Asia (with the exception of Malaysia) while maize is currently the most economical source of starch in Northeast Asia and India. In Malaysia, where the cost of cassava production is relatively high, maize appears to be the cheapest source of starch at present. However, in China, starch from sweetpotato will have considerable potential if the starch content can be increased to 30 percent or more. In Southeast Asia, sweetpotato does not appear to be a competitive source of starch even considering the high-starch varieties. Irish potato, rice, and wheat are not competitive sources of starch anywhere in Asia. These commodities, especially

potatoes, are relatively expensive sources of energy and carbohydrates in the countries considered. Their use as starch is restricted to niche markets that offer high price premiums for functional properties unique to those commodities.

For processors willing to pay a price premium for starch with special functional properties, the results give an indication of how large a premium must be before a commodity with such characteristics will be in demand. For example, in Indonesia, the relative price of cassava starch to sweetpotato starch is 2.11 (2.05 divided by 0.97). Thus, if a starch user was willing to pay 111 percent more for sweetpotato starch than cassava starch because sweetpotato starch offers some functional characteristics not found in cassava, then sweetpotato would be an economic source of raw materials for that starch use.

The relative prices of starch derived in Table 2b closely follow the actual pattern of starch utilization in Asian countries today. In Table 3 shows the size and source of global starch utilization in the early 1990s. More than 15 million metric tons of starch were used annually in Asia. In Southeast Asia most starch was derived from cassava (which Table 2b indicated was the cheapest source of starch in these countries). In Northeast Asia and India, maize is the most important source of starch. Table 3 also shows sweetpotato provided a large share of starch in Northeast Asia, about 4 million tons per year. Much of this is utilized for making starch noodles, a use that is not well suited for maize starch. This is an example of where starch from a particular commodity (in this case, sweetpotato) offers a functional property that is not readily provided in starch from other commodities. Food manufacturers are often willing to pay a price premium for such starch.

### **Animal Feed from Root and Tuber Crops**

An economic assessment of which commodities are most competitive in supplying animal feed requires not only consideration of the cost of carbohydrates but also protein.<sup>2</sup> Tropical roots and tubers are low in protein and must be supplemented with high-protein feed concentrates like soybean or fish meal to make a balanced feed ration. The foliage of sweetpotato and cassava are also good sources of protein but are too bulky to be used by feed millers to make manufactured compound feeds for feed concentrates. However, these foliages (especially from sweetpotato) are often used by farmers in feeding pigs, dairy cattle, and other ruminants when these crops are grown on the farm. Thus, an economic assessment of root and tuber crops for animal feed must not only consider least-cost sources of feed but also the structure of animal production, especially the extent to which manufactured or farm-grown feeds are used in animal production.

In the analysis below we restrict our attention to supplying feed for pig production. Pigs and poultry are the most important sources of meat in Asian diets. In Asia, poultry is increasing produced by specialized producers using manufactured feeds (and often part of large, integrated systems), while pigs are still mainly raised by traditional, “backyard” producers relying mainly on farm-grown feeds (Table 4). Sweetpotato is a particularly important component of pig feed among small producers in China and Vietnam, where both farm-grown roots and foliage are used for feed.

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<sup>2</sup> Balanced animal feed rations are composed of carbohydrates, protein, vitamins and minerals. Carbohydrates and protein make up the great bulk of feed while vitamins and minerals are usually supplied from special additives. Not considering the cost of vitamins and minerals is unlikely to affect our analysis of which commodities are most economical at meeting the energy and protein animals need for growth.

Linear programming is well-suited for identifying least-cost sources of animal feed and is widely employed by millers for determining components of manufactured feeds. Let  $C$  be the cost of a feed ration that is composed of up to  $n$  commodities, each contributing some energy and protein to the ration. Let  $Q_i$  be the quantity of the  $i$ th commodity used in a feed ration and  $P_i$  its unit price. Technical parameters  $\alpha_i$  and  $\beta_i$  measure the energy and protein content of 1 kg of the  $i$ th commodity, respectively, and  $\lambda_i$  is the maximum feed allowance of commodity  $i$  that is palatable to the animal. Let  $E$  be the energy requirement and  $P$  the protein requirement of an animal feed ration. Then, the least-cost feed ration is given by the solution to the following linear programming problem:

**Eq 1** **1**

$$\begin{aligned} \text{Minimize } C &= \sum_{i=1}^n P_i Q_i \\ \text{subject to } \sum_i \alpha_i Q_i &\geq E, \quad \sum_i \beta_i Q_i \geq P, \quad \text{and } Q_i \leq \lambda_i \text{ for } i = 1, 2, \dots, n. \end{aligned}$$

The solution to Eq 1 tells us which commodities are used in a feed ration to provide the required combination of energy and protein.<sup>3</sup> Through sensitivity analysis we can vary the prices in the model to determine the conditions where other feed sources will become economical and what existing feeds they will replace in the ration.

Table 5 shows the technical coefficients used to solve for the least-cost pig feed ration. The principal sources of carbohydrates considered are maize, cassava, and sweetpotato. Soybean meal and sweetpotato tops are the main sources of protein that are included in the model (maize also supplies significant protein to feed rations). Sweetpotato foliage for protein only enters the model for farm-grown feed and not for manufactured feeds. While other sources of feed could be added, the purpose of this analysis is to see where and under what conditions tropical root and tubers crops are most likely able to compete with maize and soybean, the most widely used feed combination in manufactured animal feed globally.

In Table 6 we show the most economical feed sources under current prices in China and several countries in Southeast Asia. We also examine how sensitive the least-cost feed rations are to price changes. In all countries except Thailand, maize and soybean are the most economical components of manufactured compound feed (and are in fact the mostly widely used commodities for this purpose). The results show that for Thailand, cassava is just competitive with maize. Boonjit (1999) found a similar result using Thai seasonal wholesale commodity prices. But the result for Thailand is sensitive to small fluctuations in the price of either cassava, maize, or soybean (2-3% of the prices used in the model). This may explain why cassava is not more widely used in Thailand to manufacture animal feed at the present time.

In addition to manufacture feeds, the maize-soybean combination dominates most countries for farm-grown feed as well, with the important exception of Vietnam. In Vietnam, a combination of cassava roots with sweetpotato roots and foliage is considerably cheaper than maize-soybean for a balanced pig ration. The use of sweetpotato foliage as a protein source is also robust to price changes: soybean price would have to fall by 60% or sweetpotato price increase by 94% before soybean would become a competitive source of protein in farm-grown feed. In fact, a cassava-sweetpotato feed combination is widely used for pig feed by farmers in Vietnam (Peters et al., 1998). This choice by farmers reflects their efforts to minimize costs of

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<sup>3</sup> A complete feed ration model would include vitamins and minerals. But the model in Eq 1 is adequate for identifying conditions where tropical root and tuber crops will be competitive sources of the major nutrients in animal feed.

pork production. Cassava would become competitive in manufactured pig feeds (replacing maize) in Vietnam if its price could be reduced by 10%.

In the model we identified three other cases where root and tuber crops are likely to be competitive with maize and soybeans in pig feed, or would be with small productivity improvements. In China, farm-grown sweetpotato (using foliage as well as roots) replaces soybean in the ration with only an 8% decrease in sweetpotato price. We get a similar result for Indonesia with only a 13% decrease in sweetpotato price. In fact, in each of these countries sweetpotato is used for pig feed in regions where sweetpotato and pigs are both important commodities. Sweetpotato is currently the 2<sup>nd</sup> most important pig feed in China, behind maize, and is largely consumed on the farm where it is grown (Huang et al., 2002). Maize, on the other hand, is used both on-farm and as a key ingredient in manufactured feeds in China, as the model predicts. While we used average national prices in the analysis, it is likely that in some regions sweetpotato is relatively cheaper and in these regions enters a least-cost feed ration.

One implication of these findings is that sweetpotato's competitiveness as animal feed would be enhanced if its protein supply can be increased. An assessment of sweetpotato genetic diversity in CIP's germplasm holdings showed that among varieties that are high in total dry matter yield, there is a wide range in the amount of dry matter apportioned to roots and to foliage (Leon-Velarde et al., 1997). Through breeding it is possible to develop new varieties that give either high root (carbohydrate) yield or high foliage (protein) yield, or some combination of the two. High protein-yielding sweetpotato varieties grown as a forage crop are likely to be of great value to farmers in countries where protein sources are scarce and costly. It is also important to have simple and low-cost processing methods, like ensilaging, that extend the shelf-life of crop foliage after harvest (Peters et al., 2002).

Besides Thailand, cassava looks to have good potential as a component of manufactured feeds in Vietnam and the Philippines. In Vietnam, cassava would be an economical substitute for maize if either cassava or soybean price declined by 10%. The reason that cassava would be substituted for maize if soybean price fell is due to the higher protein content of maize. In countries where feed concentrates (e.g., soybean meal) are relatively expensive, low-protein feeds like cassava become uncompetitive. If the cost of feed concentrates can be reduced, then tropical root and tuber crops can provide a low-cost source of energy in the feed ration.<sup>4</sup> In many countries of Asia protein concentrates are priced artificially high due to tariffs and other trade barriers on imported soybean. For example, price ratio of soybean to maize in Vietnam, Malaysia and Indonesia ranged from 3.4 to 4.0, compared with only 2.2 in the free-trade port of Singapore, reflecting the higher level of protection given soybean. This is done to encourage domestic production and reduce the trade deficit in this crop. But in many cases it comes at a cost of increased reliance on imported corn and less use of domestically-produced tropical root and tuber crops.

## **Summary and Conclusions**

Tropical root and tuber crops face a bright future in Asia. Even though per capita consumption directly as food is declining, the utilization of cassava and sweetpotato to meet

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<sup>4</sup> This explains why, in the 1980s and 1990s, Thailand and Indonesia exported cassava to Europe but imported maize for animal feed. Due to the high cost of protein in Southeast Asia, it was more economical to use maize for feed. But in Europe, agricultural policy placed high tariffs on imported maize but low tariffs on imported soymeal and cassava, making a feed combination of the latter ingredients more economical than maize in pig rations (Koester, 1982).

rapidly rising demand for starch and animal feed is increasing. The extent to which cassava and sweetpotato will be used to meet the demand from these markets depends critically on its cost-competitiveness with other sources of carbohydrates, especially maize.

What our analysis showed is that cassava will continue to be an economical source of starch in Southeast Asia. Sweetpotato will face growing competition from maize to supply starch in China and is currently uneconomical for starch in Southeast Asia except in niche markets. When high-starch yielding varieties of sweetpotato currently under development become available to farmers, sweetpotato will become a more competitive source of starch in China.

In many parts of East and Southeast Asia, sweetpotato is an economical source of animal feed when it is grown on the farm so that the protein-rich tops can be incorporated into feed rations. In fact, protein deficiency remains a key constraint to animal productivity especially among small growers who raise their own feed. New varieties of sweetpotato with higher foliage protein content, and improved methods for on-farm handling and processing of foliage, could play a major role in overcoming this constraint.

Cassava and sweetpotato are unlikely to be a major ingredient into manufactured feeds unless their prices can be significantly reduced relative to maize or if the cost of protein (e.g. soybean meal) needed to balance the ration is brought down. Since most countries use high import tariffs to protect local soybean producers, the cost of protein for animal feed in most countries of East and Southeast Asia is significantly above world prices. If trade liberalization reduced the cost of protein (imported soybean), then cassava would emerge as an economical source of carbohydrates in manufactured feeds in Southeast Asia. Thus, trade policy is likely to have a pivotal influence on the prospects for tropical root and tuber crops in manufactured animal feed in the future.

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**Table 1. Projected growth in total utilization of selected commodities, 1993-2020**

Country	Cassava	Sweetpotato	Potato	Rice	Maize	Wheat
	(average annual rate of growth)					
China	0.84	0.60	1.47	0.58	2.53	1.11
Other East Asia	0.05	0.86	1.29	0.44	1.86	1.64
India	0.93	0.14	3.09	1.56	2.44	1.98
Other South Asia	1.62	1.18	2.95	1.84	2.34	2.77
Southeast Asia	0.96	1.39	2.30	1.23	2.27	2.29
Developing countries	1.93	1.25	2.02	1.23	2.24	1.77
World	1.74	1.23	0.96	1.19	1.49	1.22

Source: Scott, Rosegrant, and Ringler (2000) tables 9 and 10.

**Table 2a. Prices commodities relative to maize**

	Maize	Sweetpotato	Cassava	Potato	Rice	Wheat	Soybean
Indonesia	1.00	0.63	0.45	1.79	1.18		3.41
Malaysia	1.00	0.71	0.65		1.92		4.04
Philippines	1.00	0.65	0.41	1.88	1.10		2.30
Thailand	1.00	1.80	0.29	2.77	1.32		2.90
Vietnam	1.00	0.29	0.27	0.50	0.96		3.53
Singapore *	1.00		0.36			1.24	2.52
China	1.00	0.46	0.68	0.52	1.43	1.32	2.22
Japan	1.00	1.54		0.56	2.56	1.34	1.97
South Korea	1.00	0.94		1.13	2.64	1.25	3.59
India	1.00	0.96	0.71	0.95	1.20	1.19	1.18

\*Singapore prices are import prices

Source: FAOSTAT Producer Prices 1980-1995, except for Vietnam. Vietnam prices for 1976-1990 and are from Vu Ke Toai, Pham Thanh Binh, and Ferrari (1993).

**Table 2b. Prices of starch relative to starch from maize**

	Maize	Sweetpotato	Cassava	Potatoes	Rice	Wheat	<i>Sweetpotato</i>
Starch content:	65%	20%	30%	20%	65%	65%	30%
Indonesia	1.00	2.05	0.97	5.83	1.18		1.37
Malaysia	1.00	2.30	1.41		1.92		1.53
Philippines	1.00	2.12	0.90	6.12	1.10		1.41
Thailand	1.00	5.85	0.62	9.00	1.32		3.90
Vietnam	1.00	0.94	0.59	1.63	0.96		0.63
Singapore	1.00		0.78			1.24	
China	1.00	1.51	1.48	1.69	1.43	1.32	1.00
Japan	1.00	4.99		1.80	2.56	1.34	3.33
S. Korea	1.00	3.06		3.68	2.64	1.25	2.04
India	1.00	3.12	1.54	3.10	1.20	1.19	2.08

Cheapest source of starch in each country shown in bold large print.

Source: Table 2a.

**Table 3. Global starch production in the early 1990s**

	(million metric tons of starch/year)						
	Maize	Wheat	Sweetpotato	Cassava	Potato	Other	Total
WORLD	24.16	2.13	4.15	5.00	2.36	0.14	37.92
ASIA	5.96	0.23	4.15	4.64	0.80	0.12	15.90
Indonesia				2.00			2.00
Thailand				1.80			1.80
Malaysia				0.07		0.09	0.16
Philippines	0.08			0.02			0.09
Vietnam				0.09			0.09
China	2.06	0.06	4.00	0.30	0.40		6.83
Japan	2.50	0.15	0.12		0.40		3.17
South Korea	1.07		0.01				1.09
Taiwan	0.05	0.02	0.02	0.02		0.03	0.12
India	0.20			0.35			0.55

Source: Ostertag (1993) and updated from various industry sources as reported in Fuglie and Oates (2002).

**Table 4. Structural change in Asian livestock production**

	Poultry for meat (broilers)		Pigs	
	'Backyard' producers	Specialized producers	'Backyard' producers	Specialized producers
	(percent share of total production)			
Vietnam	n.a.	n.a.	90	10
China	52	48	74	26
Indonesia	30	70	85	15
Thailand	35	65	88	12

'Backyard' producers are small farmers who raise a few animals (less than 20-30 pigs or about 200 birds) as part of mixed crop-livestock systems, relying primarily on farm-grown crops, residues and wastes for feed, although they may purchase some feed supplements. Specialized producers are farmers whose primary activity is animal production and who rely primarily on manufactured animal feeds. Specialized producers are sometimes part of large integrated systems.

Sources: China for 1997 (Zhang, 2002); Vietnam for 1999 (IFPRI, 2001); Thailand for 1978 (Poapongsakorn, 1985), Indonesia for 1990 (McEvoy 1993).

**Table 5. Technical coefficients for animal feed rations**

Commodity	Energy kcal/kg	Protein g protein/kg	Maximum feed allowance (kg/kg)
Maize	3,394	85	
Soybean meal	2,822	440	0.20
Cassava, dried	3,800	25	0.30
Sweetpotato roots, dried	3,110	42	0.30
Sweetpotato foliage, dried	0	168	0.30
Minimum pig feed requirement, per kg	3,000	160	
Minimum poultry feed requirement, per kg	2,800	160	

Source: Nelson (1986); Woolfe (1992).

**Table 6. Commodities that provide least-cost pig feed rations under alternative markets and scenarios**

Least-cost feed under current prices			Changes in current prices necessary for root & tubers to enter/exit least-cost feed rations (substitution commodity in parentheses)				
	Manufactured feed	Farm-grown feed	Maize	Soybean	Cassava (roots only)	Sweetpotato (roots only)	Sweetpotato* (roots & foliage)
China	Maize-Soybean	Maize-Soybean	+ 22% (on-farm sweet-potato for soybean)	+ 16% (on-farm sweetpotato)	-50% (maize)	-49% (maize)	-8% (soybean)
Vietnam	Maize-Soybean	Cassava-Sweetpotato	-27% (cassava)	-10% (cassava for maize)  -60% (on-farm sweetpotato)	-10% (maize)	-32% (maize)	+ 94% (soybean)
Indonesia	Maize-Soybean	Maize-Soybean	+ 37% (cassava)	+ 24% (on-farm sweetpotato)	-44% (maize)	-69% (maize)	-13% (soybean)
Thailand	Cassava-Soybean	Cassava-Soybean	-2% (cassava)	+ 3% (maize for cassava)	+ 3% (maize)	--	--
Philippines	Maize-Soybean	Maize-Soybean	+ 15% (cassava)	-43% (cassava for maize)  + 91% (on-farm sweetpotato)	-19% (maize)	-65% (maize)	-34% (soybean)

\*Assumed to available for farm-grown feed only.

Cassava and sweetpotato roots are primarily sources of energy in feed rations that substitute for maize when prices low enough. High cost of protein concentrates (e.g. soybean) reduce the competitiveness of root and tuber crops in feed rations, because maize requires less protein supplement than root and tubers crops for a balanced ration. Sweetpotato foliage add a significant portion of protein to feed rations and substitute for concentrates (e.g. soybean) when available on the farm.