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Sweet Potato as Animal Feed and Fodder

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ABSTRACT

Alternative sources of livestock feed to spur livestock production and to free cereal supplies for human consumption are receiving closer attention. Sweet potato has higher biological efficiency as food and shows highest productivity (35-45 t ha^{-1}). It has relatively short vegetative cycle (4-5 months). Hence, fits nicely into tight cropping systems. It also competes better with weeds than other root and tuber crops. The DM content of sweet potato varieties ranges from 21.70 to 34.78% which is more than cassava. Its tubers can be given to all ruminants as fresh, chopped tubers, dried chips and silage for energy supplements along with locally available grasses during the dry season. Sweet potato vine and foliage is a common feed for pigs, and other livestock, in many countries, including China, India, Indonesia, Korea, Philippines, Papua New Guinea, Taiwan, Uganda and Vietnam as protein supplement. The skin and leaf tips contain comparatively higher protein, 50-90% and 18-21%, respectively. Tubers also contain essential amino acids, with the exception of the sulfur-containing amino acids, especially cystine/cysteine. Digestibility of tubers appears to be a problem for some varieties that are grown under certain types of conditions. The digestibility of sweet potato carbohydrate fraction is reported to be above 90%. Selections of varieties with low trypsin inhibitor activities helps in expand the plant's potential for wider use as an animal feed. Sweet potato roots are the good source energy (3500 kcal kg^{-1}) for poultry. Main reasons for adoption of dual-purpose sweet potato are economical viability, net returns and crude protein (CP) content of the fodder.

Keywords: concentrate, dual purpose variety, root crops, silage, nutrition
Abbreviations: CF, crude fiber; **CP**, crude protein; **DM**, dry matter; **EE**, ether extract; **ME**, metabolic energy; **NFE**, nitrogen free extract; **PER**, protein efficiency ratio

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INTRODUCTION

Many developing countries are under increasing pressure to make more effective use of available resources in the agricultural sector both to satisfy the growing demand for livestock products and to raise rural incomes by generating additional value addition through processing (Scott *et al.* 1993). The cost of balancing domestic demand for livestock products with feed or livestock imports has become prohibitively expensive. The prospects for increasing in the output of cereals of the magnitude required to meet livestock and human requirements remain problematic. Consequently, alternative sources of livestock feed both to spur domestic livestock production and to free cereal supplies for human consumption are receiving closer attention.

Sweet potato (*Ipomoea batatas* (L.) Lam.) is among the five most important food crops in developing countries in terms of total production (Phuc *et al.* 2001). Although the sweet potato is of New World origin, over 90% is produced in Asia; 85% in China alone. While sweet potato production and area planted in Africa practically doubled over the last three decades, they remain less than 5% and 15% respectively of developing country totals (FAO 2011). Latin America accounts for about 2% of output and 3% of area planted. Sweet potato is cultivated for food in more than 100 countries. The area under cultivation was 8.5 million ha in 2009 and the worldwide tuber yield was 12648 kg/ha (FAO 2010). Sweet potato tuber is one of only seven world food crops with an annual production of more than 100 million metric tons. Average tubers yields are 5 t/ha in Africa, 10 t/ha in South America and 16 t/ha in Asia. Sweet potato tuber is considered a major staple food only in a few coun-

Received: 1 November, 2011. Accepted: 1 November, 2012.

Invited Mini-Review

Table 1 Different parts of sweet potato use as animal feed in Asia.

Country	Part plant	Form	Animal(s) fed
Bangladesh	Vines	Green	Cattle
China	Roots	Sliced, dried, ground, cooked	Principally pigs but also for cattle, poultry
	Vines	Green, ensilage	Pigs, cattle, poultry
	Waste from processing starch, noodles	Waste water	Pigs
India	Roots	Sun-dried chips	Pigs
	Vines	Green, ensilage	Cattle
Indonesia (Java)	Roots, culls, vines	Fresh	Cattle
Republic of Korea	Roots, culls, stored roots	Fresh, stored limited quantity for high carbohydrate feed	Pigs, composite feeds for pigs, poultry and other domestic animals
	Vines, foliage	Silage	Livestock
Papua New Guinea	Roots	Fresh, stored	Pigs
	Leaves, vines	Green	Pigs
Philippines	Roots	Cooked, dried chips, composite feed	Pigs mainly, also poultry
	Vines	Fresh	Pigs, carabao
Taiwan	Roots	Sliced and dried	Pigs
Vietnam	Roots	Fresh, sliced and dried	Pigs
	Vines	Fresh	Pigs

Source: FAO, 2011

tries but is much appreciated as alternative food in many countries. Because of its fast growing period, low input and work requirements, sweet potato is often planted in Africa as a security crop or famine prevention crop (Scott *et al.* 1993). The main sweet potato producers are China, Indonesia, Vietnam, India, Philippines and Japan in Asia, Brazil and the USA in the Americas and Nigeria, Uganda, Tanzania, Rwanda, Burundi, Madagascar, Angola and Mozambique in Africa (FAO 2010). It is interesting to note that about 43% of the world's annual sweet potato production is used as animal feed. Sweet potato has higher biological efficiency as food and shows the highest rate of production per unit area (35-45 t ha^{-1}). Feeding sweet potato roots to pigs and other livestock is a common practice in many countries, including China, North and Central Vietnam, some eastern islands of Indonesia, Philippines, Papua New Guinea, Cuba and Uganda (FAO 2011). Sweet potato is also a very valuable feed for all classes of livestock (Woolfe 1992). The tubers are relished by pigs and cattle and tuber processing by-products may also be fed to livestock. The vines and foliage can be dried and fed to cattle and compare favourably with alfalfa hay (Duke 1983). In 2007, half of the sweet potato tuber production went to animals or starch industry (Lebot 2009; Chittaranjan 2007). Sweet potatoes can be used on-farm or be an ingredient in industrial compound feeds (Scott 1992; Gupta *et al.* 2009).

Sweet potato is also used as an energy crop: the tubers can be fermented and produce alcohol and the plant can be grown in areas where maize and other cereal crops does not grow. The economic interest of sweet potato as animal feed used to be debatable as producing sweet potato at 30% DM was as costly as importing grain at 89% DM (Woolfe 1992). However, modern varieties now produces more edible energy per ha per day than any other major food crop; it produces 30% more starch/unit area than maize (Chittaranjan 2007).

In India, it is grown in an area of 0.14 million ha producing 1.17 million tons (NHB 2011). The habit of using sweet potato roots for feeding purpose is common in eastern and north eastern regions of India. This paper tries to sail deep into the sweet potato production, their modifying usage around the world and growing potential and their alternative uses in India.

CURRENT SCENARIO ON USE OF SWEET POTATO FOR FEED PRODUCTION IN DIFFERENT CONTINENTS

Sweet potato is almost always used, in some form and amount, as an animal feed wherever it is produced in developing countries. Unfortunately, information about the exact nature, extent and evolution of these practices is handicapped by a lack of knowledge about the crop generally and the use for animal feed specifically. With that observation as a caveat, the meager evidence available about present practices suggests that sweet potato is most commonly used as animal feed on the farm itself. Roots, vines, and foliage are fed principally to pigs and cattle in unprocessed form. However, with certain notable exceptions, animal feed currently constitutes a minor share of the total utilization of sweet potato production.

Asia

Roots for pigs and vines for cattle are the most commonly cited forms of sweet potato utilization as animal feed in Asia (**Table 1**). Both are employed in a variety of ways. Virtually, all feed production from sweet potato takes place at the farmer or village-level. Only limited quantities of composite feeds are produced industrially. In sweet potato, parts of the plant are fed as is or after ensilage to cattle in Bangladesh, China, India, Indonesia, and the Philippines (IPC 1998). They also serve as a form of pig feed in Papua New Guinea, Vietnam and are fed to poultry in China. In Bangladesh, India, and Indonesia, vines and/or foliage serve as a principal source of animal feed from sweet potato production (Chin and Lee 1980). Nevertheless, available estimates indicate only a tiny fraction of sweet potato output used for this purpose.

Uncooked roots are fed to pigs in China, parts of Indonesia (Irian Jaya), Korea, Papua New Guinea, Thailand, and Vietnam (World Bank 2006). These roots may be used as fresh or after storage. Some farmers in China slice up the fresh roots to make them more digestible or feed them mixed with vines, other household feed sources (e.g. rice hulls, corn husks) or even purchased protein supplements. In Korea, these fresh roots include culls left from sales to the market (Chin and Lee 1980). In Papua New Guinea, pigs will forage for roots or culls left in the field (**Table 1**).

Many sweet potato farmers in northern China slice and then dry sweet potato roots before using them as pig feed (Zhang *et al.* 1988). This type of simple processing often takes place in the field itself. Slicing, then sun drying of the roots is a well-known procedure for production of pig feed from sweet potatoes in Taiwan (Tsou and Hong 1989; Van Soest *et al.* 1991). It has also been done on a more limited basis in the Philippines and Vietnam (Hoang *et al.* 2003).

In China, sweet potato roots are also ground by various types of small scale machines and used to make starch for noodles (Tawe 1991). After draining off the starch, the remaining pulp is then used as is, fermented, dried, or stored to make pig feed. Waste water from village-level starch and noodle production also is fed to pigs.

Table 2 Different parts of sweet potato use as animal feed in Africa and South America.

Country	Plant part	Form	Animal(s) fed
Africa			
Egypt	Vines	Green fodder	Cattle
Kenya	Vines	Green fodder	Cattle, pigs
Mozambique	Vines	Green fodder	Small animals
Rwanda	Damaged roots, vines	Fresh	Livestock
Uganda	Surplus roots and vines	Fresh	Livestock, pigs, fish
	Leaves	Fresh	
South America			
Argentina	Roots, vines	Fresh	Pigs, cattle
Brazil	Roots, vines	Fresh	Dairy and beef cattle, pigs
Ecuador	Roots	Fresh	Pigs, goats, beef cattle
	Vines	Green fodder	Beef cattle, goats
Dominican Republic	Roots	Fresh	Pigs
	Vines	Green, ground	Cattle
Haiti	Culls, roots left in the field after harvest	Fresh	Pigs
Jamaica	Roots	Fresh	Pigs
	Vines	Fresh	Pigs, cattle, other farm animals
Peru	Roots	Fresh	Cattle, pigs, rabbits
	Vines	Fresh	Dairy cattle, small ruminants
Venezuela	Roots, vines	Fresh	Livestock

Source: FAO, 2011

Africa

Information about the use of sweet potato for animal feed in Africa is particularly sparse. The limited reports suggest that nearly all roots are for human consumption with only damaged ones being fed for livestock e.g. Rwanda (Tsou and Hong 1989). Vines and foliage from the sweet potato plant are fed principally to cattle in a number of countries (Buxton 1996). However, in Egypt, Kenya, Mozambique, Rwanda, and Uganda vines and/or foliage are utilized as green fodder for cattle principally, but also for pigs and other small animals (**Table 2**). Two reasons why this practice is not more widespread are: i) farm households eat the vines in boiled form along with basic staple food (e.g. in rice in Sierra Leone); ii) farmers will leave vines in the field to improve the soil fertility (NIAH 1995; IPC 1998).

Latin America

Sweet potatoes roots, vines and foliage are used for animal feed in a number of Latin America countries (**Table 2**). As the crop is typically grown on small farms, often for household consumption, Argentina, Brazil and Peru are notable exceptions; statistics on utilization patterns for animal feed are clearly not available (Mero and Uden 1997). An estimated 35% of sweet potato production is used for animal feed in Brazil (**Table 2**), about 15% in the Dominican Republic (Walter *et al.* 1984). This percentage is negligible for other countries in the region except in those cases where total sweet potato production in absolute terms is itself insignificant. Except in Brazil (Etela *et al*. 2009) and Peru (Banser *et al.* 2000) where the roots are used for cattle, roots are fed generally to pigs. In Argentina, the roots are the culls left after grading for market. In Haiti, pigs will dig up the roots that remain in the field after the final harvest (Gerpacio *et al.* 2003). In every instance, these roots appear to be utilized in fresh form i.e. without cooking or drying. In Argentina, Brazil, Ecuador, the Dominican Republic, and Peru, the vines and foliage are fed principally to cattle, but also to pigs and rabbits (Peru) and to goats (Ecuador) (Peters *et al.* 2001). In Argentina, Brazil, and the Dominican Republic in particular, fodder from sweet potatoes has served as an emergency supply of cattle feed for farmers in periods of drought or during the dry seasons (Bradbury *et al*. 1985; Foulkes *et al*. 1997). The vines and foliage are used in unprocessed form in every instance except in the Dominican Republic where they first ground and then mixed with sugarcane by-products before being fed to livestock.

POTENTIAL FOR SWEET POTATOES AS ANIMAL FEED

Expanded use of sweet potato as animal feed appears to be promising for both agro-biological and socio-economic reasons. On the agro-biological side, sweet potato has a relatively short vegetative cycle (4-5 months). Hence, it fits nicely into tight cropping systems. It also produces much more dry matter per hectare and per day than cassava (Ash *et al.* 1992). Sweet potato is widely adapted to diverse altitudes (up to 2000 msl) and temperature conditions. It requires practically no cash inputs and minimal horticultural practices. Sweet potato also competes better with weeds than other root and tuber crops. It also has more potential for greater mechanized harvesting than cassava.

Improvements in yield, dry matter (DM) content, and digestibility of the crop should make sweet potato increasingly more attractive as a source of animal feed. Average yields for sweet potatoes in developing countries doubled over the last twenty-five years primarily because of developments of improved varieties in China (Goodchild and McMeniman 1994). Yield increases in the People's Republic appear to have been largely the result of changes in cultural practices (i.e. increased plant density) rather than the utilization of improved varieties or of chemical fertilizers and pesticides. Moreover, average yields in China (17 t ha^{-1}) are 50% or less of what is commonly achieved on experiment stations in developing countries. As pressure mounts on farmers to raise productivity, the potential gains to be made from improved sweet potato varieties and modern inputs should be more widely realized.

Most sweet potatoes currently cultivated in developing countries have a dry-matter content of around 30%. Results of research at the Asian Vegetable Research and Development Center (AVRDC) showed that the mean DM content of breeding lines improved from 25.9 to 35.1% (Tsou and Hong 1989; Tugia *et al.* 1997). Moreover, the international germplasm collection for this crop includes varieties whose DM content is as high as 45.0%. Clearly the potential is there to raise the sweet potato's utility for processing by incorporating varieties with higher DM content into the material available to growers in developing countries.

Digestibility appears to be a problem in some countries for some varieties that are grown under certain types of conditions and for some types of animal feed (Tsou and Hong 1989; Moat and Drylen 1993). Improved digestibility of sweet potato varieties through bio-technology, or as Tsou and Hong (1989) point out through selection of varieties with low trypsin inhibitor activities should also help expand the plant's potential for wider use as an animal feed in developing countries.

Influence of socio-economic factors on spread of sweet potato

Sweet potato's potential for animal feed will also depend on socioeconomic factors including: i) growth in population and incomes, ii) growth in demand for cereals for human consumption and for the animal products, and iii) the capacity of a given country to cover food deficits through imports (Larbi *et al*. 2007).

Growth in population can affect the prospects for sweet potato utilization as animal feed in various ways. If population growth outstrips growth in cereal production, then those cereals currently used for livestock feed will be required for sustaining levels of cereal consumption so as to minimize the need for expanded food or feed imports (Scott 1995). Population growth in the countryside may induce farmers away from expanded cereal production to more high valued crops so as to maintain income levels. Growth in incomes may further aggravate this situation to the extent that consumers utilize these higher incomes in an effort to raise their consumption of both cereals and livestock products (Larbi *et al*. 2007).

Growth in the demand for cereals for human consumption and livestock products will also influence the prospects for sweet potato use as animal feed (Claessens *et al*. 2008; Ongadi *et al*. 2010). The 1980's witnessed a slowdown in the rate of increase of production of cereal crops in a number of developing countries partly because the rate of increase in yields became more difficult to sustain and population growth rates fail to decline, the prospects for meeting domestic food requirements with local supplies become more problematic (Adjei 1995). Furthermore, if consumers, particularly in Africa and Asia, try to improve their diets by increasing consumption of cereals and livestock products for their cattle and pigs at the same time, the pressure on the agricultural sector to meet the demand for livestock products through development of alternative production schemes could well increase utilization of sweet potatoes for animal feed.

Many countries have witnessed dramatic reversals of government policy as regards food and feed imports over the last few years partly as a result of changes in world markets, the burden of accumulated debt, or in an effort to create more opportunities for domestic agricultural production. These policy changes in the years ahead will strongly influence the potential for sweet potato use as animal feed (Dahlanuddin 2001).

Sweet potato: a fitting tuber for feed and fodder purpose

Sweet potatoes store starch and sugar in the edible underground tuber. The parts above ground; the vine and the leaves are also edible, but they contain relatively little starch. Starch is a carbohydrate that when eaten becomes an energy source. The DM content of sweet potato varieties ranged from 21.70 to 34.78% (**Table 3**). The DM content was high in improved line 442074 (34.78%) and the low (21.70%) was in line 440127. The DM content is directly related to starch content and the biochemical composition varies with genotypes (Ravindran and Sivakanesan 1996). The nutritional parameters like organic matter, crude protein, ether extract, crude fibre, nitrogen free extract and total ash of different varieties ranged from 96.54 to 97.83%, 3.90 to 6.41%, 1.65 to 2.12%, 1.83 to 2.86%, 85.88 to 89.99% and 2.17 to 3.51%, respectively (**Table 3**). A value of 0.70 and 74.00% for digestible crude protein and total digestible nutrients respectively has been observed in cattle (Moat and Drylen 1993). The average fresh, DM and nitrogen free extract (NFE) yields of the tubers were found to be 33.11±2.46, 8.75±8.58 and 7.73±0.51 t ha^{-1}, respectively. The cultivars differed considerably ($P < 0.01$) for these parameters. Gouri gave the highest DM yield (11.07 t ha^{-1}) followed by cv. 440038 (10.04 t ha^{-1}) and 442074 (9.99 t ha^{-1}) while the lowest one was observed in Sree Gouri (3.95 t ha^{-1}). The NFE yield followed the similar trend as for DM yield (Ruiz *et al*. 1980). The mean tuber yield (DM basis) was higher than the average yield of 4-6 t $ha^{-1}$for maize grain. Significant ($P < 0.01$) differences were observed among the cultivars for proximate parameters except ether extract (EE). Like tapioca, sweet potato tubers were also rich in carbohydrates but poor in fat and fibre. The protein content ranged from 4.04 (cv. 442074) to 6.41% (cv. 440038). The mean values for crude protein (CP), EE, crude fiber (CF), NFE and total ash were recorded to be 4.87±0.20, 1.90±0.06, 2.38±0.08, 88.20±0.45 and 2.65±0.15%, respectively (Scott 1995).

Sweet potato vines, commonly left unused, can also be used as a protein feed for animals. They do not have as much protein as cassava leaves, but they do have more protein than several grasses (**Table 3**). 100 kg of dried sweet potato vines can supply 10-12 kg of protein. Grasses that commonly grows in tropical climates supply much less protein than sweet potato. Sweet potato vines have no substances that are bad for animals and hence they can be safely fed to animals. The skin and leaf tips contain comparatively higher protein, 50-90% and 18-21%, respectively. Tubers also contain essential amino acids, with the exception of the sulfur-containing amino acids, especially cystine/cysteine (Ravindran 1995; Ravindran and Blair 1999; Larbi *et al*. 2007). Sweet potato contains 60-85% of the nitrogen as proteinaceous, with a protein efficiency ratio (PER) equal to casein (milk protein). However, sweet potatoes contain compounds known as trypsin inhibitors that inhibit the action of protein-digesting enzymes in the gut. But, heat treatment/silage making can easily inactivate these compounds. Fermented silage containing a mixture of different, locally available food sources is the ideal for livestock feed.

Dual purpose sweet potato varieties as food and fodder

As the global demand for both sweet potato tuber consumption and utilization for fodder increases, researchers are focusing on identifying lines which can be used and satisfy both the needs (Karachi and Dzowela 1990; Karachi 2008). Though said easily, developing such lines is highly cumbersome. Lot of research and germplasm is required to screen

Table 3 Nutrient composition of different varieties of sweet potato tubers.

Variety	DM (%)	Per cent on DM basis					
		Organic matter	Crude protein	Ether extract	Crude fibre	Nitrogen free extract	Total ash
Gouri	24.66	96.49	4.99	2.12	2.38	87.00	3.51
Sree Gouri	22.92	97.72	4.97	1.78	2.58	88.39	2.28
440038	21.70	96.54	6.41	1.95	2.30	85.88	3.46
440127	30.32	97.71	4.70	2.03	2.86	88.12	2.29
Sankar	29.50	97.79	4.13	1.88	1.92	89.86	2.21
442074	31.28	97.83	4.04	1.65	2.20	89.94	2.17
187071	32.61	97.69	3.90	1.82	2.11	89.96	2.31
420027	34.78	97.11	5.30	1.96	1.83	87.95	2.89
Mean	28.47	97.36	4.81	1.90	2.27	88.38	2.64

Source: Sankaran *et al*. 2008

out the best line. CTCRI, Thiruvananthapuram, Kerala has already released one dual purpose variety Sree Vardhini for commercial scale cultivation. From dual purpose lines, DM yield of 4.3–6.0 t ha^{-1} from foliage could be obtained. The leaves are good source of protein (about 17%). The level of cell wall constituents is generally lower than cultivated fodders and straws (Yeh and Bouwkamp 1985). Like tubers, the leaves are also deficient in methionine and lysine. The vines contained satisfactory levels of Ca, Fe and Mn but were deficient in P, Cu and Zn. The DM/OM digestibility and metabolic energy (ME) were found to be 59.44/61.32% and 7.35 MJ/kg DM, respectively under *in vitro* studies. Fresh vines could provide up to 14% of total dietary DM without any adverse effect on growth and feed conversion in growing pigs.

Sweet potato vines can be fed to pigs either in the fresh form (or) after drying. Pigs readily eat the vines (Farrell *et al.* 2000). The vine production is ranging from 1.2 kg plant^{-1} in var. 440038 to 3.88 kg plant^{-1} in var. 420127 and average foliage production is about 2.1 kg plant^{-1}, which is approximately about 63.0 t ha^{-1}. Vines can be dried and grinded in to a meal. By drying 100 kg of fresh vines about 30 kg vines can easily be obtained. Sweet potato vine meal can be used in compounded pig rations, but only at low levels. It could be used up to 5% in the pig rations. The main reasons for adoption of dual-purpose sweet potato are economical viability owing to relatively high yields, net returns and crude protein content of the fodder which increases milk production and income. Average crop yield of dual-purpose sweet potato is 8 t ha^{-1} compared with 1.5 and 4.3 t ha^{-1} for maize-beans and the mixed crops, respectively. The average fodder yield for dual-purpose sweet potato was amount to 14.6 t ha^{-1} compared to 3.4 for maize-beans and 9.3 t ha^{-1} for the mixed crops. The researchers who collected the dual-purpose sweet potato yield data from on-farm field trials (Maphosa *et al.* 2003) suggested that the yields they observed were higher than most farmers would achieve because crop management and soil conditions would be less favorable than in the trial sites. Adoption rate for dual purpose sweet potato is likely to vary positively with the average total yield of dual-purpose sweet potato, the harvest index (the ratio between tuber and fodder yields), the price of milk, and the nutritional value of available fodder (Claessens *et al.* 2008).

Sweet potato vine fermentation

Sweet potato vines can also be used after fermentation. Ensiling may also increase nutritional value and feed efficiency if it involves a fermentation process that converts nitrogen into protein. Moreover, because high crude protein content does not necessarily guarantee better quality feed (Agwanobi 1999). An on-farm pig-feeding trial was conducted to test the hypothesis that sweet potato vines fermented with chicken manure results in better pig growth and economic efficiency. The experiment revealed that after 30 days of fermentation of sweet potato vine, the pH of all the treatments with chicken manure met the basic requirement of the acidity level (pH 3.7) for livestock (Ruiz *et al.* 1981). The pH of the treatments with chicken manure was significantly higher than the ones without, and had already attained the required level after only 14 days of fermentation. In terms of pH, therefore, the treatments with chicken manure may be regarded as more effective than fresh vines or fermented vines without chicken manure. The DM, CP, EE, CF and ash showed no significant difference over time (at 14, 30, 60, and 90 days of fermentation). However, these parameters did differ significantly across treatments, especially between treatments with and without chicken manure. The DM, CP and ash contents of the treatments with chicken manure were all significantly higher than those of the treatments without (Benser *et al.* 2000). Microbiological tests on vines fermented with various types chicken manure showed no aflatoxin or *Salmonella* in freshly dried chicken manure. *E. coli* was found when freshly dried, but was no longer detectable after 21 days of fermentation.

To determine whether fermented sweet potato vines could reduce feed processing costs and improve pig growth efficiency, two other on-farm trials were conducted in the Red river delta area near Hanoi (Peters *et al.* 2001; Etela *et al.* 2009). The results revealed that vines fermented with chicken manure had significantly ($P < 0.001$) higher CP, DM and ash contents than the other fermented treatments. Subsequently, a three month on-farm feeding trial was conducted with fresh sweet potato vines, vines fermented with cassava meal, vines fermented with sun-dried chicken manure and cassava meal to find out pig growth and economic efficiency. Pigs fed with the preparation containing chicken manure had significantly higher growth rates ($P < 0.05$) and feed efficiency ($P = 0.013$) than other treatments. The chicken manure preparation was also considerably cheaper than other preparation in terms of cost per kg of weight gain.

Sweet potato in pig ration

Sweet potato is a valuable pig feed: the roots provide energy and the leaves gives protein, and both can be used fresh, dried or fermented into silage (Woolfe 1992). It is a common feed for pigs, and other livestock, in many countries in Asia, including China, India, and a few eastern islands of Indonesia (Bali and Irian Jaya), Korea, Philippines, Papua New Guinea, Taiwan, Uganda and Vietnam. In China, for example, which produces 85% of the world production of sweet potato (Scott 1992), a large part of the crop goes to feed animals, mainly pigs (Huang *et al.* 2003; Zhang and Li 2004). In Vietnam, feeding sweet potatoes to pigs is common in the north and central parts of the country. Pigs have long played an important role in North Eastern India, as valuable commodities and an important source of animal protein. However, there are several problems with trying to expand the pig population, of which inadequate availability of feed occupies an important position. In many parts of world such as China, farmers have known the value of sweet potatoes for a long time. They fatten their pigs mainly on sweet potatoes. Farmers also make dried chips from sweet potatoes, store and use them throughout the year (Ruiz *et al.* 1980, 1981). Some make silage with sweet potato tubers to feed their pigs. The DM intake for the older pigs of mean live weight of 90 kg is around 900 g day^{-1}, while the younger pigs (<30 kg) can consume around 450 g day^{-1}. It has also been claimed that feeding sweet potato reduces the parasitic load, thus having an additional advantage in body weight gain of pigs.

Fresh tubers can be chopped and fed to pigs. Pigs readily eat them. Fresh sweet potato tubers are better feeds than fresh cassava roots because they have more protein and have no cyanide. However, tubers from some cultivars have high levels of trypsin inhibitor and hence they can be cooked to increase the digestibility and availability of protein. Sweet potato meal can also be prepared and fed to the pigs (Moat and Drylen 1993). Sweet potato meal is a good energy feed. It can be used in compounded rations instead of cereal grains. It must be mixed with protein feeds, mineral supplements and vitamin supplements. The energy that pigs can get from sweet potato meal is similar to that they get from cassava meal and maize. Sweet potato meal can completely replace maize in pig rations. It is safe to replace only 50% of the maize in pig ration with sweet potato meal. Sweet potato tubers can also be preserved as silage. Pigs readily eat the silage. Liu *et al.* (2001) determined nutritional status of machine grated sweet potato roots ensiled with varying proportion of special additives A, B and C, 10% grain stillage, and 20% wheat bran. The nutritional value of sweet potato silage did not differ significantly over time except for fat content and pH value. The sweet potato root ensiled for more than 9 weeks had better amino acid and nutrient contents than fresh sweet potato. When the above ensiled sweet potato roots were included in 115 days feeding weaner-finishing pigs trial, daily weight gain was 581 g for 10%, 613 g for 20%, 579 g for 40% and 618 g for 60%. In another feeding trial, the greatest growth and economic efficiency for weaner pigs (20-60 kg live weight per pig) and finishing pigs (60-90 kg live weight per pig) were both observed at the combination of 20% of sweet potato root silage and 80% basal diet. Gonzalez *et al*. (2002) reported from Venezuela that sweet potato root meal can be provided 54 and 58% of the diet during growing and finishing phases of pigs, respectively.

Onwueme and Sinha (1991) conducted a three-month pig feeding trial and compared three feeds: cooked fresh sweet potato roots (T_1), uncooked root silage with rice bran (T_2), and uncooked roots silage with sun-dried chicken manure (T_3). The results revealed that the weight gain was 552, 605 and 640 g for T_1, T_2 and T_3, respectively and the difference between the treatments were not statistically significant. Reasonable growth rate was observed with uncooked roots. Cooking in the ensiled roots decreased trypsin inhibitor, which appeared to allow farmers subsequently to triple the number of pigs raised per cycle of 3-4 months. But, cooking is labor intensive and fuel demanding (cooking pig feed on rice husks normally takes 2-3 hours per day). Manfredini *et al*. (1993) measured performance, carcass characteristics and meal quality (aged ham) by use of sweet potato chips in heavy pig production (Ravindran and Sivakanesan 1996). Pigs fed with 20 and 40% sweet potato had significantly lower dressing percentage than those fed maize meal. Growth performance, feed efficiency, carcass length, fat thickness or lean meat contents and meat quality were similar in all the treatments.

The main constraints to using sweet potato vines as pig feed are labor and storage. Regardless of how they are fed to the animals, the vines must first be chopped into small pieces, a daunting and time-consuming task mainly undertaken by women. If the vines are fed fresh, the women must allocate time each day for this task, even during the busy field season. Silage offers a potential alternative to overcome this constraint: sweet potato vine silage has been a common livestock feed during winter (Sutoh *et al*. 1973) whenever seasonal lack of feed for livestock may limit productivity (Brown and Chavalimu 1985). Use of vine silage overcomes both main constraints: the women are able to process the vines during the off-season when labor is more abundant, and store the silage for use when feed is limited. Moreover, there is also the economic advantage of ensiling/storing vines: to process and store the sweet potato vines during the harvest season when vines are cheap and feed them to pigs during off-season when vines are expensive.

Sweet potato vines can be fed to pigs either in the fresh form or after drying. Pigs readily eat the vines. Vines can be dried and grind into a meal. By drying 100 kg of fresh vines, about 30 kg of dried vines can easily be obtained. Sweet potato vine meal can be used in compounded pig rations, but only at low levels. It should not be used more than 5% level in pig rations.

Gonzalez *et al*. (2003) observed from a voluntary feed intake of fresh foliage from sweet potato study that it was possible to record high levels of performance in pigs fed *ad libitum* sweet potato foliage, provided they also received feed supplements containing 23.7 and 20.6% protein during the growing and finishing periods. Duyet *et al*. (2003) concluded that sweet potato leaves could be included up to 50% in the diets of growing and pregnant gilts (a mature pig that has not given birth before) and up to 20% during lactation. An (2004) reported that when growing pigs diets were supplemented with sweet potato leaves and synthetic lysine, their daily weight gains of 536 g were similar to those fed a control diet with fish meal as protein source. Further, he stated that the DM, organic matter and crude protein of ensiled sweet potato leaves was highly digestible in growing pigs, but that of crude fibre was low. He concluded that sweet potato leaves can be used fresh, dried or as silage, and can replace fish meal and groundnut cake as a protein source for growing pigs under small farm conditions in central Vietnam. Malavanh and Preston (2006) reported that water spinach and sweet potato leaves appear to have the same nutritive value when used to supplement a basal diet of cassava root meal and rice bran for growing pigs. Ty *et al*. (2007) found that there was no advantage of mixing sweet potato vines and mulberry leaves compared with either foliage given alone. They reported that foliage DM intakes were higher when sweet potato vines were all or part of the foliage supplement. The intake of foliage accounted for 21-28% of the total DM and approximately 55% of the CP.

In China, the farmers are using sweet potato for fattening their pigs. Some makes silage with sweet potato tubers to feed their pigs. This technology could be used to increase the production of pork. The DM intake for the older pigs mean live weight of 90 kg is around 900 g day^{-1} while younger pigs (<30 kg) can consume around 450 g day^{-1}. It has been claimed that feeding sweet potato reduces the parasitic load, thus having an additional advantage in body weight gain of pigs. Fresh tubers can be chopped and fed to pigs.

Sweet potato in poultry ration

Poultry is an important source of protein to the ever-expanding population in rural areas. The cost of feed has been indicated by farmers in the smallholder sector as the major constraint in poultry production (Wu *et al*. 2008). The poultry producers have experienced a rise in the cost of production due to the increasing cost of feed. The cost of the maize ingredient, which makes 65% of the current poultry feeds, is very high (Scott 1992; Scott 1995). The prospects to increase the output of cereals to a magnitude, which will satisfy both human and animal needs remains unforeseen. Therefore, an alternative to cereals in animal feeds might be the only immediate solution (Scott 1995). Maize and sweet potato have comparable metabolizable values of 14.5 and 14.8, respectively (Woolfe 1992). Sweet potato roots are the good source energy (3500 kcal kg^{-1}) for poultry. The digestibility of sweet potato carbohydrate fraction is reported to be above 90% (Van Soest *et al*. 1991; Ravindran 1995). Level of inclusion of sweet potato meal into a ration depends on the age of the birds. In rations of young birds that are less than eight weeks old, it should not be used beyond 20%. As the birds grow bigger, it can gradually be increased and in rations for laying chickens it can be used up to 30%. Maphosa *et al*. (2003) studied on the use of raw sweet potato root meal as an ingredient in broiler diets and concluded that it should not be added to broiler starter diets but could be used up to 50% in finisher diets without affecting performance of the birds. Ayuk (2004a, 2004b) reported from two separate studies in Nigeria that sweet potato meal could replace maize 50% rate which recorded the highest dressing percentage of 88.4% with giblet in finishing broilers while, starter rations replacing maize with sweet potato meal did not significantly decrease palatability and feed consumption.

Fresh green leaves of sweet potato can be chopped and given to birds in addition to mash. It supplies the pigments, minerals and vitamins to poultry. Giving green leaves to chickens is a good practice. The amount of mash given to the chickens can be reduced when additional greens are given. Fresh sweet potato vines can also be fed to chicken but to a level of less than 3%. However, Teguia *et al*. (1997) did not record positive results from their experiment. When sweet potato leaf meal replaced 200 or 300 g of maize per kg in the finishing broiler diets resulted depressed body weight gain and increased feed conversion ratio. But, in another study sweet potato vine meal replaced with Lucerne meal at different levels in starter diets for broiler chicken revealed that growth rate and feed conversion ratio were not different from diets of Lucerne meal (Farrell *et al*. 2000). Nguyen and Ogle (2005) reported from their study on four weeks old female Luong Phuong chickens (N=204) that intake of sweet potato vines (2.8 g day^{-1}) was significantly ($P > 0.01$) higher than water spinach (1.8 g day^{-1}) when fed *ad libitum* in addition to control diet.

Sweet potato in ruminant ration

Sweet potato tubers can be given to all ruminants. They can be fed as fresh, chopped tubers, dried chips and silage (Ongadi *et al*. 2010). Sweet potatoes can be fed to ruminants as energy supplements along with locally available grasses during the dry season for both fattening and milking animals. In China part of the produce is fed to cattle apart from pigs (Wu *et al*. 2008). In USA and Japan, 10 and 25% of sweet potato roots are utilized as cattle feed, respectively. In Costa Rica, Backer *et al*. (1980) reported that 12% of sweet potato roots that had no commercial value when fed with the rest diet made of the forage to crossbred Brahman bulls resulted in 38% profit (Etela *et al*. 2008a).

Fresh sweet potato vines make good feed for all ruminants. They can be given without any restriction (Dahlanuddin 2001). When sweet potato vines are fed to milking animals or fattening animals, no need to give any other protein supplement as vines alone can supply all the protein needed by these animals. Orodho *et al*. (1996) reported that sweet potato foliage could use as starter feed and partial milk replacer for calves. Kariuki *et al*. (1998) working in Kenya fed sole diets of fresh sweet potato vines to dairy heifers and concluded that sweet potato vines contained nutrient levels that would sustain acceptable growth in heifers. Feeding of Bunaji and N'Dama cows in early lactation with sweet potato foliage had lower milk yield than the dried brewers grains and cottonseed meal, but the metabolizable energy intakes were higher from the sweet potato foliage than the other diets (Etela *et al*. 2009). Another study Etela *et al*. (2008b) also reported that the performance of pre-weaned crossbred calves supplemented with sweet potato foliage was comparable to those fed dried brewers grains and cottonseed meal. Karachi (2008) reported that the weaners (Born calves) supplemented with the sweet potato vines had similar growth to those fed cottonseed cake and consumed 30% more total DM than those fed grass alone. Therefore, compounding feeds with sweet potato vines would be a feasible alternative to the more expensive cottonseed cake.

Many researchers stated that fresh sweet potato foliage could serve as a sustainable cost effective supplement to improve the nutritional quality of grasses (Ffoulkes *et al*. 1997; Etela *et al*. 2009; Elamin *et al*. 2011). The effect of mixing sweet potato forage into a basal diet of sugarcane was not as dramatic (Tawe 1991; Foulkes *et al*. 1997) as that observed with mixtures of sugarcane and banana forage fed to Zebu bulls. Nevertheless, rate of consumption of DM was increased by 39% with one third substitution of sugarcane by sweet potato forage (Foulkes *et al*. 1997). The large standard error for intake on the diet 33 sugarcane: 67 sweet potato indicates probably that there was considerable variation between animals on this diet in terms of selection of the two forage components. A major difference between the effects of sweet potato forage and banana forage was in the supply of protein. When banana forage was added to sugarcane the amounts of protein provided by this forage were 115, 150 and 157 g day^{-1} for increasing rates of substitution of the sugarcane; in contrast, in the present experiment the amounts were 370, 784 and 900 g day^{-1}. Etela *et al*. (2008b) demonstrated that *panicum* fodder showed improvements in rumen DM degradation characteristics following sweet potato forage supplementation. Aregheore (2004) concluded from a voluntary intake study in growing goats that sweet potato foliage in combination with *batiki* grass could provide a cheap source of nitrogen in the diets. However, the high dry matter degradability (above 85%) (Chanjula *et al*. 2003) and the high content in soluble carbohydrates may lead to acidification in the rumen. Sweet potatoes should therefore be introduced gradually and associated to roughages to minimize the risk of digestive disturbances (Otieno *et al*. 2008).

Fresh vines can be preserved as sweet potato vine silage and fed during lean season when fodder availability is inadequate (Etela and Anyanwu 2011). The method of making silage from vines is similar to that used for making silage from any other forage. Good sweet potato vine silage will be brownish green in colour. It will have a pleasant fruity smell and can be fed free choice to all ruminants.

CONCLUSION

It will take time to feel the full impact of several of the agro-biological and socio-economic factors outlined above. In the meantime, the prospects for the expanded use of sweet potatoes as animal feed would appear to be greatest in those regions and countries where a substantial supply of the commodity already exists, where feed shortages have already materialized and where continued or expanded imports of feed do not appear sustainable for economic or political reasons. A number of countries in Asia (e.g. China, Philippines) and to lesser extent in Latin America (e.g. Brazil, Peru, Dominican Republic) would appear to meet these criteria. Unfortunately, a detailed assessment of the marketing for sweet potatoes as animal feed in these countries is currently not available. That task is what merits immediate attention.

Feeding sweet potato roots to pigs offers a good opportunity to convert an undesirable and often unmarketable crop into a high-value commodity - pork. But sweet potato roots have low starch digestibility and protein content, and contain trypsin inhibitors which reduce protein uptake, and the traditional way to overcome these constraints is to cook the feed, which is expensive of labor and fuel. Moreover, sweet potato roots do not store well, so feed must be prepared fresh every day. Ensiling sweet potato roots with rice bran, cassava leaf meal or chicken manure, offers an alternative solution to some of these constraints. Silage based on uncooked sweet potato roots was found to achieve pig growth rates comparable with those achieved with cooked sweet potato roots, at no increase in cost and with considerably lower labor requirements. When used with other feed materials, even small amounts of sweet potato silage (10% of the total feed, on a dry-matter basis) can achieve good growth. But it seems that it may be more cost-effective to feed a higher amount (30% of total feed) in the first month, and then reducing this proportion in subsequent months. The effects of this feeding regime need to be verified by a trial specifically designed to test this hypothesis. In addition to reducing the level of trypsin inhibitor, silage can be stored for five months without spoilage if it is stored carefully in tightly packed plastic bags under anaerobic condition.

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