VIIth Symposium of the International Society for Tropical Root Crops,
Gosier (Guadeloupe), 1-6 July 1985, Ed. INRA, Paris, 1988.

TROPICAL ROOT CROPS : FOODS FOR A HUNGRY WORLD

Dr S. CHANDRA

Bureau of Agricultural Economics
P.O. Box 1563

Canberra City ACT 2601 Australia

ABSTRACT

Tropical root crops are important staple food for about a third of the world's population. In this paper the production and consumption of tropical root crops by major world regions and individual countries are analysed. Some of the world's leading producers and consumers of tropical root crops are China, Nigeria and Brazil. The annual global per capita consumption is bout 70 kg. The nutritional content of tropical root crops is discussed next, followed by a review of some nutritional studies done in India, Zambia, Brazil and the South Pacific. In some countries tropical root crops supply up to 75 per cent of the kilojoules in the daily diet. Tropical root crops have high return to energy expenditure in their production. The various utilization methods of tropical root crops are then discussed. There is very little international trade in tropical root crops, the main products being cassava pellets and starch. Most of the trade is domestic nature, consisting of fresh tubers for urban markets. The contribution of tropical root crops in the agricultural economy of the main producing nations varies greatly. It ranges from about 25 per cent in a highly subsistence oriented economy like Papua New Guinea, 10 per cent in a semi-subsistence economy like Fiji and only 2 per cent in highly commercialized economy like Japan. The development potential of tropical root crops is very high because they can produce large amounts of food per unit of labour or time, they are well adapted to a wide range of environments and have a strong inter-dependence with man. It is argued that in this hungry world tropical root crops have a major role to play in meeting the food needs or rural and urban populations of the less developed countries. Rural development programs in many less developed countries would have greater chances of success if they were strongly integrated with tropical root crops development programs.

RESUME

Les plantes à tubercules tropicales : aliments pour un monde affamé

Les plantes à tubercule tropicales sont des aliments de base importants pour environ un tiers de la population mondiale. Dans cette communication, on analyse la production et la consommation de plantes à tubercule tropicales dans les principales régions de divers pays. Quelques uns des grands producteurs et consommateurs mondiaux sont la Chine, le Nigéria et le Brésil. La consommation annuelle globale par habitant est d'environ 75 kg. Ensuite on discute la teneur en susbtances nutritives des plantes à tubercule tropicales puis on présente une revue de quelques études nutritionnelles faites en Inde, en Zambie, au Brésil et dans le Pacifique Sud. Dans certains pays, les plantes à tubercule tropicales fournissent jusqu'à 75 pour cent de la ration calorique quotidienne. Les plantes racines tropicales rentabilisent bien l'énergie investie dans leur production.

Ensuite on discute les diverses méthodes d'utilisation de plantes à tubercule tropicales. Il y a peu de commerce international, les principaux produits étant les cossettes et l'amidon de manioc. La plus grande partie du commerce est de nature domestique et consiste en la fourniture de tubercules frais pour les marchés urbains. La contribution des plantes à tubercule tropicales dans l'économie agricole des grandes nations productrices varie considérablement. Elle est d'environ 25 pour cent dans une économie fortement orientée vers la subsistance comme celle de la Papouasie-Nouvelle Guinée, 10 pour cent dans une économie hautement commercialisée comme celle du Japon.

Le potentiel de développement des plantes tropicales est très élevé parce qu'elles peuvent produire de grandes quantités de nourriture par unité de main d'oeuvre et ont une forte symbiose avec l'homme. On démontre que dans ce monde affamé les plantes à tubercule tropicales ont un plus grand rôle à jouer dans la satisfaction des besoins alimentaires des populations rurales et urbaines des pays moins développés.

Les programmes de développement rural dans beaucoup de pays peu développés auraient de plus grandes chances s'ils étaient fortement intégrés aux programmes de développement des plantes à tubercule tropicales.

Finalement, on fait des conclusions générales et des recommandations pour la recherche et le développement des plantes à tubercule tropicales en agronomie, en système de production, ressources génétiques, amélioration génétique, maladie et parasites, stockage, utilisation et commercialisation.

INTRODUCTION

Tropical root crops (TRCs) are important staple foods for one-third of the world's population. Most of these people are located in the less developed countries (LDCs) of the tropics and sub-tropics where poverty, malnutrition and hunger are some of their day-to-day problems. Although the contribution of TRCs to the gross domestic product (GDP) of many LDCs may not be large, the hard core of world poverty definitely lie in areas where TRCs are important staple foods. That is, the lowest 40 per cent of the world's poor are located in areas where improvement in TRCs could make substantial contribution to peoples' welfare. The purpose of this paper is to show that TRCs have a high inherent potential for increasing food supply in many LDCs where these crops can be grown successfully.

THE CROPS

The main TRCs are cassava (*Manihot esculenta* Crantz), sweet potatoes (*Ipomoea batatas* (L.) Lam.), potatoes *(Solanum tuberosum)*, yams *(Dioscorea* spp. and taro (*Colocasia esculenta* (L.) Schott) which belongs to the aroids family. Other less important aroids are tannia or new cocoyam (*Xanthosoma sagittifolium)*, giant taro (*Alocasia macrorrhiza*) giant swamp taro (*Cyrtosperma chamissonis*) and elephant yam (*Amorphophallus campanulatus*). Other minor TRCs are arrowroot (*Maranta arundinacea)*, achira *(Canna edulis*), arracacha (*Arracacia xanthorrhiza*), lairen (*Calathea allouia*) and jicamas (*Pachyrrhizus* spp.), pia or Polynesian arrowroot *(Tacca leontopetaloides)*.

PRODUCTION

Cassava, sweet potatoes, potatoes, yams and taro are important staple food crops in the world today. Table 1 shows the harvested area of these crops by major world regions. At the world level potatoes have the largest cultivated area of all root crops. Amongst the other four tropical root crops listed the most important in terms of cultivated area is cassava (55.4%), followed by sweet potatoes (30.3%), while yams (9.9%) and taro (4.4%) are far less important. The cultivated area of cassava has grown by a massive 130% in 20 years from 1965-84, representing a compound growth rate of 4.3% per annum. This represents a very rapid increase in the cultivated area of any major staple food in the world. For sweet potatoes the increase in cultivated area in the same period has been 40% or a compound growth rate of 1.7% per annum. Most of this increase in the cultivated area of cassava and sweet potatoes has occurred in Africa and Asia. For the same period the cultivated area of taro increased by 80% or a compound growth rate of 2.9% per annum. On the other hand between 1965-84 the cultivated area of yam increa-

sed by only 17%.

The production and yields of cassava, sweet potatoes, yams, taro and potatoes by major world regions are also shown in Table 1.

Potatoes have the highest production and yields in the world. Amongst the other four tropical root crops the most important in terms of production are cassava (46.4%) and sweet potatoes (42.3%), while yams (9.2%) and taro (2.1%) are less important. Most of the cassava is produced in Africa, Asia and S. America while sweet potatoes are heavily concentrated in Asia. Africa dominates the production of yams and taro. Potatoes are mostly produced in the temperate regions of the world and is heavily concentrated in Europe and USSR. Only 18% of the world production of potatoes is located in the tropics. However, potatoes are important staple food for some communities located in tropical highlands of North Central America, South America and Asia.

At the world level potatoes and sweet potatoes are the highest yielders followed by yams, cassava and taro. If yield per unit time is taken into account then the leaders would still be potatoes and sweet potatoes, followed by cassava, yams and taro. However, because of the vast differences in production technology, soil and climatic factors between countries and between regions within a country such worldwide comparisons of yield are not very useful.

The ranking of the world's top 10 producers of each crop are shown in Table 2. The table shows that there is a fairly wide dispersion in cassava production amongst the top five countries which are Brazil (16.4%), Thailand (15.4%) Zaire (11.4%), Indonesia (10.9%) and Nigeria (9.1%). The world production of sweet potatoes is heavily dominated by China which produces 83.4%. Nigeria dominates the production of yams producing 72.6%. Nigeria and China between them produce nearly 56% of the world's taro. If the production of cassava, sweet potatoes, yams and taro in each country are combined then the world's leading producers are China, Nigeria and Brazil.

CONSUMPTION

Tropical root crops are a major source of food in the world today. Table 2 also shows the annual per capita consumption (production divided by population) of tropical root crops in the top 10 producers. Some of the highest rates of per capita consumption (Kg) of cassava are Zaire (461), Thailand (395) and Tanzania (258) ; of sweet potatoes are Rwanda (161), China (93) and Uganda (51) ; of yams are Ivory

Table 1 : WORLD AREA 10^3 ha), PRODUCTION (10^3t) AND YIELD (t/ha) OF ROOT CROPS IN 1984

	CASSAVA			SWEET POTATOES			YAMS			TARO			POTATOES		
	10^3ha	10^3t	t/ha	10^3ha	10^3t	t/ha	10^3ha	10^3t	t/ha	10^3ha	10^3t	t/ha	10^3ha	10^3t	t/ha
Africa	7 482	51 002	6.8	841	5 136	6.1	2 395	24 426	10.2	926	3 392	3.7	660	5 830	8.8
North and Central America	165	922	5.6	217	1 446	6.7	49	317	6.4	2	20	9.6	746	20 353	27.3
South America	2 311	26 861	11.6	162	1 431	8.9	40	334	8.4	-	-	-	926	10 355	11.2
Asia	4 171	50 000	12.0	6 290	108 634	17.0	16	166	10.2	179	2 027	11.3	5 814	82 135	14.1
Oceania	22	235	10.7	116	559	4.8	18	246	13.7	46	319	6.9	48	1 130	23.4
Europe and USSR	-	-	-	13	131	10.4	-	-	-	-	-	-	12 109	192 406	16.4
World	14 151	129 020	9.1	7 739	117 337	15.2	2 518	25 489	10.1	1 153	5 758	5.0	20 303	312 209	15.4

Source : FAO Production Yearbooks

Table 2 : RANKING OF WORLD'S LEADING ROOT CROP PRODUCERS (% OF TOTAL) AND CONSUMERS (KG/CAPITA) IN 1984

CASSAVA			SWEET POTATOES			YAMS			TARO			POTATOES		
Country	% of total	kg/ capita	Country	% of total	kg/ capita	Country	% of total	kg/ capita	Country	% of total	kg/ capita	Country	% of total	kg/ capita
Brazil	16.4	160	China	83.4	93	Nigeria	72.6	201	Nigeria	30.5	19	USSR	27.3	310
Thailand	15.4	395	Indonesia	1.7	13	Ivory Coast	9.2	248	China	25.4	1	China	17.6	52
Zaïre	11.4	461	Vietnam	1.6	33	Ghana	3.4	67	Ghana	12.7	56	Poland	12.0	1 014
Indonesia	10.9	86	India	1.4	2	Benin	2.7	179	Japan	6.9	3	USA	5.3	69
Nigeria	9.1	128	Japan	1.2	11	Togo	1.8	159	Ivory Coast	5.4	33	India	3.9	16
India	4.4	8	Philippines	0.9	19	Cameroon	1.6	42	Papua New Guinea	3.2	51	Germany DR	2.6	480
Tanzania	4.3	258	Rwanda	0.8	161	Ethiopia	0.8	6	Philippines	2.6	3	Germany FR	2.4	126
China	3.2	4	Korea Rep.	0.8	22	Cent. Afr. Rep.	0.8	79	Burundi	1.7	22	UK	2.3	131
Mozambique	2.4	230	Uganda	0.7	51	Zaïre	0.7	6	Egypt	1.7	6	Netherlands	2.1	463
Vietnam	2.2	50	Bangladesh	0.7	8	Brazil	0.7	1	Madagascar	1.6	10	Romania	2.1	287
Total	79.7	-	Total	93.2	-	Total	94.3	-	Total	91.7	-	Total	77.6	-
World	-	27	World	-	25	World	-	5	World	-	1	World	-	66

Source : FAO Production Yearbooks.

Coast (248), Nigeria (201) and Benin (179) ; and of taro are Ghana (56), PNG (51) and Ivory Coast (33). The per capita consumption of all four crops by the leading world producers are China (98), Nigeria (348) and Brazil (161). Nigeria has one of the highest per capita consumption rates of all crops in the world at 351 Kg, comprised of 201 Kg of yams, 128 Kg of cassava, 19 Kg of taro and 3 Kg of sweet potatoes.

At the global level the per capita consumption of cassava is 27 Kg, sweet potatoes 25 Kg, yams 5 Kg and taro 1 Kg. To this could be added the production and consumption of potatoes in the tropical world (18% of the total world production) which corresponds to about 12 Kg per year for the whole world population. Hence on a world basis the tropical root crops represent a consumption rate of 70 Kg per capita per year.

The tropical root crops compare very favourably with the production and consumption of other staple foods in the world, which are wheat, rice, maize, barley, sorghum and pulses. Wheat is by far the most important staple food in the world with a cultivated area of 232 million ha and producing 522 million tonnes in 1984 (FAO Production Yearbook, 1984). For the other crops the cultivated area and production in 1984 were for rice 148 million ha and 470 million tonnes, maize 130 million ha and 449 million tonnes, barley 79 million ha and 172 million tonnes, sorghum 49 million ha and 72 million tonnes and pulses 68 million ha and 48 million tonnes. In terms of world per capita consumption these amounted to 110 Kg for wheat, 99 Kg for rice, 94 Kg for maize, 36 Kg for barley, 15 Kg for sorghum and 10 Kg for pulses.

In the LDCs the growth in consumption of most of these cereal and pulse crops is increasing at a faster rate than the population growth. For wheat alone the consumption in the LDCs is increasing at about 6% per annum. Most of the growth in cereal consumption in the LDCs is for human food with a minor fraction for livestock feed, especially in the Asian countries.

Data on consumption of tropical root crops at household levels are rare. One study carried out by Chandra (1982) in one village in Sigatoka Valley, Fiji, reported that an average adult Fijian consumed 290 Kg of cassava, 110 Kg of sweet potatoes, 25 Kg of taro and 20 Kg of yams per year. In the same village studies by Langley (1953), Wilkins (1963) and Menon (1975) showed that the total amount of prepared carbohydrate derived from tropical root crops eaten daily increased from 1.03 Kg in 1953 to 1.58 Kg in 1963. Over the years the carbohydrate fraction contributed by cassava increased from 36% in 1953 to 59% in 1975. The increase in cassava consumption was matched by a concomitant decrease in the consumption of taro and yams which are the

traditional foods of the Fijians (Parkinson, 1984).

Other studies carried out in the Pacific are those of Venkatachalan (1962), Lambert (1975), Dye (1976) and Wilkins (1965). Venkatachalan and Lambert, working amongst the Chimbu people of Papua New Guinea, found that tropical root crops provided about 75% of the diet of the people. Dye, working in Makekula, Vanuatu, found that 60% of the food energy of the communities came from tropical root crops. In Western Samoa Wilkins found that the percentage of total energy derived from tropical root crops varied between 37-50% in households close to town and between 50-64% for remote rural households.

NUTRITION AND UTILIZATION

TRCs are renowned for high outputs of food energy or kJ per unit area of land. Although the food energy of TRCs ensures that the total energy output per unit area is about 2-3 times higher than that of grain crops.

Table 3 shows the nutritive values of various TRCs. The food energy of TRCs in kJ per Kg of edible portion vary from about 2,550 for giant taro to 5,650 for cassava. The crude protein content of TRCs are low compared to grain crops ranging in g per Kg of 6 for giant taro to 22 for taro and tannia. Nevertheless, the purpose of TRCs in diets of peoples where they are consumed as staple foods is to supply the food energy or carbohydrates, not the protein. The protein is often supplemented by grains, legumes and animal-based products in the diet. On the whole the TRCs have adequate amounts of minerals and vitamins. Taro and cassava leaves are particularly high in crude protein, carotene and vitamins (Chandra, 1984).

Case studies on the consumption and nutrition of TRCs in some of the major world regions where they are grown have been reported by Goering (1979). In a study carried out in Kerala, India, it was found that cassava supplied 30% of the kJ and 9% of the protein in per capita daily diet (UN, 1975). The total daily consumption was 10,545 kJ and 37.8 g of protein. The protein needs were supplemented by rice and fish. In another study in the northwest region of Zambia where the consumption of TRCs is unusually high it was found that TRCs supplied 32% of the 7,116 kJ per capita daily intake (FAO, 1974). This study notes the lack of enough kJ and to some extent protein in the diet. A study carried out in northeastern Brazil, reported by Goering (1979), showed that 30% of the kJ in the typical diet for all income groups resulted from TRCs. Although the general quality of the diet was adequate despite the high intake of TRCs, the poorest income class was not consu-

Table 3 : Nutritive values of Tropical Root Crops (per 100g edible portion)

CROP	Food Energy	Moisture	Protein	Total CHO and fibre	Calcium	Phosphorus	Iron	Potassium	Carotene equivalent	Thiamine	Riboflavan	Niacin	Ascorbic acid	Folic acid
	kJ	%	g	g	mg	mg	mg	mg	ug	mg	mg	mg	mg	ug
Cassava	565	65.5	1.0	32.4	26	32	0.9	394	0	0.05	0.04	0.6	34	24.2
Sweet Potatoes														
White	452	72.8	1.0	25.1	21	50	0.9	210	35	0.14	0.05	0.7	21	52.0
Yellow	481	70.7	1.2	27.1	36	56	0.9	304	1 680	0.12	0.05	0.6	30	
Potatoes	335	77.8	2.0	19.1	9	55	0.7	451	30	0.11	0.04	1.2	14	
Yams	452	71.8	2.0	25.1	22	39	1.0	294	0	0.10	0.04	0.07		
Taro and tannia	393	75.4	2.2	21.0	34	62	1.2	448	tr.	0.12	0.04	1.0	8	
Giant taro	255	84.0	0.6	14.8	30	50	1.0		0	0.05			5	
Giant swamp taro	548		0.9	31.0	334	56	1.2		0	0.05	0.07	0.88		
Elephant yam	339	78.5	2.0	18.4	38	38	2.4	416	0	0.06	0.02	1.7	6	
Taro leaves	255	81.4	4.0	11.9	162	69	1.0	963	5 535	0.13	0.34	1.5	63	163.0

ming enough total kJ although their protein intake was more than enough. All these studies indicate that nutritional adequacy seems to require more of the same food mix, rather than sharply altered consumption patterns. Some remaining deficiencies, such as Vitamin A, could be addressed at low cost through home gardens or supplementation of cooking oils.

The ability of TRCs to supply high amounts of food energy per unit of productive effort is well supported by studies of energetics of crop production. A measure of the energetic efficiency of crop production is the efficiency ratio (E), which is the edible yield of crops expressed in kJ and divided by the kJ of energy expended to attain that yield (Black, 1971). The higher the E of a crop the more efficient that crop is in the energetic efficiency with which it uses resources to produce food under a cropping system of a given technology.

Studies carried out in the Sigatoka Valley, Fiji showed that E of yams was 66, sweet potatoes 60, cassava 52 and taro 21. The values of other crops grown on the same farms such as rice, maize, pulses, potatoes and vegetables were significantly lower (Chandra, De Boer and Evenson, 1974 ; Chandra, Evenson and De Boer 1976 ; Chandra, 1979 Chandra, 1981). Hence, given one level of production technology the return to energy expenditure are always higher for TRCs than for any other food crop grown on the same farms.

Most of the TRCs produced in the world are consumed as fresh human food. Only a small fraction, probably no more than 10%, are utilized for animal feed, processed into human food or manufactured into industrial products. However, individual countries vary greatly in the forms of usage and this is discussed in a later section.

The commonest form of human consumption of TRCs is in the boiled form after the tubers have been peeled. Baking of whole, unpeeled tubers is important in some communities such as the use of yams, taro and giant taro in the South Pacific. In some places, such as West Africa, cassava is made into gari. This involves grating the tubers, washing the material and compressing the mixtures in bags for 2-4 days so a to expel harmful cyanogenic glucosides. Afterwards the material is cooked in shallow metal-pots and consumed. In some countries, such as Colombia and Brazil, small fractions (10-25%) of cassava flour are added to wheat flour to make a composite flour. Apart from making flour processing of TRCs tubers for making confectionery and other food products are only a minor activity in some countries.

Other plant parts that are important for human consumption are the leaves and sometimes the petioles of

some TRCs. Cassava leaves are frequently consumed in West Africa (Nigeria and Zaire) and Indonesia (Central Java). Taro leaves are consumed in the South Pacific, especially during periods of food scarcity, such as after hurricane and flood.

The tubers and leaves of cassava and sweet potatoes are often used for animal feed on smallholder farms. Usually the material is chopped up into small pieces. The main animals that utilize the products are pigs and chickens

TRADE AND SPECIALIZATION

Most of the TRCs produced in the world are usually consumed as subsistence products by subsistence and semi-subsistence farm households. Perhaps less than 33% of total production is marketed in the monetary sector of the national economies. Data on trade and specialization in TRCs are extremely meagre. Even FAO Trade Yearbooks do not report data on TRCs except for potatoes. This is one of the problems for further development of TRCs as rigorous country data on trade, marketing and prices are some of the fundamental immediate needs.

International trade in small consignments of fresh TRCs are important in many countries. Usually the export is from LDCs to developed countries (DCs). In many cases these exports are for the consumption of migrant ethnic communities who still have a high preference for their traditional native staple foods. For example, taro is regularly shipped and air-freighted from Fiji, Western Samoa, Tonga, Cook Islands and Niue for Polynesians and Melanesians living in New Zealand, Australia and the United States. Usually such migrants are prepared to pay 3-4 times higher price than local substitutes such as potatoes. Similarly TRCs from Latin America are exported to USA and Canada, from Africa to Europe and from developing Asia to more developed Asia such as Japan, Hong Kong and Singapore.

International exports of dried and processed forms of TRCs are restricted to very few countries. The most important are the export of cassava pellets from Thailand, Indonesia and Brazil to EEC countries, USA and Japan for animal feed. Total world export in 1978 was estimated to be about 5 million t (Goering, 1979), reflecting an annual growth rate in recent years of nearly 20%. The main exporter of cassava starch is Thailand. The world export of cassava starch has totalled about 250,000 t in recent years with the importers being USA and Japan.

Domestic trade in fresh TRCs are important in most producing countries, especially ther larger producers in Latin America, Africa and Asia. In this context fresh

TRCs are transported to urban areas or important rural centres and marketed in open-air markets. The sellers are usually the more innovative farmers, middlemen or business men. The buyers are almost invariably urban workers and landless labourers. TRCs are usually purchased by the lower income groups in a society. Cassava and sweet potatoes are usually the cheapest foods while yams and taro are usually the more expensive TRCs.

CONTRIBUTION TO NATIONAL ECONOMY

The importance of TRCs to the national economy of each nation growing these crops varies considerably. However, instead of reporting masses of inter-country data showing similar patterns, it was thought appropriate to choose three very different countries and give detailed information on each so that the global range is covered. The countries chosen are Papua New Guinea, Fiji and Japan. In each country TRCs have markedly different levels of influence on the overall national economy.

Papua New Guinea is representative of an almost pure subsistence economy, heavily dependent on TRCs for stample foods and where over 90% of the total production is utilized for farm family subsistence. Fiji represents a semi-subsistence economy where TRCs are still very important in the peoples' diet and where about 67% of the total production is consumed by the rural population, the remainder consumed by urban population who purchase root crops for cash. Japan represents a highly commercialized economy, where TRCs are one group among several staple foods and where over 70% of the total production is purchased and consumed by the urban population. Each of these countries represent and interesting case. All other TRCs producing nations in the world can be categorized into one of these cases. Hence the following discussion is applicable to any nation in the world, depending on which group it belongs.

Table 4 shows the contribution of TRCs to the national economy of Papua New Guinea, Fiji and Japan. The highlights of this Table can be summarized as follows. Progressing from an almost pure subsistence economy of Papua New Guinea to a highly commercialized economy like Japan the important features are : (1) The average yield of the flour root crops increases markedly ; (2) The annual per capita consumption decrease substantially ; (3) The degree of fresh food utilization decreases and that of processed foods, animal feeds and non-food usage increases significantly ; (4) The contribution of food energy and protein supply from root crops in the total diet of an adult decreases sharply ; (5) The degree of farm household subsistence decreases while consumption by urban population increases greatly ; (6) In terms of total economic activity the per

Table 4 : Contribution of Tropical Root Crops in Three National Economies

Parameters	Papua New Guinea	Fiji	Japan
1. Main crops (in order of importance)	Sweet Potatoes Taro Yams Cassava	Cassava Taro Yams Sweet Potatoes	Potatoes Sweet Potatoes Taro Yams
2. Area (1000 ha)	150	16	231
3. Production (1000 t)	917	153	5 496
4. Yields (t/ha)	6.1	9.6	23.8
5. Population (1000)	3 601	674	120018
6. Consumption (kg/capita)	255	227	46
7. Utilization :			
fresh food (%)	98	94	42
processed food (%)	-	1	8
animal feed (%)	2	5	10
non-food (%)	-	-	40
8. Energy supply : % kJ per adult unit per day	64	48	7
9. Protein supply : % g per adult unit per day	36	21	3
10. Human consumption : subsistence farm products (%)	93	67	28
urban population (%)	7	33	72
11. Income levels per capita (US$)	783	1650	16568
12. Gross domestic product per capita (US$)	935	2358	18192
13. Contribution to agricultural economy (%)	25	10	2

Source : (1) Cooperators in Root Crop Statistics Project from various countries
(2) FAO Production Yearbook, 1984.
(3) UN Statistical Yearbook, 1983-84.

capita income levels and GDP increases substantially ; (7) The overall contribution of TRCs in the agricultural economy decreases sharply.

What are the implications of these findings ? First, TRCs are important food products in countries that are strongly agricultural based and especially where subsistence and semi-subsistence characteristics are prevalent. In these situations production and consumption are an integral part of farm household decisions. Also, in the marketing structure and distribution channels are undevelopped or poorly developed and very little cash sales take place. Second, technological development, industrialization and urbanization lead to reduced dependence on TRCs as fresh human food. Other foods, especially the storable grains such as rice and wheat products, may become important in the human diet. However, a greater fraction of total production of TRCs are processed into human or animal feeds or are utilized for non-food purposes. Marketing and distribution channels become well organized and developed. The urban populations become the major users of fresh TRCs and processed products.

DEVELOPMENT POTENTIAL

The main development potential of TRCs is that they can produce large amounts of food per unit of effort (labour) or per unit of the (crop duration). This aspect has been well documented by the pioneering works of D.G. Coursey, as in Coursey and Haynes (1970) and his more recent paper (Coursey, 1984).

Unlike the grain crops such as rice, maize and wheat, in which massive investments in research and development occurred in the 1950s and 60s leading to the green revolution, no such revolution has yet taken place in TRCs. This can be attributed to several factors some of which are only the recent (last 2-3 decades) recognition of their importance as staple foods and the obsession of national governments with improving exotic and exportable crops. However, now many countries are increasing their research and development efforts so that in the long term the potential for a green revolution in TRCs is there as demonstrated below.

The high development potential of TRCs emanates from three sources which are : (a) physical and biological factors, (b) adaptation to a wide range of environments, and (c) man-plant inter-dependence. The physical and biological potential of TRCs are demonstrated in Table 5. First, the data shows that even after the green revolution in rice and no major improvement in TRCs, the TRCs can still outyield rice, both in total edible yield and in food energy.

Table 5 Highest recorded edible yield per crop

Crop	t/ha	kJ/ha (10^6)	Country
Cassava	68	384	Brazil
Sweet Potoes	47	212	Taiwan
Yams	36	163	Nigeria
Taro	65	255	Hawaii, USA
Potatoes	72	226	Netherlands
Rice	8	118	Japan

Even if the measure of yield per unit time is used for comparison cassava, sweet potatoes and perhaps taro can still out-yield rice. In terms of total dry matter production Doku (1984) estimated that the use of improved varieties under conditions of good husbandry would result in yearly production levels of 140 t/ha for cassava and yams, and 200 t/ha for sweet potatoes and taro. Hence the highest recorded edible yield per crop shown in Table 5 are only a small fraction of the total dry matter production that can be attained in these crops. Second, because some yield components of TRCs can be harvested and consumed even prior to half-way through its crop duration, they are potentially able to supply food over a long time horizon during crop growth, a very desirable characteristic for subsistence and semi-subsistence smallholders. On the other hand, grain crops have a very sharp maturity period which culminates in a few days and hence the potential risk of crop failure, due to natural calamities such as floods, is very high. Third, TRCs have suitable plant engineering for yield increases. Since the storage organs in TRCs are underground, except in giant taro in which case it is the plant stem, these crops are very able to accept high amounts of yield increasing inputs such as fertilizers. In the case of grain crops, major restructuring of the plant was required in form of short-statured varieties to stand high fertilizer inputs without lodging before the green revolution was achieved. Hence, TRCs are already in a form which can stand high fertilizer inputs without the fear of a higher yield risk penalty.

Most TRCs are adapted to a wide range of climatic and edaphic environments and hence they can be grown in most of the agroclimatic zones present in the tropical and subtropical world. Each crop also has a large number of cultivars, each suitable for a particular locality even within individual country basis. The plants also can readily adapt to new conditions as has been the historical experience with potatoes.

Probably the most important reason why TRCs have a high potential for development is because of their strong inter-dependence with man in historical perspective. These groups of crops have been cultivated in confined ecological niches in many regions and islands of the developing world for thousands of years. Over this period man has adapted his life around the life of TRCs plants and the TRCs themselves have been adapted to fit the neeeds of the people. Because these cultivators have a strong affinity for TRCs it follows thatany suitable research and development efforts in TRCs would have a high potential for acceptance by the farmers. In the long run this will make a substantial gain to the welfare of the root crop communities.

FOODS FOR HUNGRY WORLD

The future development of TRCs will be strongly influenced by two main factors which are population growth and urbanization. In those countries which are heavily dependent on root crops for human food the demand for these crops will be directly associated with population growth. Given the present population growth rates of 2-3% in many TRCs producing nations of Central and South America, Africa and Asia, the problem of maintaining even the present levels of subsistence will become acute since national populations are likely to double within 30 years or by year 2015AD. That is, in just three decades over three billion people will be directly dependent on TRCs for their staple foods and altogether over six billion will consume these crops on a fairly regular basis. Hence, the problems of meeting such growth in food needs will be enormous both for national governments and on a global perspective.

The main problems of maintaining food supply will be in the African and Latin American countries where population growth is fastest, about 2.5-3.0% per annum. The main African nations concerned are Nigeria, Ivory Coast, Ghana, Zaire, Tanzania, Mozambique, Togo, Benin, Ethiopia, Sudan, Egypt, Burundi and Rwanda. The main Latin American countries are Brazil, Colombia, Venezuela, Mexico, Peru, Central American countries and the Caribbean nations. In Asia, where population growth is less rapid and in the order of 2.0-2.5% per annum, the main countries concerned will be China, India and Indonesia. It is likely that in most of the above

countries population growth will be faster than TRCs production in the next three decades. Hence more malnutrition and under-nutrition can be expected in many of these countries, especially those in Africa where food scarcity is already very high. Therefore, major efforts will need to be directed at increasing TRCs production in these countries. Hence in many LDCs dependent on TRCs for staple foods the main problem will be one of supply which cannot be ignored from agricultural policy. There has to be considerable commitment of resources into the development of TRCs if mass hunger and starvation are to be avoided in many parts of the world.

In the LDCs urbanization is occurring rapidly and it has been forecast that the total urban population of 972 million in 1975 wil increase to 2,116 million in 2000 AD, a compound growth rate of 4% per annum (Todaro, 1981). Some cities in Africa such as Nairobi, Lagos and Accra presently have growth rates of over 7% per annum while many Asian and Latin American cities average over 5% per annum. The world's 12 fastest growing cities are all in LDCs. Todaro (1981) notes that rural-urban migration accounts for 35-60% of this growth in urbanization.

It is therefore reasonable to assume that urbanization in the LDCs where TRCs are staple foods would create and added demand for these foods. TRCs are generally regarded as having low income and price elasticities of demand. Added to this if the historical experience of other countries are any indication urbanization would tend to favour the consumption of grain crops rather than TRCs in fresh form. Nevertheless there will be increased demand for processed forms of TRCs as well as products for animal feeds, both for domestic consumption and international markets, as a result of their comparative price advantage. However, on the whole urbanization would not create as large a demand for TRCs as that due to responses to rural population growth. In the long-run it is very likely that the diet of the urban dwellers and migrants would slowly change towards storable convenience foods such as rice, maize and wheat products and this could be the result of both income and price effect. This, in itself, will be a major dilemma for the developing nations which can be demonstrated in this way. As noted earlier, TRCs, because of physical and biological factors, are highly efficient producers of kJ per unit of input such as land, labour or capital (Chandra, 1980 ; Evenson and De Boer, 1978). Under the same level of inputs TRCs are capable of producing more kJ per ha per unit time than any other crop, except perhaps sugar cane. In other words, TRCs, compared to other crops such as rice, have particularly suitable production functions as shown by the theoretical responsable curves in Figure 1. However, price ratios between TRCs and a crop such as rice are not normally in favour of TRCs and hence the economic justification for maximazing production of TRCs is not usually present. As noted later there are other problems such as markets and infrastructure

development in LDCs which inhibit the commercialization of TRCs. However, it is clear that in the LDCs where TRCs are important staple foods of the majority of the population, the first priority for food production program should be based on root crops. Therefore, it follows that TRCs have a major role to play in supplying for needs of future population of many LDCs.

TRCs AND RURAL DEVELOPMENT

About one-third of the world's population, consisting of 1.67 billion inhabitants, are dependent on TRCs for their staple foods. Most of these people are located in the LDCs encompassing the tropical and subtropical regions. It is in these regions where the problems of mass poverty, hunger and low incomes exist. Here even modest improvements in the production and consumption of TRCs can make substantial gains to the welfare of the people. The main opportunities for TRCs are in increasing the amounts of human food and livestock feed within rural development programs.

Rural development, as defined by the World Bank (1975) is 'a strategy designed to improve the economic and social life of a specific group of people - the rural poor. It involves extending the benefits of development to the poorest among those who seek a livelihood in the rural areas. The group includes small-scale farmers, tenants and landless'

The World Bank and other international agencies and institutions did place the main emphasis on increasing production, raising productivity, increasing employment and mobilizing what land, labour and capital were available. But there was also recognition that inequalities had to be reduced, that development involved values and quality of life issues, and that the poor should participate in activities and be involved in decision-making. This strategy came to be known as 'growth with justice' but few can now see much evidence of the evolution of just or equitable societies. These issues are the basic problems of rural development in areas where TRCs are important. Hence there are strong complementary relationships between rural development and TRCs development.

One of the greatest challenge facing research workers in TRCs is in the design of suitable farming systems strategies that will combine their excellence in food production with the overall issues in rural development. In this context TRCs have to be considered the dominant staple crops but they have to be grown with other crops (and perhaps livestock) to provide adequate nutrition and establish a basis for increasing incomes. How can this be done ?

Presently there exists very little information as to what the optimum combination of crops (and livestock) are for various regions, farm sizes and diets. However, the payoffs can be very high for and LDC trying to develop quickly and at the same time ensuring that mass hunger and starvation will not occur. Here consumption based studies may provide useful insight into ideal crop mixtures. For example, it is easily possible to calculate the area of a crop required to sustain a farm familiity. If cassava was the dominant food with a consumption rate of 4,186 kJ per capita per day and the fresh tuber yield was 15t/ha then only 0.2 ha per year would be required to feed a family of five adult equivalents. Hence a farm size of 0.25 ha may be quite feasible to meet total nutrient requirements. Using intercropping, rotations and relay planting, it may be possible to further reduce the area required for satisfactory subsistence.

However, meeting subsistence food needs by itself will not provide the momentum for rural development. Incomes have to be increased as well. Maximizing both is a problem as usually TRCs are not high-priced crops when sold commercially. However, the major problem in many LDCs is that the market structure is not developed or poorly developed and this, together with poor transport and communication channels, makes the feasibility of producing TRCs for cash sales extremely difficult. This problem has been addressed by some researchers who have designed two-goods theoretical models which ensures that after the demand ceiling for food has been met from farm resources the remainder of the resources can be allocated to the production of cash crops (Fish, 1962, 1964 ; Shand, 1965 ; Stent and Webb, 1975 ; Chandra and De Boer, 1978 ; De Boer and Chandra, 1978). However, the process of change from pure subsistence to producing for markets is a long term development strategy and depends largely on other factors such as incentives for cash and education and the development of innovations, transportation infrastructure, markets and prices. In fact all these processes are manifestations of rural development in its totality.

REFERENCES

BLACK J.N. (1971). Energy relations in crop production - a preliminary survey. Proc. Assoc. Appl. Biol. 62 : 272-8.

CHANDRA S. (1979). Energetics of crop production in Fiji. Agricultural Mechanization in Asia 10, 3 : 19-24.

CHANDRA S. (1980). Root crops in Fiji - Part 2 : Development and future food production strategy. Fiji Agric. J. 42 : 11-17.

CHANDRA S. (1981). Energetics and subsistence affluence in traditional agriculture. Development Studies Centre Occasional Paper 24, Australian National University Press, Canberra, 34 p.

CHANDRA S. (1982). Food production and consumption in a Fijian village and Indian settlement in the Sigatoka Valley, Fiji. Agricultural Systems 9 : 1-13.

CHANDRA, S. (1984). Edible Aroids. Oxford University Press, London, 250 p.

CHANDRA, S. and A.J. De BOER (1978). Productive efficiency of Fijian and Indian farming systems in semi-subsistence agriculture - Part 6 : Energetic efficiency analysis and results. Fiji Agric. J. 40 : 37-50.

CHANDRA S., J.P. EVENSON and A.J. De BOER (1976). Incorporating energetic measures in an analysis of crop production practices in Sigatoka Valley, Fiji. Agricultural Systems 1 : 301-311.

COURSEY D.G. (1984). Potential utilization of major root crops, with special emphasis on human, animal and industrial uses ; pp. 25-35 in Tropical root crops : production and uses in Africa, IDRC-221e, Ottawa, 231 p.

COURSEY D.G. and P.H. HAYNES (1970). Root crops and their potential as food in the tropics. World Crops 22 : 261-265.

De BOER A.J. and S. CHANDRA (1978). A model of crop selection in semi-subsistence agriculture and an application to mixed agriculture in Fiji. Amer. J. Agr. Econ. 60, 3 : 436-444.

DOKU E.V. (1984). Production potentials of major tropical root and tuber crops ; pp. 19-24 in Tropical root crops : production and uses in Africa, IDRC-221e, Ottawa, 231 p.

DYE E. (1976). Unpublished masters thesis ; University of Hawaii.

EVENSON, J.P. and A.J. De BOER (1978). Role of root and tuber crops in food production strategy for semi-subsistence agriculture. Agricultural Systems 3 : 21-232.

FAO Production Yearbooks (various years, 1965-84), FAO Publication.

FAO (1974). Report on tropical root crops consumption in Zambia. FAO report ESN:DP/ZAM/69/512.

FISK E.K. (1962). Planning in a primitive economy : special problems of Papua New Guinea. Econ. Rec. 38 : 462-478.

FISK E.K. (1964). Planning in a primitive economy : from pure subsistence to the production of a market surplus. Econ. Rec. 40 : 156-174.

GOERING T.J. (1979). Tropical root crops and rural development. World Bank Staff Working Paper 324, Washington, 85 p.

LAMBERT J. (1975). A study of nutritional status and economic development in the Chimbu district, Papua New Guinea, 1956-76. Unpublished masters thesis, University of London.

LANGLEY D. (1953). Dietary survey and growth records in a Fijian village, Naduri. Report of : the Fiji School of Medicine, Suva, 35 p.

MENON, S. (1975). Food consumption trends in Naduri village, 1953-74. Report of the Fiji School of Medicine, Suva.

PARKINSON S. (1984). The contribution of aroids in the nutrition of people in the South Pacific ; pp. 215-224 in S. Chandra (ed.) Edible Aroids, Oxford University Press, London, 250 p.

SHAND R.T. (1965). The development of trade and specialization in a primitive economy. Econ. Rec. 41 : 193-206.

STENT W.R. and L.R. WEBB (1975). Subsistence affluence and market economy in Papua New Guinea. Econ. Rec. 51 : 522-38.

TODARO, M.P. (1981). Economic development in the Third World. (Sec. Ed.) Longman, London.

UN (1975) Poverty, unemployment and development policy : A case study of selected issues with reference to Kerala. ST/ESA/29.

UN STATISTICAL YEARBOOKS (various years, 1983-84) UN Publication.

VENKATACHALAN P.S. (1962). A study of the diet, nutrition and health of the people of the Chimbu area. PhD Monograph 4, Port Moresby Department of Public Health, Port Moresby.

WILKINS, R.M. (1963). Dietary survey in a Fijian village, Naduri, Nadroga. Report of the Nutrition Department, Fiji School of Medicine, Suva, 37 p.

WILKINS, R.M. (1965). Nutrition survey, Western Samoa, 1965. South Pacific Health Service Department, Suva.

WORLD BANK (1975). Rural development : Sector policy paper. Washinghton.