Potato production and utilization in world perspective with special reference to the tropics and sub-tropics

D.E. VAN DER ZAAG and D. HORTON

Reprint: Potato Research 26 (1983) 323-362

Potato Research 26 (1983) 323 362

Potato production and utilization in world perspective with special reference to the tropics and sub-tropics*

D. E. VAN DER ZAAG[1] and D. HORTON[2]

[1]Directorate for Agricultural Research (DLO), Wageningen, Netherlands
[2]International Potato Center (CIP), Lima, Peru

Accepted for publication: 21 June 1983

Zusammenfassung, Résumé p. 357

Additional keywords: developing countries, energy, food consumption, food prices, production costs, technology, stock feed, starch

Summary

Potato production is increasing rapidly in the tropics and sub-tropics and is declining gradually in the temperate zone. It is not expected that in the near future potato production for ethanol production will become important or that the production for starch or stock feed will increase. Consumption per capita is more or less stable in Western Europe and North America but is increasing in Africa and Asia. On average, energy and protein from potatoes cost the developing-country consumer at least three times as much as from wheat or rice. Better application by farmers of existing and newly developed technologies including better adapted cultivars, healthy seed tubers, botanical seed and low-cost storage and processing - can reduce costs per unit of output substantially, mainly by increasing yield. Doubling the yield without considerable increases in production costs per hectare would allow the potato to become a cheap vegetable in many tropical or sub-tropical areas and to become a staple food in others with favourable growing conditions.

Introduction

The first section of this paper ('Present situation') outlines current world potato production and use; the second examines future developments in production for alcohol, starch, livestock feed and human consumption; and the third section examines potential contributions from research and technology to the expansion of production in the tropics and sub-tropics.

Some of our predictions and conclusions must be controversial, but we hope they will stimulate discussion and further research and development for the potato as a major world food crop.

* Derived from a paper prepared for the International Symposium 'Research for the potato in the year 2000' (CIP, Lima, 1982).

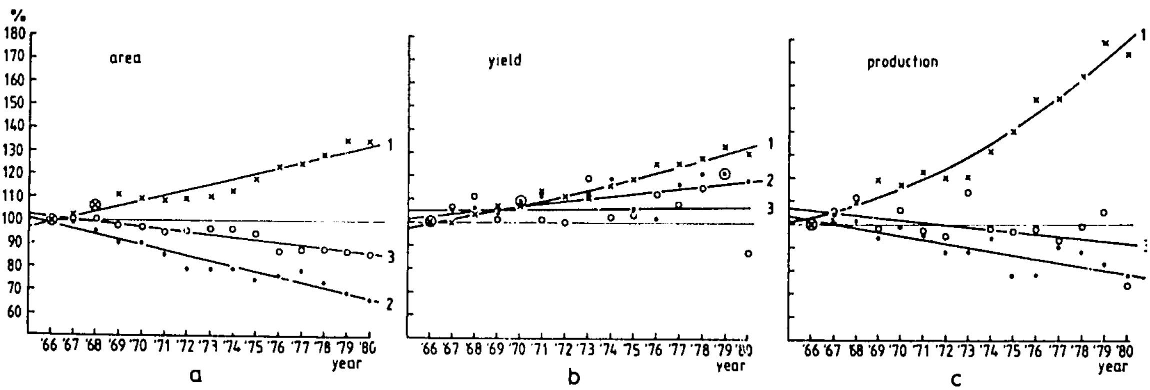
Present situation

Production

Area, yield, and total production

From 1966 to 1980, the area under potatoes in North America and Western Europe decreased annually by more than 2 % (Fig. 1a) and yield increased by almost 1 % (Fig. 1b) to give a net production decrease of about 20 % (Fig. 1c). In Eastern European and Asian countries with centrally planned economies, the ca. 1 % decrease in the area cropped to potatoes (Fig. 1a) was nearly matched by a 1 % yield increase (Fig. 1b) so that production remained constant (Fig. 1c).

Fig. 1. Development of the area cropped (a), yield (b) and total production (c) in (1) developing countries with market economies (×), (2) North America and Western Europe (●), and (3) countries in Eastern Europe and Asia with centrally planned economies (○) (data from FAO Production Yearbooks).



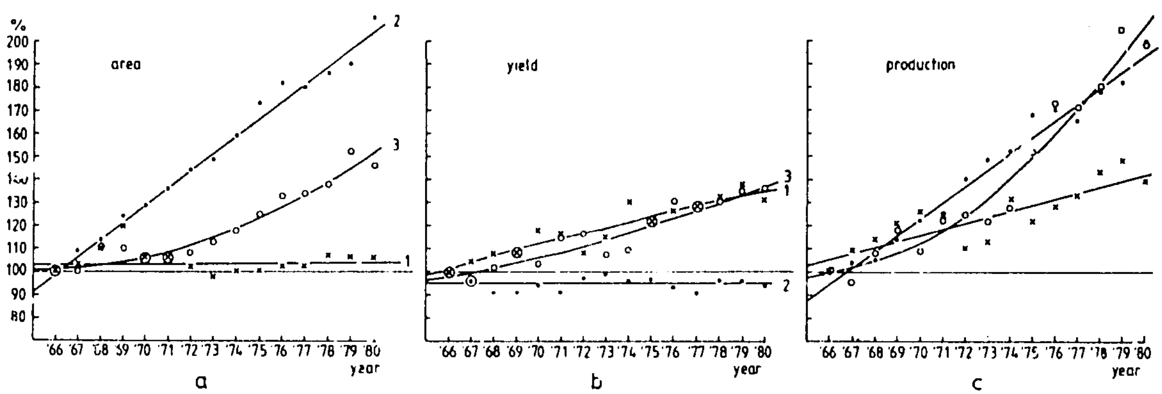
a	b	c
1) $\hat{y} = 2132 + 51.7x$	1) $\hat{y} = 7.89 + 0.1427x + 0.0030x^2$	1) $\hat{y} = 17968 + 285.16x$
(100 = 2208 × 10^3 ha)	(100 = 8.1 t/ha)	(100 = 17810 × 10^3 t)
$r = 0.96$	$r = 0.98$	$r = 0.98$
2) $\hat{y} = 4153 - 94.6x$	2) $\hat{y} = 20.09 + 0.22x$	2) $\hat{y} = 84358 - 1300.7x$
(100 = 4133 × 10^3 ha)	(100 = 19.8 t/ha)	(100 = 81725 × 10^3 t)
$r = -0.97$	$r = 0.74$	$r = -0.84$
3) $\hat{y} = 14624 - 166.0x$	3) $\hat{y} = 12.55 + 0.02x$	3) $\hat{y} = 183696 - 1787.7x$
(100 = 14223 × 10^3 ha)	(100 = 12.0 t/ha)	(100 = 170499 × 10^3 t)
$r = -0.95$	$r = 0.10$	$r = -0.51$

Area - *Fläche* - *Surfaces cultivées;* Yield - *Ertrag* - *Rendement;* Production - *Produktion* - *Production;* Year - *Jahr* - *Année*

Abb. 1. Entwicklung der Fläche (a), des Ertrages (b) und der Gesamtproduktion (c) in (1) Entwicklungsländern mit Marktwirtschaft (×), (2) Nordamerika und Westeuropa (●) und (3) Ländern in Osteuropa und Asien mit Planwirtschaft (○) (Daten entnommen aus den FAO Production Yearbooks).

Fig. 1. Evolution des surfaces cultivées (a), du rendement (b) et de la production totale (c) dans (1) les pays en voie de développement à économie libre (×), (2) en Amérique du Nord et Europe de l'Ouest (●) et dans certains pays d'Europe de l'Est et d'Asie à économie dirigée (○) (sources FAO Production Yearbooks).

Fig. 2. Development of the area cropped (a), yield (b) and total production (c) in (1) developing countries in Latin America (×), (2) developing countries in Africa (●), and (3) developing countries with market economies in Asia (○) (data from FAO Production Yearbooks).



a

1) $\hat{y} = 1063 + 0.80x$
(100 = 1033 × 10^3 ha)
$r = 0.10$

2) $\hat{y} = 199 + 15.9x$
(100 = 214 × 10^3 ha)
$r = 0.99$

3) $\hat{y} = 967 + 1.064x + 2.119x^2$
(100 = 961 × 10^3 ha)
$r = 0.98$

b

1) $\hat{y} = 7.35 + 0.1963x - 0.0012x^2$
(100 = 7.4 t/ha)
$r = 0.93$

2) $\hat{y} = 6.66 - 0.00x$
(100 = 7.0 t/ha)
$r = 0.07$

3) $\hat{y} = 8.71 + 0.1557x + 0.0063x^2$
(100 = 9.1 t/ha)
$r = 0.94$

c

1) $\hat{y} = 7856 + 197.2x$
(100 = 7607 × 10^3 t)
$r = 0.86$

2) $\hat{y} = 1317 + 105.6x$
(100 = 1494 × 10^3 t)
$r = 0.99$

3) $\hat{y} = 8560 + 68.1x + 37.9x^2$
(100 = 8709 × 10^3 t)
$r = 0.98$

Area, Yield, Production, Year – *Siehe Abb. 1* – *Voir fig. 1*

Abb. 2. Entwicklung der Fläche (a), des Ertrages (b) und der Gesamtproduktion (c) in (1) Entwicklungsländern in Lateinamerika (×), (2) in Afrika (●) und (3) in Entwicklungsländern mit Marktwirtschaft in Asien (○) (Daten entnommen aus den FAO Production Yearbooks).
Fig. 2. Evolution des surfaces cultivées (a), du rendement (b) et de la production totale (c) dans (1) les pays en voie de développement d'Amérique latine (×), (2) d'Afrique (●) et (3) certains pays à économie libre d'Asie (○) (Sources FAO Production Yearbooks).

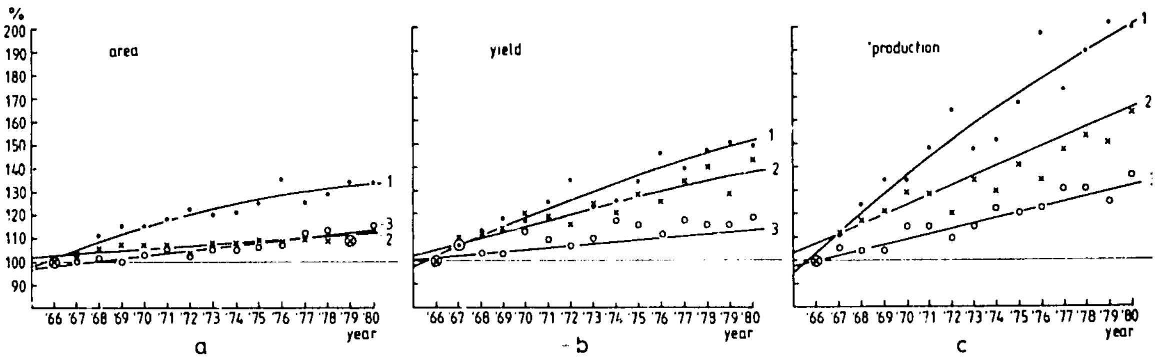
In countries with developing market economies, both the area (Fig. 1a) and yield (Fig. 1b) increased annually by over 2 % to almost double production (Fig. 1c). In Africa and Asia the area increased by almost 7 % and 4 % per year respectively, while in Latin America it remained almost unchanged (Fig. 2a). Yields increased annually by >2 % in Latin America and in Asia but they remained constant in Africa so that in all three regions production increased; by 100 % in Asia and Africa and 40 % in Latin America (Fig. 2b, c).*

Production comparisons

Corresponding changes in yield and production of wheat, rice, and maize in developing market economies show that the area under wheat increased annually by 2 %, while rice

*For further information about world potato production see 'World potato facts' (CIP, 1982).

Fig. 3. Development of the area cropped (a), yield (b) and total production (c) of (1) wheat (●), (2) rice (×), and (3) maize (○) in developing countries with market economies.



a

1) $\hat{y} = 49.52 + 1.985x - 0.054x^2$ $(100 = 50.5 \times 10^6$ ha) $r = 0.96$

2) $\hat{y} = 87.70 + 0.59x$ $(100 = 86.2 + 10^6$ ha) $r = 0.89$

3) $\hat{y} = 49.24 + 0.52x$ $(100 = 50.6 \times 10^6$ ha) $r = 0.94$

b

1) $\hat{y} = 0.934 + 0.0414x - 0.0005x^2$ (100 = 0.95 t/ha) $r = 0.96$

2) $\hat{y} = 1.59 + 0.0401x - 0.0002x^2$ (100 = 1.55 t/ha) $r = 0.93$

3) $\hat{y} = 1.20 + 0.01x$ (100 = 1.19 t/ha) $r = 0.88$

c

1) $\hat{y} = 45.89 + 4.2206x - 0.0546x^2$ $(100 = 48.2 \times 10^6$ t) $r = 0.96$

2) $\hat{y} = 139.45 + 4.48x$ $(100 = 133.7 \times 10^6$ t) $r = 0.92$

3) $\hat{y} = 59.13 + 1.39x$ $(100 = 60.4 \times 10^6$ t) $r = 0.95$

Area, Yield, Production, Year - *Siehe Abb. 1* - *Voir fig. 1*

Abb. 3. Entwicklung der Fläche (a), des Ertrages (b) und der Gesamtproduktion (c) von (1) Weizen (●), (2) Reis (×) und (3) Mais (○) in Entwicklungsländern mit Marktwirtschaft.
Fig. 3. Evolution des surfaces cultivées (a), du rendement (b) et de la production totale (c) pour (1) le blé (●), (2) le rix (×) et (3) le maïs (○) dans les pays en voie de développement à économie libre.

and maize increased by <1 % (Fig. 3a). Both wheat and rice yields increased annually by about 3 % but maize yields by only 1 % (Fig. 3b). The changes in seeded area and yield resulted in net production increases for wheat, rice and maize of ca. 100 %, 60 % and 30 %, respectively (Fig. 3c).

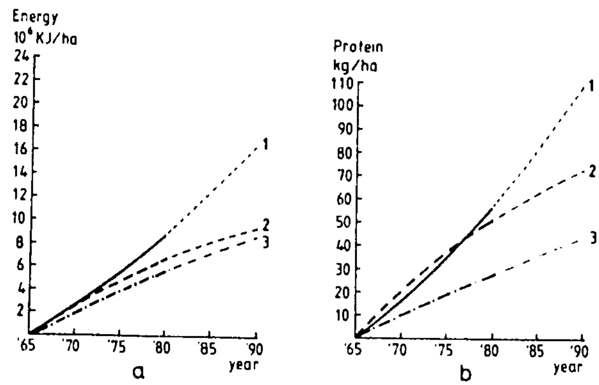
It is noteworthy that whereas the annual percentage increases in rice and potato yields have been about equal, the increase in wheat has been higher, although the increase in edible energy and protein yield per ha was slightly higher for potatoes than for wheat and rice (Fig. 4) despite the 'green revolution' in wheat and rice varieties.

Per capita potato production

Estimates of potato production (Table 1) show that Eastern European countries produce most potatoes, but much of their crop is used for stock feed whereas elsewhere potatoes are grown primarily for human consumption.

In most developing countries, except Latin America and the Near East, production is low and in Africa and the Far East it is small relative to major staples (FAO, 1981). Over the past 15 years the average growth rate of potato production in many developing countries has exceeded that of most other food crops.

Fig. 4. Accumulated calculated increase in yield expressed in terms of energy (a) and protein (b) for (1) potatoes, (2) wheat, and (3) rice (70 % edible) in developing countries with market economies and based on the regression curves given in Fig. 1 and 3 (for energy and protein values see Table 6).



Year - *Jahr* - *Année*; Protein - *Protein* - *Protéine*

Abb. 4. Berechnete Steigerung des Ertrages ausgedrückt als Energie (a) und Protein (b) für (1) Kartoffeln, (2) Weizen und (3) Reis (70 % essbar) in Entwicklungsländern mit Marktwirtschaft, basierend auf den Regressionskurven der Abb. 1 und 3 (Energie- und Proteinwerte siehe Tab. 6).
Fig. 4. Calcul de l'augmentation cumulée du rendement exprimée en tonnes d'énergie (a) et de protéines (b) pour (1) la pomme de terre, (2) le blé, et (3) le riz (70 % consommable) dans des pays en voie de développement à économie libre, à partir des courbes de régression des figures 1 et 3 (voir tableau 6 pour les valeurs en énergie et protéines).

Table 1. Per capita potato production (kg) 1978 (CIP, 1982).

Regions[1]	
World[2]	66
Developed countries[3]	
North America	79
Western Europe	143
Eastern Europe (including USSR)	415
Developing countries with market economies[4]	
Latin America	32
Africa	9
Near East	26
Far East	9

[1] *Gebiet - Régions*; [2] *Welt - Monde*; [3] *Industriestaaten - Pays industrialisés*; [4] *Entwicklungsländer mit Markthandel - Pays en voie de développement avec économie de marché*

Tabelle 1. Pro-Kopf-Produktion von Kartoffeln (kg) 1978 (CIP, 1982).
Tableau 1. Production de pomme de terre par habitant (kg) en 1978 (CIP, 1982).

Energy requirements and efficiency of energy conversion

Potatoes can produce more edible energy and protein per hectare than most food crops and high levels also of energy and protein per day (van der Zaag, 1976). However, the large gross energy input for potatoes is exceeded only by that of irrigated rice and is equal to that of vegetables such as cauliflower (Table 2).

In efficiency of energy conversion, potatoes are intermediate between cereals and most vegetables (Heichel, 1975). Energy budgets are not generally available for crops in developing countries; we have developed them (Table 3) for potatoes in Peru, the Philippines and Rwanda, illustrating a wide range of production technologies, and we have compared them with Pimentel's (1974) US budget and that of the Netherlands (van der Zaag, 1978). Where yields are highest, fertilizers and pesticides account for much of the energy input. In general, the energy conversion ratio is similar for traditional systems, based on hand labour (highland Peru and Rwanda), and for systems based on fossil fuels (coastal Peru, the Philippines, the USA, and the Netherlands). In contrast, the net energy output is higher for modern than for traditional systems.

The ability of the potato to yield a large quantity of energy per ha and per day is an asset where cropland is scarce but its dependence for high yields on systems based on fossil fuels is a liability.

Table 2. Protein, energy production and energy input and output for selected crops in the USA (after Pimentel et al., 1975).

	Crop yield/ha[1]			Energy inputs/ha for production[5]		Output per unit of fossil energy input[8]	
	total[2] (t)	protein[3] (kg)	food energy[4] (GJ)	fossil energy[6] (GJ)	labour (man-hours)[7]	protein[9] (g/MJ)	energy[10] (GJ/GJ)
Soya beans[11]	1.9	640	31.8	22.2	15	28.7	1.4
Brussels sprouts[12]	12.3	604	23.0	35.6	60	16.7	0.6
Potatoes[13]	26.2	524	84.5	37.2	60	14.3	2.3
Maize[14]	5.1	457	74.9	27.6	22	16.7	2.7
Rice[15]	5.8	388	87.9	64.9	30	4.8	1.4
Dry beans[16]	1.4	325	20.9	18.8	15	16.7	1.1
Oats[17]	1.9	276	31.0	12.6	6	21.5	2.5
Wheat[18]	2.3	274	31.4	15.9	7	16.7	2.0

[1] *Ernteertrag/ha - Rendement/ha;* [2] *Gesamt - Total;* [3] *Eiweiss - Protéine;* [4] *Nahrungsenergie - Energie alimentaire;* [5] *Energieeinsatz/ha für die Produktion - Apport d'énergie/ha pour la production;* [6] *Fossile Energie - Energie fossile;* [7] *Arbeit (Mannstunden) - Main d'oeuvre (h UTH);* [8] *Ausstoss pro Einheit des fossilen Energieeinsatzes - Production par unité d'énergie fossile apportée;* [9] *Eiweiss - Protéine;* [10] *Energie - Energie;* [11] *Sojabohnen - Soja;* [12] *Rosenkohl - Choux de bruxelles;* [13] *Kartoffeln - Pomme de terre;* [14] *Mais - Maïs;* [15] *Reis - Riz;* [16] *Bohnen - Haricots secs;* [17] *Hafer - Avoine;* [18] *Weizen - Blé*

Tabelle 2. Protein- und Energieproduktion und Energieeinsatz und -ausstoss für ausgewählte Früchte in den Vereinigten Staaten (nach Pimentel et al., 1975).

Tableau 2. Production de certaines cultures aux Etats-Unis en protéines et en énergie ainsi que les quantités d'énergie apportées et produites (Pimentel et al., 1975).

Table 3. Energy budget for the potato crop in selected countries expressed in gigajoules (GJ) (data derived from (a) CIP estimates; (b) PCARR, 1979; (c) Durr, 1980; (d) Pimentel, 1974; (e) van der Zaag, 1978).

	Peru[a]			Philippines[b]	Rwanda[c]	USA[d]	Netherlands[e]
	highland[1]		coastal areas[4]				
	modern[2]	traditional[3]					
Labour[5]	1.02	0.95	0.43	1.24	1.35	0.14	0.08
Oxen[6]	0.35	·	1.44	–	–	–	–
Seed[7]	9.33	5.30	9.75	14.82	3.97	1.13	6.20
(1) Sub-total[8]	10.70	6.25	11.62	16.05	5.32	1.27	6.28
Tractor and equipment[9]	0.82	–	–	·	0.11	12.43	21.86
Fertilizers[10]: N	24.30	2.58	12.30	6.70	–	10.88	
P	1.88	0.61	2.08	6.70	–	3.42	35.79
K	1.18	0.23	0.62	1.39	–	2.29	
Pesticides[11]	1.29	0.34	0.31	0.10	–	1.70	2.28
(2) Sub-total	29.47	3.76	15.31	14.89	0.11	30.72	59.93
(3) Total input[12] (1) + (2)	40.19	10.01	26.93	30.95	5.43	31.99	66.21
(4) Gross energy output[13]	69.32	23.21	53.74	63.60	19.08	82.48	149.70
(5) Net energy output[14] (4) – (3)	29.13	13.20	26.81	32.65	13.65	50.49	83.49
Gross energy output per unit non-renewable energy[15] (4)/(2)	2.35	6.17	3.51	4.27	173.45	2.68	2.50
Gross energy output per unit total energy input[16] (4)/(3)	1.72	2.32	2.00	2.05	3.51	2.58	2.26
Yield[17] (t/ha)	21.8	7.3	16.9	20.0	6.0	25.6	41.0

[1] *Hochland – Hauts-Plateaux;* [2] *Modern – Moderne;* [3] *Herkömmlich – Traditionnel;* [4] *Küstengebiet – Régions littorales;* [5] *Arbeitskräfte – Main d'oeuvre;* [6] *(Ochsen) tierische Zugkräfte – Travail animal (boeufs);* [7] *Saatgut – Semences;* [8] *Zwischensumme – Sous-total;* [9] *Schlepper und Maschinen – Tracteur et équipement;* [10] *Düngemittel – Fertilisants;* [11] *Pflanzenschutzmittel – Pesticides;* [12] *Gesamtenergieeinsatz – Apport énergétique total;* [13] *Bruttoenergieaussstoss – Energie produite totale;* [14] *Netto-Energieausstoss – Energie produite nette;* [15] *Bruttoenergieausstoss pro Einheit der nicht erneuerbaren Energie – Energie produite totale par unité d'énergie non renouvelable;* [16] *Bruttoenergieausstoss pro Einheit des Gesamtenergieeinsatzes – Energie produite totale par unité d'énergie totale apportée;* [17] *Ertrag – Rendement*

Tabelle 3. Energiebilanz für die Kartoffel in ausgewählten Ländern ausgedruckt in Gigajoules (GJ) (Daten von (a) Schätzungen des CIP; (b) PCARR, 1979; (c) Durr, 1980; (d) Pimentel, 1974; (e) van der Zaag, 1978).

Tableau 3. Compte énergétique de la culture de la pomme de terre dans certains pays, exprimé en gigajoules (GJ) (données issues de (a) estimations CIP; (b) PCARR, 1979; (c) Durr, 1980; (d) Pimentel, 1974; (e) van der Zaag, 1978).

Production costs

The estimated production costs for potatoes, wheat, rice, and sweet potatoes can be compared from Tables 4 and 5. Table 6 summarizes production costs averaged from many developing countries and Table 7 those from the Netherlands.

In developing countries, production costs for sweet potatoes, rice, and wheat, expressed in kg dry matter or in terms of energy, are lower than those for potatoes, whereas in the Netherlands those for energy or protein from potatoes do not differ greatly for those from wheat. The production costs for wheat in developing countries and in the

Table 4. Production cost (US$/ha) for selected crops in different regions in 1977 (FAO estimates of yields and farm-level prices; production cost per kg assumed as 90 % of the farm-level price).

	Potato[1]	Wheat[2]	Rice[3]	Sweet potato[4]
Africa (10 countries[5])	1018	131	293	597
Latin America (7 countries)	1274	227	315	702
Far East (9 countries)	1830	192	312	652

[1,2,3] *Siehe Tabelle 2 – Voir tableau 2;* [4] *Süsskartoffeln – Patate douce;* [5] *Länder – Pays*

Tabelle 4. Produktionskosten (US$/ha) für ausgewählte Früchte in verschiedenen Gebieten 1977 (basierend auf Schätzung der FAO des Ertrages und der Erzeugerpreise und der Annahme, dass die Produktionskosten pro kg 90 % des Erzeugerpreises betragen).

Tableau 4. Coût de production (US$/ha) de certaines cultures dans certaines régions, 1977 (à partir d'estimations du FAO sur les rendements et les prix d'exploitation en supposant un coût de production par kg égal à 90 % du prix d'exploitation).

Netherlands are about the same, but the production costs for potatoes are more than twice as high in developing countries as in the Netherlands. In developing areas production costs often vary with altitude; in Kenya, for example, at high altitudes the cash outlay for maize and potatoes is about equal while at mid-elevation maize is much cheaper than potatoes (Table 8).

Estimates for several countries (Tables 9–11) show that seed potatoes are the single highest input accounting in South America and tropical Africa for 20–40 %, in Asia 30–55 %, and in Central America about 50 % of production costs. In developing countries, labour at 15–60 % or more is usually the second-highest input. Equipment, fuel, chemical fertilizers, and pesticides account for a small proportion of the costs in Africa, 0–25 %, rising to 40 % or more in Asia and Latin America.

In the USA and the Netherlands, seed and labour account for ca. 20 % and 8–16 % of the production costs respectively, but industrial inputs account for >66 % of the costs.

While the cost structures vary between countries, total costs mostly lie between US$ 1000 and US$ 2000 per ha and are much higher than those for other major foods

Table 5. Production cost (US$) per kg dry matter for selected crops in some regions, 1977 (data from Table 4).

Developing market economies in[5]	Potato[1]	Wheat[2]	Rice[3]	Sweet potato[4]
Africa	0.78	0.22	0.25	0.34
Latin America	0.67	0.21	0.20	0.33
Far East	0.86	0.16	0.17	0.30

[1,2,3,4] *Siehe Tabelle 2, 4 – Voir tableau 2, 4;* [5] *Entwickelte Marktwirtschaft in – Pays en voie de développement avec économie de marché en*

Tabelle 5. Produktionskosten (US$) pro kg Trockensubstanz für ausgewählte Früchte in einigen Gebieten 1977 (Daten siehe Tabelle 4).

Tableau 5. Coût de production (US$) par kg de matière sèche de certaines cultures dans certains pays, 1977 (chiffres à partir du tableau 4).

Table 6. Production cost and consumer price of potatoes, wheat, and rice per ha and per unit energy and protein in developing countries (based on data from Horton, 1983).

	Average yield [1] 1978–80 (t/ha)	Production cost in US$ per[2]			Consumer price in US$ per[5]	
		ha	10^6 kJ energy*[3]	1 kg protein*[4]	10^6 kJ energy	1 kg protein
Potatoes[6]	10.5	1524	47	7	97	15
Wheat-bread[7]	1.4	252	14	2	47	5
Rice[8]	2.1 **	382	18	4	37	7

* Potatoes – *Kartoffeln* – *Pommes de terre* US$ 0.30/kg; 100 g = 310 kJ; protein 2 %
Bread – *Brot* – *Pain* US$ 0.43/kg; 100 g = 907 kJ; protein 7.9 %
Wheat – *Weizen* – *Blé;* 100 g = 1297 kJ; protein 10 %
Rice – *Reis* – *Riz* US$ 0.52/kg; 100 g = 1415 kJ; protein 7 %.
** 70 % edible – *70 % essbar* – *70 % consommable.*

[1] *Durchschnittlicher Ertrag* – *Rendement moyen;* [2] *Produktionskosten in US$ pro* – *Coût de production en US$ par;* [5] *Verbraucherpreise in US$ pro* – *Prix de détail en US$ par;* [7] *Weizen-Brot* – *Pain à base de blé;* [3,4,6,8] *Siehe Tabelle 2* – *Voir tableau 2*

Tabelle 6. Produktionskosten und Verbraucherpreise in Entwicklungsländern für Kartoffeln, Weizen und Reis pro ha und pro Energie- und Proteineinheit (basierend auf Angaben von Horton, 1983).
Tableau 6. Coût de production et prix de détail de la pomme de terre, du blé, du riz par ha et par unité d'énergie et de protéines dans les pays en voie de développement (à partir des chiffres de Horton, 1983).

(Table 4) confirming that in all regions the potato is a high-input/high-output crop. Yields and costs per ha are higher in developed than in developing countries, but since the yield gap is greater than the difference in costs per ha, costs per kg output are higher in developing than in developed countries.

Utilization

Utilization in general

Estimates of world potato utilization (Table 12) show that nearly one third is used for fodder. Some Western European countries used to grow fodder potatoes on a large scale but now only Eastern European countries do so. Fodder accounts for ca. 66 and 55 % of production in Poland and Russia respectively, the world's two largest potato-producing countries.

Production for starch and alcohol is of only limited importance except in the Netherlands where ca. 33 % of the crop is grown for starch.

Human consumption

Poats (1982) has shown that the FAO statistics we have used may significantly underestimate potato consumption in developing countries and our estimates probably show no more than orders of magnitude.

Table 7. Yields, costs and prices (US$) for production and to the consumer for three crops in the Netherlands (derived from Anon., 1981).

	Average yield[1] (t/ha)	Production cost per[2]			Consumer price[a] per[5]	
		ha	10^6 kJ energy[b3]	1 kg protein[b4]	10^6 kJ energy	1 kg protein
Potatoes[6]	45	2500	18	3	81	13
Wheat[7]	6.5	1400	17	2	116	13
Sugar-beet[8]	50	1900	14	-	51	-

[a] US$/kg: pre-packed potatoes 0.25 (wide fluctuations); brown bread 1.05; sugar 0.85 - 100 g = 1673 kJ - *US$/kg: Abgepackte Kartoffeln 0,25 (starke Schwankungen); Mischbrot 1,05; Zucker 0,85 - 100 g = 1673 kJ - US$/kg: Pommes de terre pré-emballées 0,25 (fortes fluctuations); Pain de son 1,05; Sucre 0,85 - 100 g = 1673 kJ.*
[b] Energy and protein for potatoes, wheat and bread see Table 6 - *Energie und Protein für Kartoffeln, Weizen und Brot siehe Tabelle 6 - Energie et protéines pour la pomme de terre, le blé et le pain voir tableau 6.*
[c] Sugar equivalent of 8 t/ha - *Zucker Aequivalent von 8 t/ha - Sucre équivalent de 8 t/ha.*

[1-7] *Siehe Tabelle 2, 6 - Voir tableau 2, 6;* [8] *Zuckerrüben - Sucre de betterave*

Tabelle 7. Erträge, Kosten und Preise (US$) für Produktion und für den Verbraucher in den Niederlanden für drei Früchte (basierend auf Daten von Anon., 1981).
Tableau 7. Rendements, coût et prix (US$) de production et de consommation pour trois cultures aux Pays-Bas (chiffres issus de Anon., 1981).

Table 8. Growth periods, yields, costs and productivity of maize and potatoes at two altitudes in Kenya (van der Zaag, 1982a).

Altitude[1] (m)	Crop[2]	Growth period (days)[3]	Productivity/ha[4]			Production costs[9] (Ksh)[a]		
			total yield[5] (kg)	per day[6] energy[b7] (10^3 kJ)	per day[6] protein[b8] (1 kg)	yield (kg/ha)	energy (10^6 kJ)	protein (1 kg)
1700-2300	maize[10]	150	1350	135	0.9	1200	59	9
	potatoes[11]	120	7200	158	1.0	2800	148	23
>2300	maize	300	900	45	0.3	1300	96	15
	potatoes	150	11 000	193	1.2	2900	100	16

[a] Ksh = Kenian shilling - *Kenia Schilling - Shilling kénian.*
[b] Potatoes 100 g = 310 kJ; 2 % protein (85 % edible - *essbar - consommable*).
Maize 100 g = 1498 kJ; 9.5 % protein.

[1] *Höhenlage - Altitude;* [2] *Kultur - Culture;* [3] *Wachstumsperiode (Tage) - Période de croissance (jours);* [4] *Produktion - Production;* [5] *Gesamtertrag - Rendement total;* [6] *Pro Tag - Par jour;* [9] *Produktionskosten - Coût de production;* [7,8,10,11] *Siehe Tabelle 2 - Voir tableau 2*

Tabelle 8. Wachstumsperiode, Erträge, Kosten und Produktion für Mais und Kartoffeln in zwei Höhenlagen in Kenia (van der Zaag, 1982a).
Tableau 8. Période de croissance, rendements, coût et production pour le maïs et la pomme de terre à 2 altitudes au Kénya (van der Zaag, 1982a).

Table 9. Cost structure for the potato crop in selected countries of South America (based on: (a) CIP estimates; (b) Soliz, 1978; (c) Flórez et al., 1979; (d) Fu, 1979).

	Peru[a]		Ecuador[b] highlands	Colombia[c] highlands	Chile[d]	
	coast[11]	highlands[12]			South[13]	Central[14]
Structure[1] (%)						
Labour[2]	17	16	37	34	15	24
Equipment (incl. fuel)[3]	11	10	7	6	21	25
Seed[4]	38	29	27	24	33	37
Fertilizers[5]						
chemical[6]	12	14	19	22	31	12
organic[7]	8	14	-	-	-	-
Pesticides[8]	14	17	10	14	-	2
Total[9]	100	100	100	100	100	100
Total in 1980 in US$[10]	1653	1591	1496	1240	2357	1444

[1] Struktur – Exploitation; [2] Arbeitskräfte – Main d'oeuvre; [3] Maschinenausrüstung (einschliesslich Treibstoff) – Equipement (carburants inclus); [4] Saatgut – Semences; [5] Düngemittel – Fertilisants; [6] Mineralisch – Chimiques; [7] Organisch – Fumure organique; [8] Pflanzenschutzmittel – Pesticides; [9] Gesamt – Total; [10] Insgesamt im Jahr 1980 in US$ – Total en 1980 exprimé en US$; [11] Küstengebiet – Littoral; [12] Hochland – Hauts-Plateaux; [13] Süden – Sud; [14] Zentral – Central

Tabelle 9. Kostenstruktur für die Kartoffel in ausgewählten Ländern Südamerikas (basierend auf Daten von (a) Schätzungen des CIP; (b) Soliz, 1978; (c) Flórez et al., 1979; (d) Fu, 1979).
Tableau 9. Coût d'exploitation de la culture de la pomme de terre dans certains pays d'Amérique du Sud (à partir: (a) d'estimation CIP; (b) Soliz, 1978; (c) Flórez et al., 1979; (d) Fu, 1979).

Table 10. Cost structure for the potato crop in selected countries of Asia (based on data in (a) Elias et al., 1980; (b) Menegay & Huang, 1975; (c) Anon., 1977; (d) Wustman & Mahfooz, 1980; (e) PCARR, 1979).

	Bangladesh[a]	India[b]	Korea[c]	Pakistan[d]	Philippines[e]
Structure[1] (%)					
Labour[2]	20	18	38	18	16
Equipment (incl. fuel)[3]	15	6	3	6	2
Seed[4]	36	45	32	53	55
Fertilizers[5]					
chemical[6]	26	18	26	7	8
organic[7]		9		13	9
Pesticides[8]	1	4	1	3	10
Total[9]	100	100	100	100	100
Total in 1980 in US$[10]	2589			1352	1893

[1–10] Siehe Tabelle 9 – Voir tableau 9

Tabelle 10. Kostenstruktur für die Kartoffel in ausgewählten Ländern Asiens (basierend auf Daten von (a) Elias et al., 1980; (b) Menegay & Huang, 1975; (c) Anon., 1977; (d) Wustman & Mahfooz, 1980; (e) PCARR, 1979).
Tableau 10. Coût d'exploitation de la culture de la pomme de terre dans certains pays d'Asie (à partir: (a) Elias et al., 1980; (b) Menegay & Huang, 1975; (c) Anon., 1977; (d) Wustman & Mahfooz, 1980; (e) PCARR, 1979).

Table 11. Cost structure for the potato crop in selected countries of Africa, Central America, USA and the Netherlands (based on data in (a) Durr, 1980; (b) Anon., 1975; (c) Ferroni, 1981; (d) Grieg, 1975; (e) Anon., 1981).

	Kenya[a]	Rwanda[a]	Guatemala[b]	Mexico[c]	USA[d]	Netherlands[e]*
Structure[1] (%)						
Labour[2]	54	62	10	18	8	16
Equipment (incl. fuel)[3]	6	-	5	14	39	27
Seed[4]	21	38	53	47	19	18
Fertilizers[5]						
chemical[6]	4	-	17	16	23	11
organic[7]	8	-	-	-	-	-
Pesticides[8]	7	-	15	5	11	8
Total[9]	100	100	100	100	100	100
Total in 1980 in US$[10]	637	306	1453	1079	1777	2500

* Fixed cost 20 % - *Feste Kosten 20 % - Charges fixes 20 %.*

[1-10] *Siehe Tabelle 9 - Voir tableau 9*

Tabelle 11. Kostenstruktur für die Kartoffel in ausgewählten Ländern Afrikas, Zentralamerikas, in den USA und den Niederlanden (basierend auf Daten von (a) Durr, 1980; (b) Anon., 1975; (c) Ferroni, 1981; (d) Grieg, 1975; (e) Anon., 1981).

Tableau 11. Coût d'exploitation de la culture de la pomme de terre dans certains pays d'Afrique, d'Amérique Central, aux Etats-Unis et aux Pays-Bas (à partir: (a) Durr, 1980; (b) Anon., 1975; (c) Ferroni, 1981; (d) Grieg, 1975; (e) Anon., 1981).

In Western Europe consumption has stabilized at about 90 kg per capita per annum and in the USA, where it is lower than in Western Europe, consumption is gradually increasing (Fig. 5). Eastern Europe has the highest per capita consumption of any world region; in Poland, Rumania, USSR, DDR and Hungary it is 168, 158, 140, 130 and 120 kg per annum respectively (Kapsa, personal communication).

Annual consumption is stable in Latin America (20-25 kg), while in other developing regions, especially Asia, consumption is increasing (Fig. 6) but in Africa and the Far East it is only about 6 kg per capita.

Table 12. Utilization of the world potato crop (based on data in CIP, 1982).

Use[1]	Quantity[2] (10^6 t)	%
Human consumption[3]	126	45
Stock feed[4]	88	31
Starch[5]	6	2
Seed[6]	39	14

[1] *Verwendung - Utilisation;* [2] *Menge - Quantité;* [3] *Menschlicher Verzehr - Consommation humaine;* [4] *Viehfutter - Alimentation animale;* [5] *Stärke - Fécule;* [6] *Pflanzgut - Plant*

Tabelle 12. Verwertung der gesamten Kartoffelmenge der Welt (basierend auf Daten des CIP, 1982).

Tableau 12. Utilisation de la pomme de terre dans le monde (à partir des chiffres du CIP, 1982).

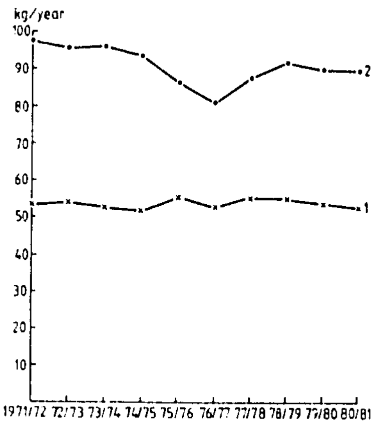


Fig. 5. Annual consumption per capita in (1) USA (×), and (2) Belgium, Federal Republic of Germany, France, Netherlands and UK (●) (Sources: Potato Statistical Yearbook, 1981, Denver, Colorado, USA; Produktschap voor Aardappelen, Den Haag, the Netherlands).

Abb. 5. Jährlicher Pro-Kopf-Verbrauch in (1) USA (×) und (2) Belgien, Bundesrepublik Deutschland, Frankreich, den Niederlanden und Grossbritannien (●) (Quellen: Potato Statistical Yearbook, 1981, Denver, Colorado, USA; Produktschap voor Aardappelen, Den Haag, Niederlande).

Fig. 5. Consommation annuelle par habitant (1) aux Etats-Unis (×) et (2) en Belgique, en République Fédérale Allemande, en France, aux Pays-Bas et au Royaume-uni (●) (Sources: Potato Statistical Yearbook, 1981, Denver, Colorado, USA; Produktschap voor Aardappelen, Den Haag, Pays-Bas).

Farm-level and retail prices

Retail prices of potatoes are higher in developing countries than in Western Europe, while the prices of bread and rice are lower (Table 13). Consumer costs of nutrients in these foods (Table 14) are based on ILO (1978) retail prices and USDA (1975) food composition tables. The relative retail costs of energy and protein derived from potatoes, wheat flour and rice in several countries are shown in Table 15. Assuming 100% consumption, then in developing countries energy and protein cost much less from bread and rice than from potatoes.

Table 13. Average retail prices for potato, bread, and rice in different parts of the world 1977 (US$/100 kg) (data derived from ILO, 1978; UN, 1980; IMF, 1980).

	Potato[1]	Bread[2]	Rice[3]
Developed countries[4]			
USA	40	82	79
Western Europe (14 countries[6])	27	93	112
Eastern Europe (4 countries)	39	75	120
Developing market economies[5]			
Africa (20 countries)	53	55	71
Latin America (13 countries)	40	70	56
Near East (4 countries)	44	31	87
Far East (9 countries)	28	55	34

[1] *Kartoffeln – Pomme de terre;* [2] *Brot – Pain;* [3] *Reis – Riz;* [4] *Industriestaaten – Pays industrialisés;* [5] *Entwicklungsländer mit Markthandel – Pays en voie de développement avec économie de marché;* [6] *Länder – Pays*

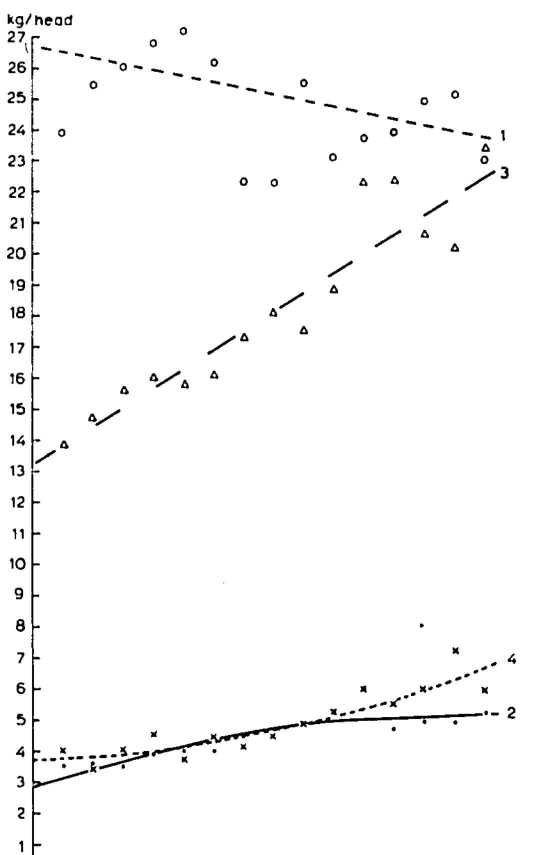
Tabelle 13. Durchschnittliche Verbraucherpreise 1977 für Kartoffeln, Brot und Reis in verschiedenen Teilen der Welt (US$/100 kg) (Daten von ILO, 1978; UN, 1980; IMF, 1980).

Tableau 13. Prix de détail moyens de la pomme de terre, du pain, du riz dans différentes régions du monde en 1977 (US$/100 kg) (chiffres issus de ILO, 1978; UN, 1980; IMF, 1980).

In countries with market economies the fluctuating prices of ware potatoes are determined by supply and demand whereas the average price over long periods is determined by costs of production, storage, and distribution. Available data do not support the often argued view that retail potato prices are high in developing countries because of high marketing costs and retail profits. Indeed, farmers receive a higher proportion of the retail price in developing than in developed countries (Table 16). Moreover, while the marketing margin is lower, the production cost per unit of edible

Fig. 6. Development of the annual consumption per head in developing countries with market economies in (1) Latin America (○), (2) Africa (●), (3) Near East (△), and (4) Far East (×) (assumed that rate of consumption = [0.9 × total production (in kg) − 1500 × area cropped (in ha)]/ population (based on the production and population in 1978–1980, FAO Production Yearbook).

1) $\hat{y} = 25.7 - 0.13x$, $r = 0.39$
2) $\hat{y} = 2.91 + 0.3084x - 0.0106x^2$, $r = 0.88$
3) $\hat{y} = 13.2 + 0.62x$, $r = 0.94$
4) $\hat{y} = 3.68 + 0.0407x + 0.0105x^2$, $r = 0.91$



kg/ head – *kg/ Kopf* – *kg/ habitant*
year – *Jahr* – *Année*

Abb. 6. Entwicklung des jährlichen Pro-Kopf-Verbrauches in Entwicklungsländern mit Marktwirtschaft in (1) Lateinamerika (○), (2) Afrika (●), (3) Nah-Ost (△) und (4) Fernost (×) (unter der Annahme, dass die Verbrauchsrate berechnet wird aus: [0,9 × Gesamtproduktion (kg) − 1500 × Fläche (ha)]/ Bevölkerung (basierend auf Produktion und Bevölkerung 1978–1980. FAO Production Yearbook).

Fig. 6. Evolution de la consommation annuelle par habitant dans les pays en voie de développement à économie libre (1) d'Amérique latine (○), (2) d'Afrique (●), (3) du Proche-Orient (△) et (4) d'Extrême-Orient (×), en estimant que le niveau de consommation est égal à [0,9 × la production totale (kg) − 1500 × la surface cultivée (en ha)]/population (basé sur la production et la population en 1978–1980, FAO Production Yearbook).

Table 14. Average cost (US$) of 10^6 kJ food energy and 1 kg protein from potato, bread and rice 1977 (derived from Table 13).

	Potato[1]		Bread[2]		Rice[3]	
	energy[6]**	protein[7]**	energy	protein	energy	protein
Developed countries[4]						
USA	129	20	90	10	56	11
Western Europe (14*)	87	14	103	12	79	16
Eastern Europe (4)	126	20	83	9	85	17
Developing countries[5]						
Africa (20)	171	27	61	7	50	10
Latin America (13)	129	20	77	9	40	8
Near East (4)	142	22	34	4	61	12
Far East (9)	90	24	61	7	24	5

* Number of countries - *Zahl der Länder - Nombre de pays.*
** For energy and protein values see Table 6 - *Energie- und Proteinwerte siehe Tabelle 6 - Voir tableau 6 pour les valeurs de protéines et d'énergie.*

[1,2,3,4] *Siehe Tabelle 13 - Voir tableau 13;* [5] *Entwicklungsländer - Pays en voie de développement*

Tabelle 14. Durchschnittliche Kosten (US$) für 10^6 kJ Nahrungsenergie und 1 kg Protein aus Kartoffeln, Brot und Reis 1977 (abgeleitet aus Tabelle 13).
Tableau 14. Coûts moyens (US$) de 10^6 kJ d'énergie alimentaire et d'1 kg de protéines à partir de la pomme de terre, le pain et le riz en 1977 (issus du tableau 13).

energy is higher in developing countries than in the Netherlands, an industrialized country (Table 17). Hence, the high retail prices in developing countries is due not to high distribution costs, but to high production costs.

Price and income elasticities
It is often assumed that potato consumption is insensitive to changes in prices and income levels. Regression analyses were used to study the relationships between prices, income and consumption by using estimates of consumption (FAO, 1980), incomes (ILO, 1978) and prices (ILO, 1978) for 51 countries. Based on previous work (FAO, 1972; Quintanilla, 1978; Amat y León & Curonisy, 1981), the following relationship was postulated:

$$C = aI^b P^c \qquad (1)$$

where:
C = per capita consumption (kg),
I = hourly wage rate of bricklayer (US$),
P = retail potato price (US$),
a = constant,
b = income elasticity of demand,
c = price elasticity of demand.

The logarithmic form of Eq. 1 allows coefficients a, b and c to be estimated with least

Table 15. Retail prices relative to ware potatoes as 100 in each case for wheat flour and rice in terms of energy and protein (based on data from: Centraal Bureau voor de Statistiek, the Netherlands).

Countries (city)[1]	Date[2]	Wheat flour[3]		Rice[6]	
		energy*[4]	protein*[5]	energy	protein
Congo	1977-79	32	26	15	20
India (Bombay-Calcutta)	1973-77	21	17	24	31
Irak (Bagdad)	1973-76	15	12	41	54
Israel	1975-78	21	17	40	52
Jamaica (Kingston)	1973-77	16	14	20	25
Jemen (Aden)	1974-75	15	15	20	25
Jordan	1974-77	13	13	36	46
Kenya (Nairobi)	1976-78	46	38	31	40
Pakistan (Lahore)	1974-80	17	15	30	39

*See Table 14 - *Siehe Tabelle 14 - Voir tableau 14.*

[1] *Land (Stadt) - Pays (ville);* [2] *Zeitraum - Date;* [3] *Weizenmehl - Farine de blé;* [4,5,6] *Siehe Tabelle 2 - Voir tableau 2*

Tabelle 15. Durchschnittliche Verbraucherpreise in Bezug auf Speisekartoffeln (= 100) für Weizenmehl und Reis in Bezug zu Energie und Protein (basierend auf Daten vom Centraal Bureau voor de Statistiek, Niederlande).
Tableau 15. Prix de détail relatif à des pommes de terre de consommation (= 100) de la farine de blé et du riz, en termes d'énergie et de protéines (à partir des chiffres du Centraal Bureau voor de Statistiek, Pays-Bas).

Table 16. Farm price as percentage of retail price in selected regions and countries (based on FAO, unpublished; and ILO, 1978).

Africa (10 countries[1])	52
Latin America (6 countries)	69
Near East (2 countries)	54
Far East (7 countries)	61
North America (2 countries)	22
Netherlands	33

[1] *Länder - Pays*

Tabelle 16. Erzeugerpreise als Prozent der Verbraucherpreise in ausgewählten Regionen und Ländern (basierend auf unveröffentlichten Angaben der FAO; und ILO, 1978).
Tableau 16. Prix d'exploitation en pourcentage du prix de détail dans certaines régions et pays (sources: FAO, non publiée, et ILO, 1978).

Table 17. Production cost, consumer price, and marketing margin for 10^6 kJ edible energy from potatoes, wheat and rice (based on data in Tables 6 and 7).

	Netherlands			Developing countries[4]		
	potatoes[1]	wheat/ bread[2]	sugar[3]	potatoes	wheat/ bread	rice[5]
1. Consumer price[6] (US$)	81	116	51	97	47	37
2. Production cost[7] (US$)	18	17	14	47	14	18
3. Marketing margin[8] (1-2)	63	99	37	50	33	19
3 as % of 1[9]	78	85	73	52	70	51

[1] *Kartoffeln - Pomme de terre;* [2] *Weizen/Brot - Blé/pain;* [3] *Zucker - Sucre;* [4] *Entwicklungsländer - Pays en voie de développement;* [5] *Reis - Riz;* [6] *Verbraucherpreis - Prix de détail;* [7] *Produktionskosten - Coût de production;* [8] *Marktgewinn - Marge bénéficiaire;* [9] *3 als % von 1 - 3 comme % de 1*

Tabelle 17. Produktionskosten, Verbraucherpreis und Marktgewinn für 10^6 kJ essbare Energie von Kartoffeln, Weizen und Reis (basierend auf Daten in den Tabelle 6 und 7).
Tableau 17. Coût de production, prix de détail et marge bénéficiaire pour 10^6 kJ d'énergie consommable à partir de la pomme de terre, du blé et du riz (à partir des chiffres des tableaux 6 et 7).

squares (*t* values are given in parenthesis):

$$\log C = -0.205 + \underset{(8.62)}{0.965} \log I - \underset{(8.25)}{2.209} \log P \qquad (2)$$

Eq. 2, which accounts for 75 % of the variation, shows that per capita consumption is highly responsive to changes in income and price. The estimated income elasticity of 0.965 means that if incomes increase by 1 % consumption will similarly increase; the price elasticity of -2.208 means that for each 1 % decrease in potato prices, consumption will increase by 2 %. It should be noted that the values of these elasticities are much greater than those published for most developed countries, and assumed to prevail in most developing countries (FAO, 1972; IFPRI, 1977).

Future development and limiting factors

Ethanol as energy

Biomass production has been studied as a potential source of energy in many countries by examining (1) the cost of production and processing, (2) the energy output/input ratio, and (3) energy or ethanol production per ha. In Western Europe both fodder and sugar-beets can produce more ethanol per ha than potatoes (Dambroth & Bramm, 1980; Brand, 1979), sugar being considerably cheaper than potatoes (Table 18). In terms of both energy yield per unit area and cost per unit of energy, wood is much more promising than field crops, but production from wood is economic only where it can be produced on land unsuitable for other crops.

The results of studies in the USA (Krochta, 1980) showing the energy output/input ratio for various crops and the overall energy balance for production of ethanol from

Table 18. Cost of biomass production for energy for Dutch conditions (Brand, 1979).

Crop[1]	Energy production[2] (GJ/ha)	Energy used for crop[3] (GJ/ha)	Net energy production[4] (GJ/ha)	Cost per unit biomass energy (guilders per GJ)[5]
Sugar-beet[6]	180	25	155	29.3
Potatoes[7]	141	55	86	52.0
Wheat[8]	94	28	66	49.0
Wood for energy production[9]	288	18	270	9.3

[1] *Bestand - Culture;* [2] *Energieproduktion - Production d'énergie;* [3] *Für den Bestand verbrauchte Energie - Utilisation d'énergie par la culture;* [4] *Nettoenergieproduktion - Production nette d'énergie;* [5] *Kosten pro Energieeinheit aus Biomasse (Gulden/GJ) - Coût de l'énergie produite par unité de biomasse (florins par GJ);* [6] *Zuckerrüben - Sucre de betterave;* [7] *Kartoffeln - Pomme de terre;* [8] *Weizen - Blé;* [9] *Wald zur Energieproduktion - Bois pour la production d'énergie*

Tabelle 18. Kosten für die Produktion von Biomasse zur Energiegewinnung unter holländischen Bedingungen (Brand, 1979).
Tableau 18. Coût de production de la biomasse aux Pays-Bas pour l'énergie (Brand, 1979).

various biomass, are shown in Table 19; the overall balance is usually negative or near break-even and only processes with crop residues have a clear positive balance.

A small positive balance (1.1) can be obtained with potatoes if the input for crop production is 19×10^3 Btu/gal ethanol and the output/input energy ratio is 4.4, viz 84/19, an exceptionally high ratio compared with a more acceptable figure of 2.5 (Pimentel et al., 1975; van der Zaag, 1978; Brand, 1979). Waelti (1981) calculated a total output/input energy ratio of 1.35 if by-products of ethanol production are not dried, but his calculation is based on a yield of 124 t/ha; if yields were reduced to 99 t/ha, the energy balance is near the break-even point. From these examples we conclude that the potato is not likely to be used for ethanol production as a source of energy.

Starch

Van der Zaag (1976), comparing potatoes with maize, concluded that production of potatoes for starch would be competitive only if maize prices were above Dfl. 30-35 per 100 kg. If it is now assumed that to produce 1 kg starch (dry matter (DM) content 88 %) about 5.5 kg potatoes (22 % DM) or about 1.55 kg maize are needed, and that the processing cost of 1 kg potato starch (disregarding the price of raw material and possible returns from by-products) is Dfl. 0.25 higher than the processing cost of 1 kg maize starch, then the total production cost of 1 kg starch is:

$5.50\,y + (p + 0.25)$ for potato starch
$1.55\,x + p$ for maize starch

where:
y = price of potatoes per kg,
x = price of maize per kg,

Table 19. Overall energy* balance for production of fuel-grade, anhydrous ethanol from various biomass (Krochta, 1980).

	Maize[1]	Sorghum[2]	Wheat[3]	Potatoes[4]	Sugar-beets[5]	Sugar-cane[6]	Molasses[7]	Residues[8]
Inputs[9]								
Crop production[10]	33-65	38-76	29-64	19-69	21-41	11-31	33-65	0
Feedstock preparation[11]	9	9	9	9	9	9	0	18-36
Fermentation[12]	0	0	0	0	0	0	0	0
Distillation[13]	30	30	30	30	30	30	30	60**
By-product recovery[14]	30	30	37	12	39	0	0	15
Miscellaneous[15]	15	15	15	15	15	15	15	30
Electricity[16]	10	10	10	10	10	10	10	20
Total[17]	127-159	132-170	130-165	95-145	124-144	75-95	88-120	143-161
Outputs[18]								
Ethanol[19]	84	84	84	84	84	84	84	84
By-products[20]	50	50	62	20	65	0	0	168***
Total	134	134	146	104	149	84	84	252
Outputs/inputs	0.8-1.1	0.8-1.0	0.9-1.1	0.7-1.1	1.0-1.2	0.9-1.1	0.7-0.9	1.6-1.8

*In 1000 Btu/gal ethanol; 1 Btu ≈ 1.055 kJ; 1 gal ≈ 4.546 l (GB) or 3.785 l (USA).
** Distillation of ethanol and pentose-conversion product - *Destillation von Aethanol und Pentose-Umkehrproduktion - Distillation de l'éthanol et du produit de conversion du pentose.*
*** Includes pentose-conversion and lignin products - *Einschliesslich Pentoseumkehr- und Ligninprodukten - Y compris la conversion du pentose et les produits lignifiés.*

[1] *Mais - Maïs;* [2] *Sorghum - Sorgho;* [3] *Weizen - Blé;* [4] *Kartoffeln - Pomme de terre;* [5] *Zuckerrüben - Sucre de betterave;* [6] *Zuckerrohr - Canné à sucre;* [7] *Melasse - Mélasse;* [8] *Rückstände - Résidus;* [9] *Einsatz - Apport;* [10] *Pflanzenproduktion - Production;* [11] *Viehfutterausbereitung - Préparation animale;* [12] *Fermentation - Fermentation;* [13] *Destillation - Distillation;* [14] *Rückgewinnung der Beiprodukte - Récupération de sous-produits;* [15] *Verschiedenes - Divers;* [16] *Elektrizität - Electricité;* [17] *Summe - Total;* [18] *Ausbeute - Production;* [19] *Aethanol - Ethanol;* [20] *Beiprodukte - Sous-produits*

Tabelle 19. Gesamtenergiebilanz für die Herstellung von treibstoffartigem wasserfreien Aethanol aus verschiedener Biomasse (Krochta, 1980).
Tableau 19. Balance énergétique totale pour la production d'un carburant éthanol anhydre à partir de différentes biomasses (Krochta, 1980).

p = processing cost per kg.
Hence, for production of 1 kg starch of equal cost from potatoes and maize:

$$5.50\,y + (p + 0.25) = 1.55\,x + p, \text{ or} \quad (3)$$
$$y = 0.28\,x - 0.045$$

Based on (a) the price relationship of Eq. 3, (b) average yields for maize and potatoes in the Netherlands (Table 20), and (c) revised gross margin calculations for these two crops (Appendix 1), the gross margins per ha at 5, 7 and 8.5 t/ha yield for maize and 30, 40 and 50 t/ha yield for potatoes have been calculated for a range of prices. From Fig. 7 it can be concluded that even at a maize price of Dfl. 0.70/kg, a potato crop yielding 40 t/ha cannot compete with a maize crop yielding 7 t/ha.

In the Common Market, where the maize price is about Dfl. 0.55/kg, starch production from potatoes is competitive with maize only if the potato price is below about Dfl. 0.11/kg, at which price potatoes are less profitable for farmers than maize. There is, therefore, no reason to expect an increase in potato production for starch in countries where maize can be imported at less prices below Dfl. 0.70 (US$ 0.23)/kg.

Stock feed

Van der Zaag (1976) concluded that production of potatoes for stock feed was feasible only if barley and maize prices rose above Dfl. 45 and Dfl. 60 per 100 kg respectively. Despite a recent increase in the price of barley to Dfl. 50 per 100 kg potato production for stock feed has almost disappeared in Western Europe; its persistence in Eastern Europe may reflect a relative production advantage for potatoes in countries with centrally planned economies.

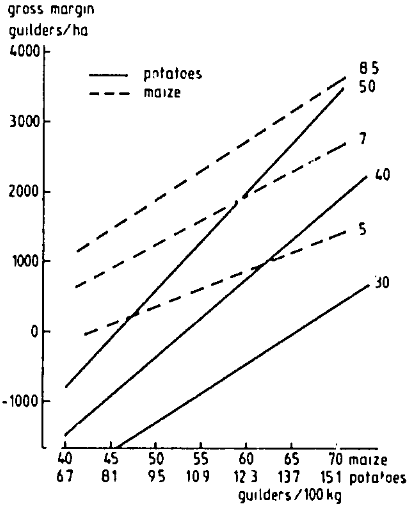
Table 20. Average and relative yields of potatoes, barley and maize 1978-1980 (based on FAO Production Yearbook, 1980).

	Potatoes[1]	Barley[2]	Maize[3]
Average yield[4] (t/ha)			
North America	25.4	2.48	6.27
Western Europe	22.5	3.53	4.87
Netherlands	37.6	4.80	6.80
Relative yield (potato = 100)[5]			
North America	100	10	25
Western Europe	100	16	22
Netherlands	100	11	16

[1] *Kartoffeln - Pomme de terre;* [2] *Gerste - Orge;* [3] *Mais - Maïs;* [4] *Durchschnittlicher Ertrag - Rendement moyen;* [5] *Relativer Ertrag (Kartoffel = 100) - Rendement relatif (pomme de terre = 100)*

Tabelle 20. Durchschnittliche und relative Erträge von Kartoffeln, Gerste und Mais 1978-1980 (basierend auf FAO Production Yearbook, 1980).
Tableau 20. Rendements moyens et relatifs de la pomme de terre, de l'orge et du maïs pour 1978-1980 (Source: FAO Production Yearbook, 1980).

Fig. 7. Estimated relationship between prices of maize and potatoes for starch production and the gross margins per ha at 5, 7 and 8.5 tonnes yield of maize and 30, 40 and 50 tonnes yield for potatoes (for price relation maize - potatoes see text and for gross margin calculations Appendix 1).



Gross margin - *Bruttogewinn* - *Marge brute*
Guilders - *Gulden* - *Florins*
Potatoes - *Kartoffeln* - *Pomme de terre*
Maize - *Mais* - *Maïs*

Abb. 7. Geschätztes Verhältnis zwischen den Preisen für Mais und Kartoffeln für die Stärkeproduktion und den Bruttogewinnen pro ha bei 5, 7 und 8,5 Tonnen Maisertrag und 30, 40 und 50 Tonnen Kartoffelertrag (Preisrelation Mais-Kartoffeln siehe Text und Berechnung des Bruttogewinns siehe Anhang 1).

Fig. 7. Rapports estimés entre les prix et les marges brutes à l'hectare du maïs et de la pomme de terre féculière pour des rendements de 5, 7 et 8,5 tonnes en maïs et de 30, 40 et 50 tonnes en pommes de terre (voir texte pour la relation des prix maïs-pommes de terre et annexe 1 pour le calcul des marges brutes).

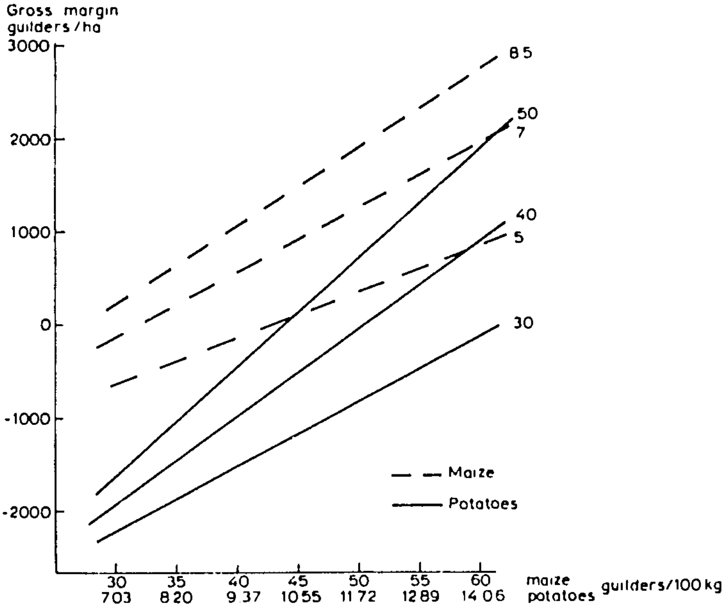
A revised comparison based on the 1982 figures can be made as follows. Assume that (1) 4 kg fresh potatoes yield 1 kg dehydrated product, and (2) the relative food values per kg of maize, barley, and dehydrated potatoes are 0.80, 0.70 and 0.75 respectively; then for 1 kg of stock feed of equal cost and food value, given x, y and z equal the prices for 1 kg of maize, fresh potatoes and barley respectively:

$$\frac{4y}{0.75} = \frac{x}{0.8} = \frac{z}{0.7} \tag{4}$$

The calculated gross margins per ha in 1981 for a good farm in the Netherlands where all three crops grow well, are shown in Appendix 1. Fig. 8 and 9 show relative gross margins per ha for maize, barley and potatoes for a range of prices based on Eq. 4. With yields of 40, 5 and 7 t/ha for potatoes, barley and maize respectively, potatoes for stock feed are competitive only at prices above Dfl. 0.65/kg for barley and far above this price for maize.

In the Common Market, where barley and maize prices are now about Dfl. 0.50 and Dfl. 0.55/kg respectively, potato production for stock feed is not profitable. On the world market generally, barley, maize and other stock feeds are cheaper than in the Common Market making potato fodder production even less profitable, a relationship unlikely to change.

Fig. 8. Estimated relationship between prices of maize and feed potatoes and the gross margins per ha at 5, 7 and 8.5 tonnes yield for maize and 30, 40 and 50 tonnes yield for potatoes (for price relationship maize-potatoes see text and for gross margin calculations Appendix 1).



Gross margin, Guilders, Maize, Potatoes - *Siehe Abb. 7 - Voir fig. 7*

Abb. 8. Geschätztes Verhältnis zwischen den Preisen für Mais und Futterkartoffeln und den Bruttogewinnen pro ha bei 5, 7 und 8,5 Tonnen Maisertrag und 30, 40 und 50 Tonnen Kartoffelertrag (Preisrelation Mais-Kartoffeln siehe Text und Berechnung des Bruttogewinns siehe Anhang 1).

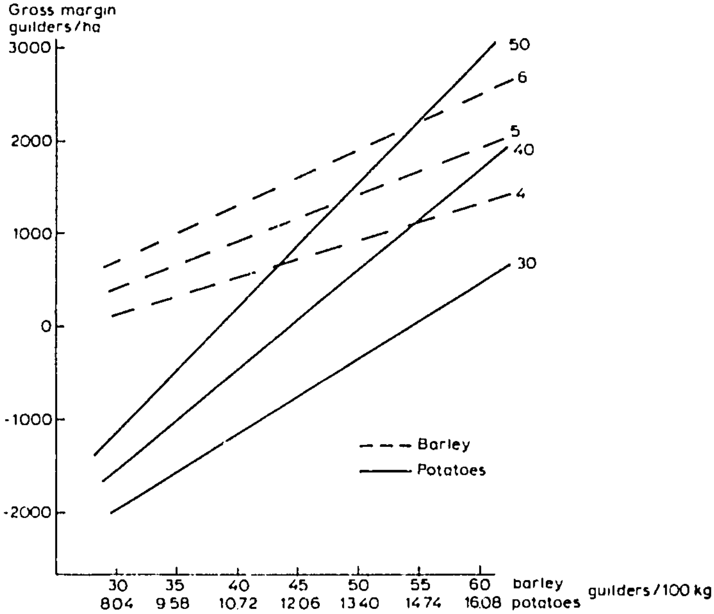
Fig. 8. Rapports estimés entre les prix et les marges brutes à l'hectare du maïs et de la pomme de terre destinée à l'alimentation animale pour des rendements de 5, 7 et 8,5 tonnes en maïs et 30, 40 et 50 tonnes en pommes de terre (voir texte pour la relation des prix maïs-pommes de terre et annexe 1 pour le calcul des marges brutes).

Human consumption

Temperate zone

In industrial countries with market economies, per capita potato consumption has stabilized, the gradual decline in fresh potato consumption being offset by an increased consumption of processed potatoes. Assuming constant consumption per capita, constant population, and ca. 1 % annual yield increase, the area under ware potatoes should decrease by ca. 1 % per year so that by the year 2000, the area under ware potatoes in North America and Western Europe should fall by about 20 %. It is not feasible to forecast changes in countries with centrally planned economies.

Fig. 9. Estimated relationship between prices of barley and feed potatoes and the gross margins per ha at 4, 5 and 6 tonnes yield for barley and 30, 40 and 50 tonnes yield for potatoes (for price relationship barley-potatoes see text and for gross margin calculations Appendix I).



Gross margin, Guilders, Potatoes - *Siehe Abb. 7* - *Voir fig. 7*
Barley - *Gerste* - *Orge*

Abb. 9. Geschätztes Verhältnis zwischen den Preisen für Gerste und Futterkartoffeln und den Bruttogewinnen pro ha bei 4, 5 und 6 Tonnen Gerstenertrag und 30, 40 und 50 Tonnen Kartoffelertrag (Preisrelation Gerste-Kartoffeln siehe Text und Berechnung des Bruttogewinns siehe Anhang I).

Fig. 9. Rapports estimés entre les prix et les marges brutes à l'hectare entre l'orge et la pomme de terre destinée à l'alimentation animale pour des rendements de 4, 5 et 6 tonnes en orge et de 30, 40 et 50 tonnes en pommes de terre (voir texte pour la relation des prix orge-pommes de terre et annexe I pour le calcul des marges brutes).

Tropical and sub-tropical zone

Poats (1982) has discussed the potential for increasing potato consumption in the tropics and the few brief remarks here relate to Poats (1981).

In many developing countries, potato consumption is low because of the high price of ware potatoes relative to those of other foodstuffs. According to Poats' definitions the potato can be considered as: a staple food where per capita consumption ranges from 60 to 200 kg per year; a complementary vegetable at 15 to 50 kg per year; and a luxury vegetable below 10 kg per year.

The future of the potato crop in developing countries depends on reducing its prices relative to those of other foods. Given our findings on retail prices and consumption levels (pages 331 and 334), the potato will remain a luxury vegetable as it now is in most lowland tropical areas as long as the potato price, expressed in food nutrients, remains 3 or more times the price of alternative foods. At a price ratio of ca. 2, it may become a complementary vegetable, as it is shortly after harvest in lowland sites where potatoes are grown in short, cool winter seasons or supplied from nearby highland zones if transport costs are not too high. At price ratios approaching 1, the potato may become a basic staple food as it is in the temperate zone and in tropical highland zones in the Andes, Central and Eastern Africa (see also Table 8) and in scattered places throughout Asia.

Discussion and preliminary conclusions

Our analysis shows that although potato prices are lower in Europe than in other regions of the world, it is not the most economical crop for ethanol production in Europe. Fodder beets and wood are cheaper but even these crops are not competitive with conventional sources of energy. No demand is therefore foreseen for potatoes for ethanol production, although surplus and waste tubers might be used.

Potatoes are not currently competitive with maize for starch production. Moreover, as a starch stock, potatoes may be more sensitive to the costs of energy consumption and pollution prevention than maize. The use of potatoes for starch production rather than increasing will probably remain stable or decrease slightly unless maize prices increase substantially. Likewise, potato production for stock feed would be profitable in Western Europe only if high world market prices prevailed for both barley and maize, and in most other parts of the world potatoes are relatively even more expensive. Future potato production for stock feed will probably be restricted to temperate-zone countries with centrally planned economies.

In Western Europe and North America per capita potato consumption is stable. Any small increase that may be expected if consumers are better informed about the nutritive value of potatoes and if their requirements are met regarding quality, should be met by yield rather than area increases.

In the tropics and sub-tropics of Africa and Asia, per capita consumption is increasing rapidly, but this trend, any acceleration in it, and the production of enough potatoes to meet the potential demand depends on several factors discussed by Poats (1982). One key factor is the retail price ratio of potatoes to other foodstuffs; if this can be lowered then there is great scope for increased potato consumption in low-income countries.

The potato has a high energy and protein production per day and per ha and a short vegetative cycle that can fit into intensive rotations. These features make it attractive to poor farmers with little cropland who can produce a large volume of highly nutritious food for home consumption and for the market in a short time from a small area. More potatoes could readily be produced in most developing countries with current technology and production capacity, but what is needed is low-cost technology to allow farmers to produce more potatoes at lower unit cost. We believe that the future of the potato crop in the tropics and sub-tropics, like its potential consumption, is almost wholly dependent on lowering the price of ware potatoes relative to those of other foodstuffs. We also believe that an increase in consumption of potatoes is important both for improving human nutrition and the welfare of small farmers.

Potential contribution of research to potato production and consumption in the tropics and sub-tropics

Introduction

In principle, the cost per unit weight of tubers can be reduced in two ways: by reducing production cost per ha while maintaining yield, and by increasing yield while not increasing production cost per ha.

Reducing production costs per ha

In most developing countries the major costs of potato production are those of seed tubers, fertilizer and labour.

Seed

There are three ways to reduce the costs of seed potatoes: (a) breed cultivars resistant to tuber-borne diseases, (b) set up seed multiplication programmes adapted to local conditions, and (c) make use of true potato seed.

From the time of its inception, CIP has stimulated breeding for resistance to PLRV, PVY and *Pseudomonas solanacearum;* these important objectives should be intensively pursued and supported by national research institutes and breeders in industrialized countries. Although breeders and seed exporting organizations have contributed much to the expansion of potato production in the tropics and sub-tropics, they must realize that a key to further expansion is the availability of cultivars which can be easily multiplied. Results from breeding for resistance to tuber-borne diseases and viruses are promising and by the year 2000 many resistant cultivars should be available.

Not many developing countries have good seed multiplication programmes. It seems easier to produce a small quantity of high-quality seed than to distribute to farmers a large quantity of seed of reasonable quality. Too much emphasis has been placed on the production of basic seed and not enough on simple multiplication of reasonably good seed and its delivery to ware growers. Furthermore, too many seed programmes are not adapted to the needs of developing countries because they have been uncritically copied from those of industrialized countries (Monares, 1981a).

There is a need for a general study of technical and socio-economic aspects of seed programmes in developing countries which should be based on the needs of ware growers for improved seed, rather than the technical aspects of producing basic seed.

Even if a good seed programme is established so that ware growers can purchase good seed at a 'reasonable' price, that price will still remain an important cost factor. For example: if the yield is 20 t/ha and the ware price per tonne is p, then total revenue per ha is $20\,p$. If net revenue is 10 % of total revenue, then total cost is $0.9 \times 20\,p$. If the cost of seed, including storage costs and losses, is twice the price of ware potatoes and the seed rate is 1.5 t/ha, seed cost is $1.5 \times 2\,p$. It follows that the share of seed cost in the total production cost is: $1.5 \times 2\,p / 0.9 \times 20\,p = 3\,p / 18\,p = 17\,\%$. Assuming reasonable price relationships and technical efficiency, it is unlikely that this percentage of seed cost in total production cost can be reduced.

Where healthy seed tubers are very costly, true potato seed (TPS) offers perhaps the greatest potential for reducing production costs per ha and it can be used to produce either seed or ware potatoes (Sadik, 1982; Monares, 1981b). There are, moreover, several potential advantages in using TPS rather than conventional seed tubers for ware production (Sadik, 1982). We restrict our discussion here to the use of TPS to reduce production costs while maintaining yield, or to reduce production costs by more than enough to compensate for any reduction in yield.

If we compare ware production from transplanted seedlings grown from TPS with crops grown from good seed tubers, and if plants from the latter make full use of the growing season, then the transplanted seedlings are likely to yield less by an amount equal to about 3 weeks less tuber growth. Assuming that the tuber seed rate is 1.5 t/ha and that using TPS results in a yield reduction of 4 t/ha, TPS will be profitable if tuber seed costs ca. 3 or more times the price of ware potatoes, assuming that TPS is cheap and that other production costs are the same for both systems. This simple example shows that if seed tubers are costly, the use of TPS can result in a reduction in ware production cost per ha which is more than proportional to the reduction in yield. Where seed tubers are of poor quality, the use of TPS might reduce production cost per ha even with a combination of an increase in yield (pages 350–352).

In regions where healthy seed tubers are very expensive, the production of seed tubers directly from TPS may reduce production costs both per ha and per kg of ware potatoes produced. While such seed should be less expensive than conventional seed, in market economies its price should not be expected to fall below the price of small ware potatoes at harvest time. CIP is now developing a production system in which large numbers of small seed tubers can be produced from TPS on small, protected plots in the off-season (Wiersema, 1982). The Peoples' Republic of China now uses TPS for producing seed tubers for several thousand hectares of potatoes. More information on their experience and on the economics of alternative seed systems could guide research on TPS technology for developing countries.

Fertilizers

High, sustained potato yields require a high rate of nutrient input to a crop that is also sensitive to N–P–K balance.

Some cultivars respond markedly to rates of N, P or K, that are slightly below their optimal levels; others are less sensitive, tolerating a much wider range. Growers in developing countries who cannot precisely determine optimal rates of NPK would benefit from such nutrient-tolerant cultivars.

Holm (1981) found considerable differences between potato clones in efficiency of nutrient use; they differed in yield under low nitrogen levels, yield response to applied nitrogen, and the nitrogen recovery levels in tubers. He believed that it should be possible to develop cultivars which utilize nutrients more efficiently, but he did not say how. Although it may be difficult to develop efficient and reliable selection methods in breeding for nutrient-use efficiency, we feel that research on this subject would be a useful, although long-term objective.

Labour and mechanization

Temperate-zone mechanized farms now use only one-sixth to one-tenth the labour they needed for potato production a few decades ago. One hectare of ware potatoes can now be produced and stored with only about 20–30 man-hours in the Netherlands whereas in most developing countries the potato is still labour-intensive, 1 ha often requiring over 200 man-hours. Such intensive use of labour is not necessarily a disadvantage, indeed, in labour surplus areas it might be viewed as an advantage (Swaminathan, 1978). Yields can sometimes be increased through partial mechanization of ploughing, seed bed preparation, and planting but there is usually little to be gained over careful handwork (Hayami & Ruttan, 1971). In general, mechanization will reduce production costs only where labour is costly or in short supply.

Reducing the cost of production per kg output

Actual and potential yields

Average yields are not always reliable indicators of the technical efficiency of potato production. A much better measure is the ratio of actual to attainable yields; *actual yield* is defined as the average yield of all potato crops in a given region, that makes full use of the whole growing period. *Attainable yield* is what the actual yield in a region would be if all growers used the best available growing techniques which were economically justifiable under their farming conditions. Since it is difficult to estimate attainable yields for large areas, we introduce the concept of *potential yield,* defined as the yield from a crop that makes full use of the whole vegetative period and where daily tuber production has been optimized by non-limiting water and mineral supply, optimal quantity of foliage, and the absence of diseases and pests. The determinants of potential yield are temperature, solar radiation, and length of the growing period. Discussion of these concepts and estimates of potential yield for potato crops are given by van der Zaag (1977, 1984), van der Zaag & Burton (1978), and van der Zaag & Wustman (1980).

The reader should note that the actual and potential yield estimates for several countries, presented in Table 21, are no more than crude approximations. The technical level of potato production can be classified arbitrarily as follows:

Ratio actual / potential yield	*Technical level*
>0.4	high
0.3–0.4	good
0.2–0.3	low
<0.2	very low

Thus the level of production is good in Egypt and Pakistan and in the Algerian early potato crop (primeurs), although their actual yields are low relative to those in Washington State (USA) and in the Netherlands. In many tropical and sub-tropical countries the actual yield is often 10 t/ha or less and although it is somewhat higher than the average yield in a given region or country, in most of these countries the ratio actual / potential yield is usually below 0.3 and often even below 0.2. In many parts of Europe this ratio is also about 0.3 and sometimes lower, and it follows that the technical production levels in several tropical and sub-tropical countries are not as poor as is often assumed. Nevertheless, in many such areas yields could be doubled by the correct application of good techniques with the best available cultivars.

Doubling the yields in all developing countries would result in an average yield of about 20 t/ha, whereas the average potential yield, based on Table 21 and taking into

Table 21. Approximation of the actual and potential yield of potatoes in selected countries (revised; see van der Zaag, 1984).

Country[1]	Growing season[2]	Yield[3] (t/ha)		Ratio[6] A : P
		actual[4] (A)	potential[5] (P)	
USA (state of Washington)	21/3 - 15/10	65	140	0.46
Netherlands	1/4 - 1/10	45	100	0.45
Egypt	1/1 - 1/5	20	60	0.33
	1/9 - 1/1	15	45	0.33
Algeria	1/12 - 1/4	15	45	0.33
	15/3 - 1/7	12	70	0.17
	1/8 - 1/12	8	60	0.13
Tunisia	15/2 - 1/6	15	70	0.21
Morocco	15/1 - 1/5	15	65	0.23
Pakistan	15/1 - 1/5	15	50	0.30

[1] *Land - Pays;* [2] *Wachstumsperiode - Période de croissance;* [3] *Ertrag - Rendement;* [4] *Tatsächlicher - Actuel;* [5] *Möglicher - Potentiel;* [6] *Verhältnis - Raison*

Tabelle 21. Schätzung des tatsächlichen und des möglichen Ertrages von Kartoffeln in ausgewählten Ländern (veränderte Tabelle, siehe van der Zaag, 1984).
Tableau 21. Approximation du rendement actuel et potentiel de la pomme de terre dans certains pays (tableau corrigé; voir van der Zaag, 1984).

account the short growing period in many of these countries, is 50-60 t/ha. This would indicate a ratio of actual/potential yield of ca. 0.3, similar to that in parts of Western Europe.

The rapid increase in potato yields in Latin America and Asia over the last 15 years indicates the progress that can be made and CIP could follow two complementary strategies to accelerate it elsewhere:

- CIP could concentrate their effort within a few countries and by closely collaborating with local authorities, identify and resolve yield constraints with existing production principles. Besides improving productivity in the short term, long-term benefits should accrue from information gained about yield constraints and factors limiting use of new technologies by farmers.
- CIP could stimulate the breeding of cultivars less sensitive to unfavourable growing conditions so that growers, taking advantage of new knowledge, also will be less affected by unfavourable growing conditions and by incorrectly applied techniques.

Because seed quality is such an important yield determinant, it will be discussed first

Seed

Tuber seed. Reductions of seed cost (pages 347-348) are advantageous providing seed quality and hence yield is not reduced below a critical level. The importance of the relationship between seed price and quality is readily demonstrated. Virus diseases can be used as the 'quality' variable because more information is available on yield reduction from them than from changes in physiological age or other quality aspects, except size

Table 22. Economic break-even point between the price of seed tubers virtually free of virus compared with farm seed saved from the ware crop (yield healthy seed = 25 t/ha; seed rate = 1.8 t/ha) (van der Zaag, 1982b).

Virus infection of farm saved seed[1] (%)	Yield reduction when all plants are infected with leafroll virus or virus Y[2]			
	50 %		75 %	
	one generation*[3]	two generations**[4]	one generation	two generations
0–25	1 ×	1 ×	1 ×	1 ×
25	2 ×	4 ×	3 ×	6 ×
50	4 ×	8 ×	5 ×	11 ×
75	6 ×	10 ×	8 ×	14 ×
100	8 ×	12 ×	11 ×	18 ×

* One generation; the health standard of the progeny of the seed has not been incorporated – *Erster Nachbau; der gesunde Standard des Nachbaus wurde nicht eingeschlossen – Une génération; l'état sanitaire de la descendance du plant n'a pas été pris en compte.*
** Two generations; the health standard of the progeny of the seed has been incorporated for the following generation – *Zweiter Nachbau; der gesunde Standard des Nachbaus wurde für den folgenden Nachbau mit eingeschlossen – Deux générations; l'état sanitaire de la descendance du plant a été incorporé à la génération suivante.*

[1] *Virusbefall in % im selbsterzeugten Pflanzgut – % de plantes contaminées à partir du plant de l'agriculteur;* [2] *Ertragseinbusse, wenn alle Pflanzen mit Blattrollvirus oder Kartoffelvirus Y infiziert sind – Diminution du rendement lorsque les plantes sont atteintes par le virus de l'enroulement ou le virus Y;* [3] *Erster Nachbau – Une génération;* [4] *Zweiter Nachbau – Deux générations*

Tabelle 22. Oekonomischer Schwellenwert für den Preis für tatsächlich virusfreies Pflanzgut verglichen mit selbsterzeugtem Pflanzgut aus Speisekartoffeln (Ertrag aus gesundem Pflanzgut = 25 t/ha, Pflanzgutbedarf 1,8 t/ha (van der Zaag, 1982b).
Tableau 22. Limite critique entre les prix du plant certifié indemne de virus et celui du plant issu de la production de pommes de terre de consommation de l'agriculteur (rendement de la production de plant 25 t/ha, quantité de plant utilisé 1,8 t/ha) (van der Zaag, 1982b).

grading, although the physiological condition of the seed is often more important than the level of virus infection.

The price above which it is more profitable for the farmer to purchase healthy seed than to plant his own degenerated seed (100 % infected with PLRV, PVY), is called the break-even point (Table 22). It can be calculated with Reestman's (1970) formula, relating yield reduction to PLRV and PVY, and another formula giving the price relationships between seed lots with different levels of infection (van der Zaag, 1982b).

In regions where most plants are infected with PLRV or PVY the break-even point of healthy seed is about 10 times the price of ware potatoes.

The effect of reasonably priced healthy seed on yield and production cost per unit is readily illustrated. Assume that in the original situation: yield = 10 t/ha, seed rate = 1.8 t/ha, net return = 10 % of gross return, and price of ware and common farm seed = p/t; then the proportional cost of common seed in the original production cost per ha is

$(1.8 \times p)/(0.9 \times 10\, p) = 20\ \%$ and the original cost per tonne of ware potatoes produced is $(9\, p)/(10\ t) = 0.9\, p/t$.

In the new situation, as a result of using healthy seed, assume that yield = 25 t/ha and the price of healthy seed = $3\, p/t$; then the proportionate cost of healthy seed in the new production cost per ha is much higher than in the original situation, viz $1.8 \times 3\, p/(0.9 \times 10\, p + 1.8 \times 2\, p) = 43\ \%$, but the new cost of ware potatoes produced is $12.6\, p/25\ t = 0.5\, p/t$.

Thus the use of healthy seed, costing three times as much as degenerated seed, can increase the proportion of seed cost within total production costs from 20 to 43 %, but it decreases the overall cost of production from $0.9\, p/t$ to $0.5\, p/t$. The producer using healthy seed could sell his ware crop at a price 40 % lower than the original price of the grower using degenerated seed and still make 2.5 times more profit per ha.

True seed. TPS may reduce production costs per ha (pages 347 and 348); it also has the potential to reduce production costs per kg by an increase in yield that may be anticipated where the health standards of seed tubers are poor or they are not in the correct physiological state.

The yield of ware crops grown directly from TPS and kept free from early infections may be considerably higher than the yield of a crop grown from seed tubers heavily infected with PLRV, PVY, fungi or bacteria. In such cases, the production cost per kg tubers from TPS could be much lower. Where seed tubers produced from TPS can be kept reasonably healthy, their use may be economical than using TPS directly for ware production.

Where good seed is readily available at reasonable prices TPS may not increase yields or be profitable. In contrast, where yields are extremely low because of very poor seed, TPS used directly for ware production or indirectly to produce healthy seed potatoes may reduce the extremely high production cost per kg of ware.

Tolerances to drought, heat, frost, and salt

Drought. The potato is very sensitive to water stress, and for optimal production the crop should be irrigated more frequently than, say, wheat, cotton and tomatoes (van Loon, 1981). Indeed, in most potato-producing countries water supply is one of the major factors limiting yield, and where irrigation is needed, its frequency, quantity and intensity requires great care and it can be justified only in areas with a high production level.

Where potatoes cannot be irrigated and where the distribution pattern of rainfall is not optimal for crop production, as it rarely is, a large reservoir of soil moisture is more important than in sites where water can be supplied by irrigation.

Breeding for tolerance to drought should take into account: (a) the transpiration coefficient, (b) the effect of short stress periods on yield and quality, and (c) the survival of plants after long stress periods.

Cultivars which produce more tuber dry matter with the same amount of water are needed where water is scarce. Bodlaender (1982) found substantial differences in water use per unit dry matter produced between the drought-sensitive cultivar Saturna and the less sensitive cultivar Bintje indicating differences in transpiration coefficient between genotypes. Dwelle et al. (1981) concluded that plants of cv. Russet Burbank may have excessive stomatal water loss and that stomatal conductance could, perhaps, be reduced under field conditions without reducing photosynthesis. Levy (1983) described as 'optimistic' cultivars such as Désirée which do not reduce their rate of photosynthesis immediately stress occurs, and as 'pessimistic' cultivars such as Up-to-Date which close their stomata soon after the onset of stress and reduce production which again becomes optimal when water is available. For most developing countries 'pessimistic' cultivars have advantages over 'optimistic' ones, but the latter are preferred in areas where sophisticated irrigation systems are installed. In areas with very uneven rainfall distribution very 'pessimistic' plants are needed, as they can survive long stress periods. Van der Wal (1982) found large differences between cultivars in their potential for recovery after severe stress periods under glasshouse conditions.

Heat. High temperature markedly affects production by: (1) changing the partition of assimilates between various parts of the plant and (2) reducing photosynthesis and increasing respiration. In many tropical or sub-tropical countries potatoes are grown in cool seasons (spring or autumn) and temperature may be either high at the beginning or at the end of the growing season. Heat-tolerant cultivars may show more rapid growth at the beginning or a less rapid reduction in tuber growth at the end of the growing season. Such heat tolerance combined with a long growing period could greatly increase yield.

Frost. In several sub-tropical countries, or at high altitudes in the tropics, frost may shorten the growing season and tolerance to it would increase yield.

Salt. Irrigation and artesian water and soils are not usually salty. Where salt is a problem production is poor because the potato plant is salt sensitive. Because there is little information on varietal tolerance to salt, and the areas with salt problems become more important, more research is needed on this topic.

Resistance to diseases and pests

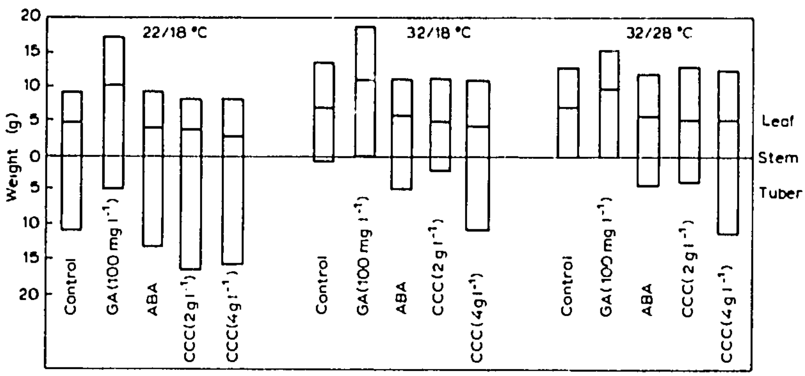
Breeding for resistance to important diseases and pests has received so much attention that it will not be discussed here. By the year 2000 cultivars should be available, for most sites and climates, with adequate resistance to the most important virus diseases, to late blight, and to *Pseudomonas solanacearum*. This is extremely important for reducing production cost, both per ha and per kg output.

Regulation of crop growth

Day length and day and night temperature can strongly affect the balance between haulm growth and tuber yield, especially in tropical and sub-tropical countries where these factors may restrict length of the growing season. Breeding cultivars that are neutral or tolerant of day length and temperature is important.

Despite much research and early optimism about manipulating the potato crop with growth regulators many physiologists are now pessimistic. Some effects of growth regulators on potato development at different day and night temperatures are shown in

Fig. 10. Effect of growth regulators on mean dry weight of leaves, stems and tubers (Menzel, 1980).



Weight - *Gewicht - Poids;* Control - *Kontrolle - Témoin;* Leaf - *Blatt - Feuille;* Stem - *Stengel - Tige;* Tuber - *Knolle - Tubercule*

Abb. 10. Einfluss von Wachstumsregulatoren auf das durchschnittliche Trockengewicht von Blättern, Stengeln und Knollen (Menzel, 1980).
Fig. 10. Influence des régulateurs de croissance sur le poids sec moyen des feuilles, des tiges et des tubercules (Menzel, 1980).

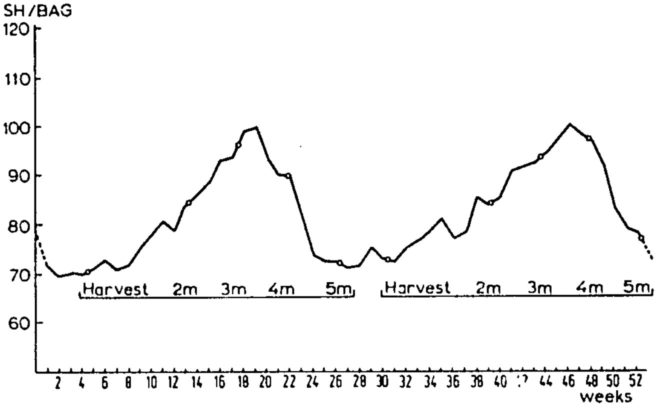
Fig. 10. Menzel (1980) suggested that both haulm growth and tuber initiation are influenced by a common hormonal control, and that temperature mediates the balance between the levels of endogenous gibberelins and inhibitors. It is still not possible successfully to apply growth regulators to the potato crop and farmers have only nitrogen application and irrigation as tools to regulate, to some extent, the balance of haulm and tuber growth. Physiologists need to develop better tools to help farmers bridge the gap between actual and potential yield especially in the tropics and sub-tropics.

Reducing storage costs for ware potatoes

In many developing countries facilities for long-term storage of ware potatoes are inadequate. Prices fall sharply at harvest and rise again in periods of scarcity (Fig. 11). Elsewhere, for example in parts of China and Bangladesh, prices rise steeply as supplies become exhausted and then potatoes remain unavailable for several months each year until the next harvest. To increase consumption in developing countries, prices must be reduced and stabilized and potatoes made available all the year round. If production costs are reduced and production expands, limited high-cost storage capacity and losses will still limit potato availability and consumption. Simple stores in which ware potatoes could be kept well for 20 weeks could help dampen price fluctuations.

Promising work has been done by CIP and others to develop such stores, especially for higher altitudes, but more local testing and adaptation of these systems is needed in other countries. In particular, tubers must often be stored in periods when maximum and

Fig. 11. Average constant weekly wholesale prices for potatoes in Wakulina market, Nairobi 1973–77 (two-week moving average) (source: Ministry of Agriculture in Kenya, published by Durr & Lorenzl, 1980).



Sh/Bag - *Schilling/Sack* - *Shilling/filet;* Harvest - *Ernte* - *Récolte;* Weeks - *Wochen* - *Semaines*

Abb. 11. Durchschnittliche wöchentliche Grosshandelspreise für rote Kartoffeln auf dem Wakulinamarkt, Nairobi 1973–77 (Durchschnitt von zwei Wochen) (Quelle: Ministry of Agriculture in Kenya, veröffentlicht von Durr & Lorenzl, 1980).

Fig. 11. Moyenne des prix de vente des pommes de terre rouges sur le marché Wakulina à Naérobi 1973–77 (moyenne des fluctuations sur 2 semaines) (Ministry of Agriculture in Kenya, publié par Durr & Lorenzl, 1980).

minimum temperatures are above 30 and 20 °C respectively, and this can be done only with refrigeration. More work should be done to develop cheap stores with local materials and simple cooling units. It is also important to breed cultivars which can be stored at high temperatures, but this cannot be done without more information on various aspects of keeping quality. Finally, if consumption is to expand there is a need, discussed by Burton & Booth (1982), to develop simple techniques to transform fresh tubers into easily stored products.

Given the important effect of seed quality on yields and the difficult conditions for seed tuber storage in many developing countries, particular attention needs to be given to improving seed storage technology and work at CIP has shown how known principles can be effectively used to improve seed storage (Rhoades & Booth, 1982).

Discussion and conclusions

Expansion of the potato crop in the tropics and sub-tropics is dependent on reducing the price of ware potatoes which, in turn, depends on reducing costs per kg.

Many developing countries have little additional land to cultivate: as populations expand and man/land ratios increase, the productivity per unit land must be increased. Crops such as the potato that produce much energy and protein per unit time and area will become more attractive. Although we have emphasized the importance of reducing production costs this must not be at the expense of the potato's productivity.

If a crop is to expand, farmers must be willing to grow it. Growers in developing countries consider risks, profitability, cash flow, and the suitability of a crop for their farming patterns and for home consumption. In general, the potato meets their needs except for the high risks associated with production and marketing so that for future expansion much depends on reducing the price of ware potatoes relative to other foods.

The scope for reducing production costs per ha are limited to breeding disease-resistant varieties, improving tuber seed programmes, and in some regions the use of true seed but the costs of chemical fertilizers and pesticides may well offset these reductions.

The scope for reducing costs per kg output are much greater:

1. In any given region*, attainable yields should be determined through field trials which would help to identify factors limiting yield and the potential yield increases that could be attained. We believe that yields in some regions could be doubled with only a small increase in production cost per ha thereby reducing ware prices by up to 50 % while increasing growers' profits.
2. Because tuber seed costs are so high, priority should be accorded to improving the health, production and distribution of cheap seed. Local advice should not be formulated until existing and new techniques (e.g. use of TPS) have been tested locally.
3. Where growing conditions are difficult, cultivars tolerant to drought, heat and frost are needed to help growers increase yields with only moderate increases in production costs.
4. More research is needed to provide reliable tools to growers for regulating the balance between the growth of haulm and tubers.
5. Simple effective systems are needed to store ware and seed potatoes over long hot periods and techniques for readily producing high-value easily stored products from fresh potatoes. More attention should also be paid to breeding for keeping quality.

To double the yield in developing countries to ca. 20 t/ha by the year 2000 requires a yield increase in the next 2 decades which is twice that of the past 15 years. If this could be achieved without substantial increases in production costs per ha and if adequate storage technology is developed, potatoes should be available all the year at about half their present price. In turn, this would greatly stimulate consumption and in many developing countries the potato could become a cheap vegetable, with an average per capita annual consumption of ca. 20 kg. However, such increases will require doubling the area under potatoes in Africa and the Far East.

In the past 15 years wheat and rice yields have increased in developing countries into which, nevertheless, large quantities of cereals have been imported at below-market prices. It is, therefore, likely that any increase in production and use of potatoes will depend also on improvements in the general developmental framework of world economic policies. In many parts of the tropics and sub-tropics, the potential yield of the potato is considerably lower than in temperate zones and it is unlikely this crop can become competitive with alternative foods better suited to local growing conditions. However, areas of low-potential potato production are not necessarily areas of low

* A region is here defined as any zone within a country that is agronomically 'coherent', i.e. the soil, climate and topography are so similar that plant responses within that zone are similar.

consumption. As transport systems improve high potential areas may supply potatoes cheaply to local adjacent increasing urban markets.

In conclusion, national agricultural development programmes should include studies of the relative values of different food crops, taking into account not only local traditional foods but including the potato as a potential high value, high protein food capable of being grown in many, varied environments.

Acknowledgement

We are grateful for the critical comments of staff members of CIP and of Mr R. A. Fox. We are also very much indebted to Mr Fox editing the manuscript so carefully.

Zusammenfassung

Kartoffelproduktion und Verwertung in der Welt mit besonderer Berücksichtigung der Tropen und Subtropen

Gegenwärtige Situation
Die Kartoffelproduktion nimmt in den gemässigten Zonen langsam ab (Abb. 1), während sie in den Tropen und Subtropen in der gleichen Rate wie die Reisproduktion (Abb. 3) zunimmt (Abb. 2). Ausgedrückt als Energie oder Protein ist der Ertragsanstieg für Kartoffeln höher als für Reis oder Weizen (Abb. 4), aber die Pro-Kopf-Produktion bleibt in den meisten Gebieten der Tropen oder Subtropen sehr niedrig (Tabelle 1).

Die Kartoffeln können mehr essbare Energie und Protein pro Zeiteinheit und Fläche erzeugen als die meisten anderen Früchte, aber der Energieeinsatz ist auch hoch (Tabelle 2). Obwohl das Energieumsatzverhältnis für traditionelle und moderne Produktionssysteme ähnlich ist, ist der Nettoenergieausstoss für moderne Systeme höher (Tabelle 3).

Die Produktionskosten pro Energieeinheit oder Trockensubstanz sind für Kartoffeln höher als für andere Feldfrüchte (Tabellen 4-6), in den Entwicklungsländern relativ höher als in den Industriestaaten wie z.B. den Niederlanden (Tabelle 7) oder in den Höhenlagen der Tropen (Tabelle 8). Die wichtigsten Kostenkomponenten sind Pflanzgut, Arbeit und Chemikalien (Tabellen 9-11).

Verwertung
Tabelle 12 zeigt die Schätzwerte der Kartoffelverwertung. Der Pro-Kopf-Verbrauch ist in West-Europa und Nordamerika nahezu stabil (Abb. 5), nimmt aber in den meisten tropischen und subtropischen Ländern noch zu (Abb. 6). Ein Grund für den niedrigen Verbrauch in den Entwicklungsländern ist der relativ hohe Verbraucherpreis (Tabellen 13-15), wofür mehr die relativ hohen Produktionskosten (Tabelle 17) als zu hohe Markterlöse stehen (Tabelle 16).

In Entwicklungsländern ist der Pro-Kopf-Verbrauch für Veränderungen im Einkommen und im Preis verantwortlich (Einkommenselastizität 0,965 und Preiselastizität -2,208).

Weitere Entwicklung und begrenzende Faktoren
Die Kartoffel ist für die Äthanolproduktion nicht die wirtschaftlichste Frucht (Tabellen 18 und 19), sie kann mit der Maisproduktion für Stärke nicht konkurrieren und sie ist in Westeuropa nicht erfolgreich als Viehfutter bei dem gegenwärtigen Preisniveau für Gerste und Mais (Abb. 8).

Geringe Steigerungen des Pro-Kopf-Verbrauches in Westeuropa und Nordamerika, die erwartet werden können, wenn die Verbraucher besser über den Nährwert der Kartoffel aufgeklärt werden, können durch eine Steigerung des Ertrages, vorausgesetzt, dass diese den Qualitätsansprüchen genügt, erreicht werden. In den Entwicklungsländern erfordert eine Ausweitung des Pro-Kopf-Verbrauches eine Senkung der Verbraucherpreise.

Möglicher Beitrag der Forschung zur Kartoffelproduktion und zum -Verbrauch in den Tropen und Subtropen
Die Ausdehnung der Kartoffel in den Tropen und Subtropen ist von einer Preissenkung für

Speisekartoffeln abhängig was, umgekehrt, abhängt von einer Senkung der Kosten/kg. Der Spielraum für die Preissenkung/ha ist begrenzt durch die Züchtung krankheitsresistenter Sorten, Verbesserung der Pflanzkartoffelprogramme und in einigen Gebieten, Verwendung von Kartoffelsamen. Der Spielraum für die Senkung der Kosten/kg Knollen ist viel grösser, wenn gesundes Pflanzgut vorhanden ist (Tabelle 22) und neue Techniken z.B. Samen ('true seed') angewendet werden. Forschung ist notwendig um (1) neue Methoden für die Pflanzgutvermehrung, (2) gegen Trockenheit, Hitze, Frost und Salz tolerante Sorten, (3) Samen, die direkt vom Anbauer benutzt werden können, (4) Methoden zur Regulierung des Stengel- und Knollenwachstums und (5) einfache Lagerungs- und Verarbeitungstechniken zu entwickeln.

Es wird angenommen, dass der Ertrag in den meisten tropischen und subtropischen Ländern verdoppelt werden kann, mit nur geringem Anstieg der Produktionskosten/ha und mit einer darauffolgenden beträchtlichen Senkung der Produktionskosten/kg. Das würde die Kartoffel in vielen tropischen und subtropischen Ländern zu einem billigen Gemüse machen und zu einem Hauptnahrungsmittel in vielen Gebieten der Höhenlagen. Mit einem möglichen Ertrag von 20 t/ha (Tabelle 21) würde das Verhältnis 'tatsächlicher/möglicher Ertrag' 0,3 betragen und damit auf westeuropäischem Niveau liegen. Das bedeutet, dass ein Ertrag von 20-25 t/ha in den Tropen oder Subtropen, aus technischer Sicht, einem Ertrag von ungefähr 40 t/ha in Westeuropa vergleichbar ist.

Résumé

Perspectives de la production et de l'utilisation de la pomme de terre dans le monde et plus particulièrement dans les pays tropicaux et subtropicaux

Situation actuelle
La production de la pomme de terre diminue lentement dans les régions tempérées (fig. 1) tandis qu'elle augmente (fig. 2) dans les zones tropicales et subtropicales, environ au même rythme que la production de riz (fig. 3). Exprimée en termes d'énergie ou de protéines, l'augmentation cumulée du rendement de la pomme de terre est plus forte que celle du riz ou du blé (fig. 4), mais la production par habitant demeure très faible dans la plupart des pays tropicaux ou subtropicaux (tableau 1).

La pomme de terre peut produire par unité de temps et de surface des quantités d'énergie consommable et de protéines supérieures à celles de la plupart des autres cultures, mais l'énergie absorbée est également élevée (tableau 2). Bien que le rapport de conversion de l'énergie soit analogue pour les systèmes de culture traditionnels et modernes, la production nette d'énergie est plus élevée dans le cas des systèmes modernes (tableau 3).

La pomme de terre a des coûts de production plus élevés, par unité d'énergie ou de matière sèche, que les autres cultures alimentaires (tableaux 4-6) mais ces coûts sont relativement plus élevés dans les pays en voie de développement que dans un pays industrialisé comme les Pays-Bas (tableau 7) ou dans les tropiques (tableau 8) à haute altitude.

Dans les pays en voie de développement, les composantes principales du coût de production sont: les semences, le travail et les produits chimiques (tableaux 9-11).

Utilisation
Des estimations d'utilisation de la pomme de terre sont données dans le tableau 12. La consommation par habitant est à peu près stable en Europe de l'Ouest et en Amérique du Nord (fig. 5) mais elle augmente encore dans la plupart des pays tropicaux et subtropicaux (fig. 6). Les prix de détail relativement élevés sont une des raisons de la faible consommation dans les pays en voie de développement (tableau 13-15) et ceci est dû davantage aux coûts de production relativement élevés (tableau 17) qu'aux marges bénéficiaires à la commercialisation (tableau 16).

Dans les pays en voie de développement, la consommation par habitant dépend largement des changements de revenu et de prix (élasticité des revenus de 0,965 et élasticité des prix de -2,208).

Développement futur et facteurs limitants
La pomme de terre n'est pas la culture la plus économique pour la production d'éthanol (tableaux 18 et 19), elle n'est pas compétitive vis à vis du maïs pour la production de fécule (fig. 7)

et elle n'est pas rentable en Europe de l'Ouest pour l'alimentation animale, avec les niveaux de prix actuels de l'orge et du maïs (fig. 8).

Une légère augmentation de la consommation par habitant, à laquelle les pays d'Europe de l'Ouest et d'Amérique du Nord pourraient s'attendre si les consommateurs étaient mieux informés sur la valeur nutritive de la pomme de terre, serait possible par des augmentations de rendement à condition de prendre en compte les exigences de qualité.

Dans les pays en voie de développement, une augmentation de la consommation par habitant suppose une diminution des prix de détail.

Contribution potentielle de la recherche à la production et à la consommation de la pomme de terre dans les pays tropicaux et subtropicaux

L'expansion de la culture de la pomme de terre dans les pays tropicaux et subtropicaux dépend de la diminution du prix des pommes de terre de consommation, qui lui même dépend de la réduction du coût par kilo.

Les possibilités de réduire les coûts de production par ha se limitent à la sélection de variétés résistantes aux maladies, à l'amélioration des programmes de production de plants et, dans certaines régions, à l'utilisation de semences vraies. Les possibilités de réduire les coûts par kg de tubercules sont plus nombreuses si les techniques existantes (plants indemnes de virus) et nouvelles (semences vraies) sont appliquées. La recherche est nécessaire pour développer (1) les techniques nouvelles de multiplication de semences, (2) les variétés tolérantes à la sècheresse, la chaleur, le gel et la salinité, (3) les semences prêtes à être utilisées par les producteurs, (4) les méthodes de régulation de la croissance des fanes et des tubercules et (5) les techniques simples de stockage et de transformation.

On estime que le rendement peut être multiplié par deux dans la plupart des pays tropicaux et subtropicaux, ceci avec une faible augmentation des coûts de production par kg.

La pomme de terre deviendrait un légume d'un bon marché dans beaucoup de pays tropicaux et subtropicaux et une denrée première pour davantage de régions de haute altitude.

Avec un rendement potentiel de 20 t/ha (tableau 21) le rapport actuel: rendement potentiel de 0,3 serait à un niveau comparable à celui de l'Europe de l'Ouest. C'est-à-dire qu'un rendement de 20–25 t/ha dans les tropiques ou subtropiques, correspond, d'un point de vue technique, à un rendement de l'ordre de 40 t/ha en Europe de l'Ouest.

References

Amat y León, C. & D. Curonisy, 1981. La alimentación en el Perú. Centro de Investigaciones de la Universidad del Pacífico, Lima, Peru.

Anonymous, 1975. Recomendaciones del I seminario nacional sobre la problemática del cultivo de la papa. COTAPYCH-Comité Pro-organización de Productores de Papa, Amatillán, Guatemala.

Anonymous, 1977. An economic study of second cropping on paddy in the northern and central regions of Korea. Farm Management Research Report, Office of Rural Development, Suweon, Korea.

Anonymous, 1981. Kwantitatieve informatie voor de akkerbouw en groenteteelt in de vollegrond: Bedrijfssynthese 1981–1982. PAGV, Lelystad, Netherlands.

Brand, L. J., 1979. De mogelijkheden van de Nederlandse landbouw om een bijdrage te leveren aan de energievoorziening. Nota, Ministerie van Landbouw en Visserij, Den Haag, Netherlands.

Bodlaender, K. B. A., 1982. Communications in the working group 'Water supply to potato crops', Wageningen, Netherlands.

Burton, W. G. & R. Booth, 1982. Post-harvest technology for developing country tropical climates. Proceedings International Congress 'Research for the potato in the year 2000', p. 40–44. CIP, Lima, Peru.

CIP, 1982. World potato facts. CIP, Lima, Peru.

Dambroth, M. & A. Bramm, 1980. Aspekte der Aethanolgewinnung aus nachwachsender Biomass. Agrar-Uebersicht - Sonderdruck aus N. 3.

Durr, G., 1980. Production and utilization of potatoes in Rwanda. CIP, Lima, Peru.

Durr, G. & G. Lorenzl, 1980. Potato production and utilization in Kenya. CIP, Lima, Peru.

Dwelle, R. B., G. E. Kleinkopf & J. J. Pavek, 1981. Stomatal conductance and gross photosynthesis of potato *(Solanum tuberosum)* as influenced by irradiance, temperature and growth stage. *Potato Research* 24: 49–59.

Elias, S. M., J. Ahmed & N. I. Mondal, 1980. Economics of potato production for different size of farms. Proceedings of the 3rd Workshop of potato research workers. Potato Research Centre, Joydebpur, Dacca, Bangladesh.
FAO, 1972. Las elasticidades de la demanda de productos agrícolas en función de los ingresos. Estudio sobre proyecciones. Documento de Trabajo No 1. FAO, Roma, Italy.
FAO, 1980. Food balance sheets 1975–77 average and per caput food supplies 1961–65 average 1967 to 1977. FAO, Rome, Italy.
FAO, 1981. FAO Production Yearbook. FAO, Rome, Italy.
Ferroni, W., 1981. El potencial de la papa como recurso alimenticio y como fuente de ingreso. INIA, Mexico.
Flórez, V., G. La-Rotta y L. D. Escobar, 1979. Costos de producción de algunos cultivos. Documento de trabajo. ICA, Tibaitatá, Colombia.
Fu, G., 1979. Producción y utilización de la papa en Chile. CENDERCO-INIA-CIP, Lima, Peru.
Grieg, W., 1975. Potatoes: estimated cost of production 8 major US regions. Washington State University, Washington, USA.
Hayami, Y. & V. Ruttan, 1971. Agricultural development: an international perspective. The Johns Hopkins Press, Baltimore, Maryland, USA.
Heichel, G. H., 1975. Energy use and crop production. Presented at AAAS Annual meeting, New York City, USA.
Holm, D. G., 1981. Selecting potato clones for nutrient-use efficiency (abstract). *American Potato Journal* 58: 503.
Horton, D., 1983. Socio-economic aspect of potato production and use in developing countries: report on a survey of national potato program leaders. CIP, Lima, Peru.
IFPRI, 1977. Food needs of developing countries: projections of production and consumption to 1990. Research Report 3. IFPRI, Washington, USA.
ILO, 1978. Bulletin of labour statistics. ILO, Geneva, Switzerland.
IMF, 1980. International financial statistics. IMF, Washington D.C., USA.
Krochta, J. M., 1980. Energy analysis for ethanol. *California Agriculture* 34 (6): 9–11.
Levy, D., 1983. Varietal differences in the response of potatoes to repeated short periods of water stress in hot climates. 1. Turgor maintenance and stomatal behaviour. *Potato Research* 26: 303–313.
Loon, C. D. van, 1981. The effect of water stress on potato growth, development, and yield. *American Potato Journal* 58: 51–69.
Menegay, M. & K. Huang, 1975. White potato. AVRDC, Shunhuor, Taiwan.
Menzel, C. M., 1980. Tuberization in potato at high temperatures: response to gibberellin and growth inhibitors. *Annals of Biology* 46: 259–265.
Monares, A., 1981a. The potato seed system in the Andean region: the case of Peru. Ph.D. thesis. Cornell University, Ithaca, NY, USA.
Monares, A., 1981b. Socio-economic analysis in the generation of a new technology true potato seed. CIP, Lima, Peru.
PCARR, 1979. The Philippines recommends for potato. PCARR, Los Baños, Laguna, Philippines.
Pimentel, D., 1974. Energy use in world food production. Report 74-1, Department of Entomology and Secundary Ecological Systems, Cornell University, Ithaca, NY, USA.
Pimentel, D., W. Dritschilo, J. Krummel & J. Kutzman, 1975. Energy and land constraints in food protein production. *Science* 190: 754–761.
Poats, S., 1981. Potato consumption in developing countries. Second social science planning conference, CIP, Lima, Peru.
Poats, S., 1982. Beyond the farmer: potato consumption in the tropics. Proceedings International Congress 'Research for the potato in the year 2000', p. 10–17. CIP, Lima, Peru.
Quintanilla, L., 1978. Estudio econométrico de funciones de consumo de papa y carnes en la zona norte del Perú. M.Sc. thesis, Universidad Nacional Agraria, La Molina, Peru.
Reestman, A. J., 1970. Importance of the degree of virus infection for the production of ware potatoes. *Potato Research* 13: 248–268.
Rhoades, R. & R. Booth, 1982. Farmer-back-to-farmer: a model for generating acceptable agricultural technology. *Agricultural Administration* 11: 127–137.

Sadik, S., 1982. Potato production from true seed: physiological aspects. Proceedings International Congress 'Research for the potato in the year 2000', p. 18-25. CIP, Lima, Peru.
Soliz, R., 1970. La papa en los sistemas de producción. Memorias del primer curso internacional sobre producción de semilla de papa. Quito, CIP-INIAP-MAG, Lima, Peru.
Swaminathan, M. S., 1978. Inaugural address. International seminar on 'Approaches towards increasing potato production in developing countries'. Jullundur, India.
United Nations, 1980. Monthly bulletin of statistics UN, New York, USA.
USDA, 1975. Composition of foods. USDA Handbook No 8. USDA, Washington D.C., USA.
Waelti, H. P. E., 1981. Considering producing alcohol from potatoes. Proceedings 20th Annual Washington State Conference, p. 57-63. Moses Lake, USA.
Wal, A. F. van der, 1982. Communications in the working group 'Water supply to potato crops'. Wageningen, Netherlands.
Wiersema, S. G., 1982. Potato seed-tuber production from true potato seed. Proceedings International Congress 'Research for the potato in the year 2000', p. 186-188. CIP, Lima, Peru.
Wustman, R. & S. Mahfooz, 1980. Introduction to potato cultivation in Pakistan. PARC, Islamabad, Pakistan.
Zaag, D. E. van der, 1976. Potato production and utilization in the world. *Potato Research* 19: 37-72.
Zaag, D. E. van der, 1977. Factors affecting the growth of the potato with special reference to the Mediterranean regions. Inter-regional workshop/seminar CIP, Izmir, Turkey.
Zaag, D. E. van der, 1978. Entwicklungstendenzen in der Stärke und Zuckerindustrie in Abhängigkeit vom Rohstoff. *Starch/Stärke* 30: 409-413.
Zaag, D. E. van der, 1982a. Potato production and utilization in the tropics and sub-tropics. Proceedings 'International Symposium' (RAI, Amsterdam, Netherlands).
Zaag, D. E. van der, 1982b. Seed potatoes: sources of supply and treatment. Netherlands Potato Consultative Institute, The Hague, Netherlands.
Zaag, D. E. van der, 1984. Reliability and significance of a simple method of estimating the potential yield of the potato crop. *Potato Research* 27 (in press).
Zaag, D. E. van der & W. G. Burton, 1978. Potential yield of the crop and its limitations. Survey paper 7th Triennial Conference EAPR (Warsaw, Poland), p. 7-22.
Zaag, D. E. van der & R. Wustman, 1980. Potential of potato production in the plains of Pakistan and suggestions to improve crop yields. *Pakistan Journal of Agriculture* 1: 98-107.

Appendix 1. Estimated gross crop margins (main operations done by contractor, from Anon., 1981).

Maize[1]				
Yield[2]: 7000 kg at Dfl. 0.30/kg				Dfl. 2100
Material[3]:	seed[4]	Dfl. 150		
	NPK	800		
	pesticides[5]	50		
	herbicides[6]	50		
		——— +		
			Dfl. 1050	
Insurance and interest[7]			50	
Contractors[8]:	sowing[9]	Dfl. 150		
	spraying[10]	100		
	harvest[11]	400		
	chopping straws[12]	100		
	drying[13]	400		
		——— +		
			Dfl. 1150	
			——— +	
				Dfl. 2250
				——— −
Gross margin[14]/ha				− Dfl. 150

Barley[15]

Yield[2]: 5000 kg at Dfl. 0.30/kg			Dfl. 1500	
Straw[16]			400	
			+	Dfl. 1900
Material[3]:	seed[4]	Dfl. 125		
	NPK	500		
	pesticides[5]	50		
	herbicides[6]	50		
		+	Dfl. 725	
Insurance and interest[7]			50	
Contractor[8]:	spraying[10]	Dfl. 100		
	harvest[11]	350		
	baling straw[17]	150		
	drying[13]	100		
		+	Dfl. 700	
			+	Dfl. 1475
				−
Gross margin[14]/ha				Dfl. 425

Potatoes (for stock feed and starch production)[18]

Yield[2]: 40 000 kg at Dfl. 0.0804/kg				Dfl. 3216
Material[3]:	seed[4]	Dfl. 700		
	NPK	850		
	fungicides[19]	100		
	herbicides[6]	100		
		+	Dfl. 1750	
Insurance and interest[7]			150	
Contractor[8]:	planting[20]	Dfl. 150		
	spraying[10]	200		
	harvest and transport[21]	900		
	dehydration at[22] Dfl. 4/100 kg*	1600		
		+	Dfl. 2850	
			+	Dfl. 4750
				−
Gross margin[14]/ha				- Dfl. 1534

*Only for stock feed - *Nur für Viehfutter* - *Pour alimentation animale seulement*

[1] Mais - Maïs; [2] Ertrag - Rendement; [3] Material - Produits de base; [4] Pflanzgut - Semence; [5] Pflanzenschutzmittel - Pesticides; [6] Unkrautbekämpfungsmittel - Herbicides; [7] Versicherung und Zinsen - Assurances et intérêts; [8] Lohnunternehmer - Entreprise; [9] Sähen - Semis; [10] Spritzen - Traitement; [11] Ernten - Récolte; [12] Stroh hächseln - Broyage; [13] Trocknen - Séchage; [14] Bruttogewinn - Marge brute; [15] Gerste - Orge; [16] Stroh - Paille; [17] Stroh ballen - Pressage des pailles; [18] Kartoffeln (für Viehfutter und Stärkeproduktion) - Pommes de terre (pour alimentation animale et production féculière); [19] Fungizide - Fongicides; [20] Pflanzen - Plantation; [21] Ernte und Transport - Récolte et transport; [22] Trocknung für - Déshydration à

Anhang 1. Beispiel für die Schätzung des Bruttogewinns (die Arbeiten werden von einem Lohnunternehmer durchgeführt, die Zahlen basieren auf Anon., 1981).
Annexe 1. Exemples de marges brutes de certaines cultures (travaux importants réalisés par entreprises, source Anon., 1981).