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Regional Characteristics of Crop Utilization

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Summary

Characteristics of crop utilization in the tropics were examined by noting the difference in percentage of harvested area of each crop to land area under temporary and permanent crops (PI) among regions. The distribution of PI reflected the temperature and water requirements of respective crops, but some regional differences in the positioning of cereals, pulses and tuber crops were found. In the tropics, the positioning of root and tuber crops, which are excellent in energy productivity and in yielding stability, tended to be high. The culture of pulses was also given important positioning in inland countries of the tropics where people have difficulty in procuring animal protein, and in the semiarid zone where the amount and distribution of precipitation are uncertain and unreliable. It is concluded from the above results that crop utilization in the tropics has been characterized by key words such as 'yielding stability', 'combination of energy and protein production' and 'utilization of nitrogen-fixing crops'.

Key words: cereals, geographical distribution, pulses, root and tuber crops

Introduction

At the species level, thousands of plant species have been cultivated by humans at some time or place, and several hundred are currently employed as crops [8]. Farmers select and cultivate a small number of crops from such a large number of options for several reasons. It is a matter of course that which crop they attach importance to differs with the climatic, historic, social, ethnic and economic backgrounds in each country.

A change for the worse in the food situation is a cause for particular concern at a time of population growth. The scenario of foods in the future will be affected strongly by food production in the tropical countries because a rapid increase in population is taking place in developing countries in the tropics, and because an unsteady equilibrium of demand and supply of foods in the world is supported by high-yielding agriculture in developed countries. So, the authors, in the present paper, will try to clarify some characteristics of crop utilization in the tropics.

Materials and Methods

The positioning of any crop in each country was assessed as follows. Firstly, the percentage of harvested area of any crop to land area under temporary and permanent crops (PHA) was calculated. Secondly, the positioning index (PI) of any crop was calculated by the following equation.

$$PI = \frac{\text{PHA of any crop in each country}}{\text{PHA of any crop throughout the world}} \quad (1)$$

Thus, a high PI value indicates that the culture of a particular crop has been regarded as important and practicable in a particular country. Thirdly, respective countries and localities of the world were classified into five categories according to PI, namely, countries without description of harvested area of a certain crop, countries having PI of over 0 up to 0.5, over 0.5 to 2.0, over 2.0 to 4.0, and over 4.0. Statistical data for 1993 from the FAO Production Yearbook [2] was used in order to derive PI.

Energy and protein productivities of cereals, pulses and tuber crops were calculated by multiplying yield by energy and protein contents per unit of yield, respectively. The percentage of any crop for energy intake (E) was calculated by the following equation:

$$E = \frac{C \times D \times CU \times E}{365 \times \text{energy intake}} \quad (2)$$

where C is consumption, D is digestibility, CU is the coefficient of utilization, and E is energy content. The consumption (kg/person) was calculated by the following equation:

$$\text{consumption} = (\text{production} + \text{import} - \text{export}) / \text{population} \quad (3)$$

D, CU, and E were assumed as 0.85, 0.8, and 14.65 MJ/kg for cereals and pulses and 4.18MJ/kg for tuber crops, respectively [4, 8]. But, the following equation was applied for rice:

$$E = \frac{C \times H \times M \times Y \times E}{365 \times \text{energy intake}} \quad (4)$$

where C is consumption, H is hulling rate, M is milling rate, Y is yield rate, and E is energy content. H, M and Y were assumed as 0.8, 0.9 and 0.9, respectively [5]. The data of production, import and export were quoted from the FAO production yearbook [2] and FAO trade yearbook [3].

Results and Discussion

1. Cereals

(1) Wheat

The PHA of wheat throughout the world was 15.4 in 1993, being the highest of all crops. The geographical distribution of PI for wheat is shown in Fig.1. Tropical countries had extremely low PI values for wheat or no description of harvested area because wheat suits a cool temperate climate [15]. Comparatively high PI values were found in countries of the Middle and Near East which are near to the primary center for wheat [4] and in semiarid countries such as Kazakhstan (2.4), Mongolia (2.3) and Pakistan (2.5).

(2) Barley

The PHA of barley throughout the world was 5.1. The geographical distribution of PI for barley had something in common with that of wheat, but the PI value was high in north and east European countries too, reflecting that the suitable temperature for growth and development of barley is 5 ℃ lower than that for wheat [4] (Fig.2).

(3) Rye

The PHA of rye throughout the world was 0.9. The PI value was remarkably higher in east European countries such as Belarus (17.4), Poland (16.2) and Latvia (11.8), reflecting that rye has still greater cold resistance than barley [4] (Fig.3).

(4) Oats

The PHA of oats throughout the world was 1.3. It is said that a comparatively cool summer is suited to the cultivation of oats [14]. In addition, oats possess the agronomic trait that decreased yield due to late frost damage is small as compared to wheat and barley [4]. The fact that the highest

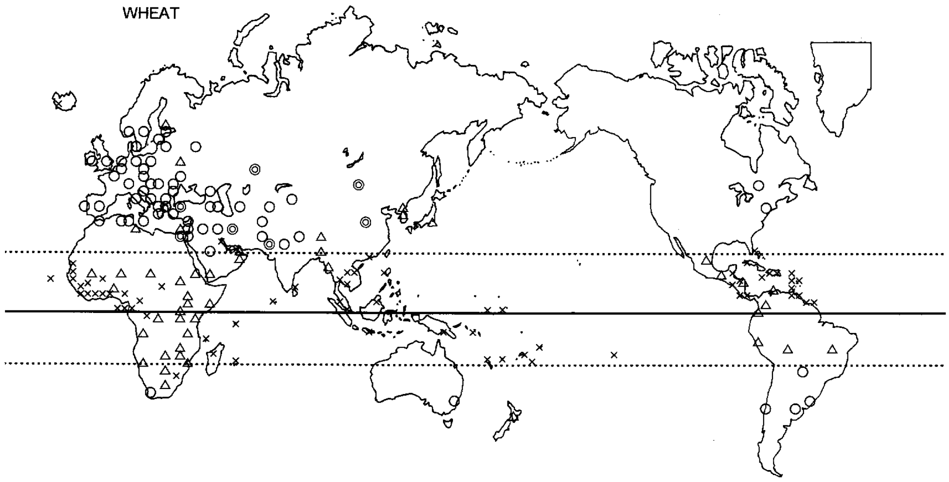

Fig. 1 Geographical distribution map of PI in wheat.
×, no description of harvested area; △, 0 < PI < 0.5 ; ○, 0.5 ≦ PI < 2.0; ◎, 2.0 ≦ PI < 4.0; ●, 4.0 ≦ PI

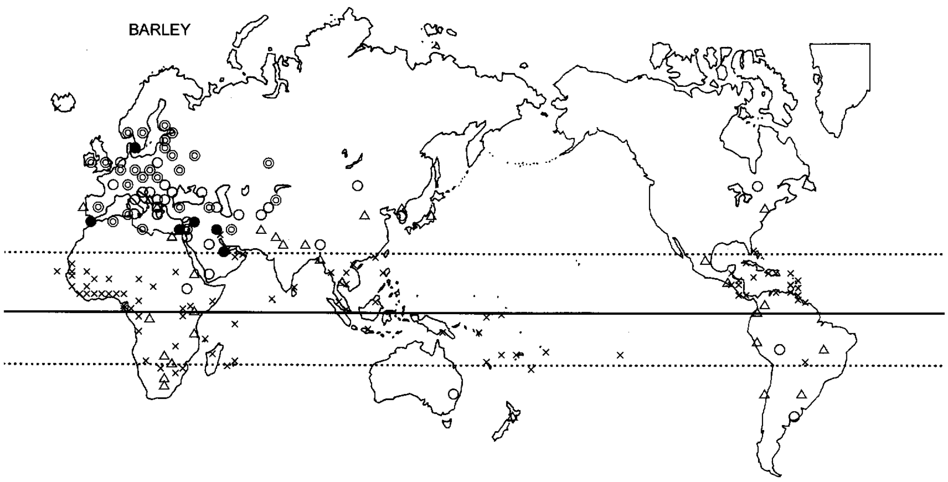

Fig. 2 Geographical distribution map of PI in barley.
Symbols are the same as those shown in Fig.1

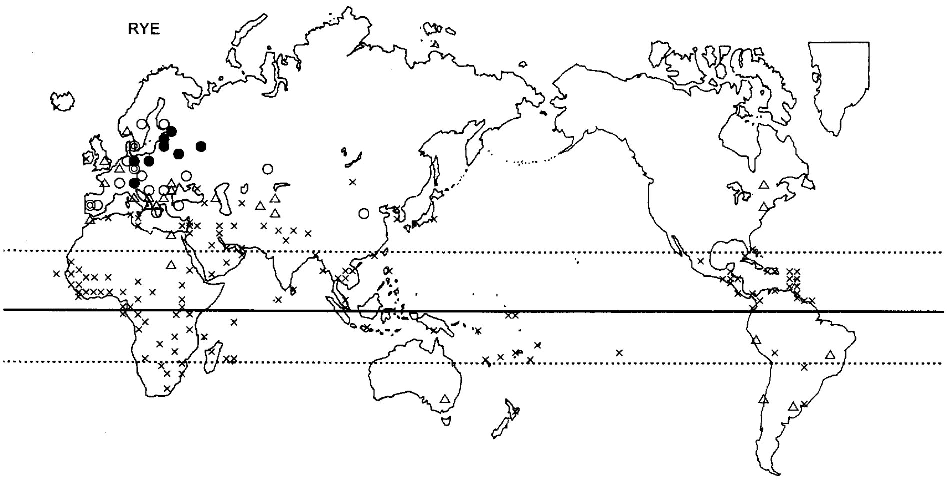

Fig. 3 Geographical distribution map of PI in rye.
Symbols are the same as those shown in Fig.1.

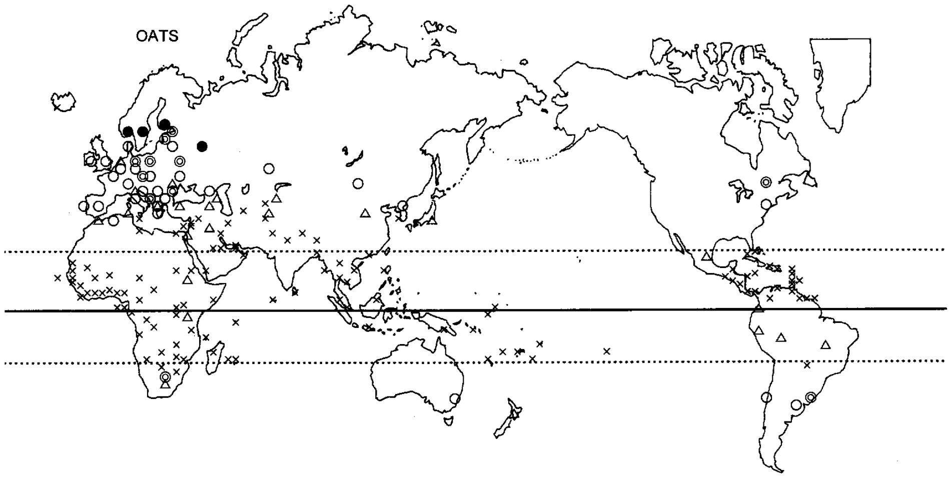

Fig. 4 Geographical distribution map of PI in oats.
Symbols are the same as those shown in Fig.1.

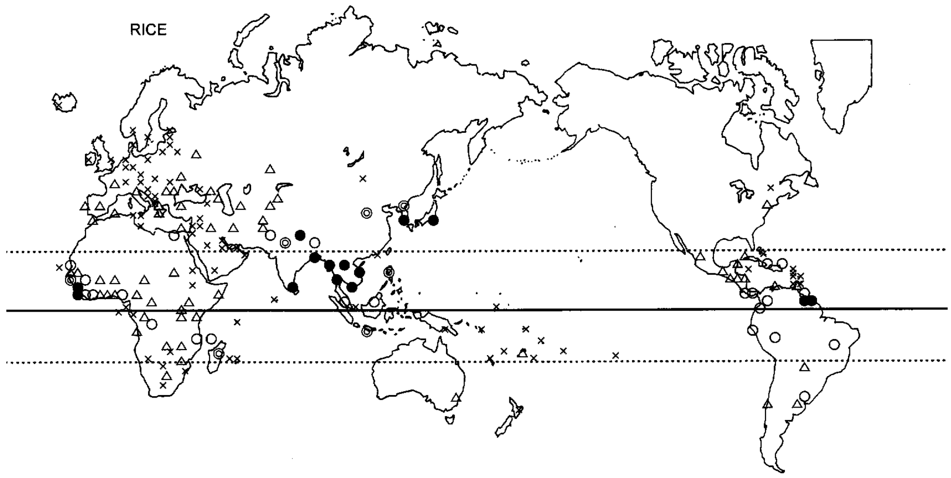

Fig. 5 Geographical distribution map of PI in rice.
Symbols are the same as those shown in Fig.1.

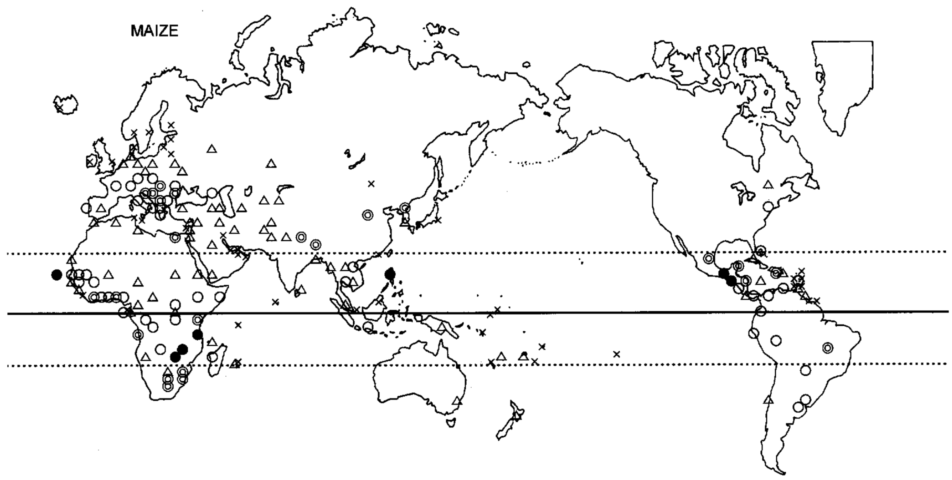

Fig. 6 Geographical distribution map of PI in maize.
Symbols are the same as those shown in Fig.1.

PI values for oats were detected in three Scandinavian countries (9.6 in Finland, 8.8 in Norway and 8.2 in Sweden) may reflect such ecophysiological traits (Fig.4).

(5) Rice

The PHA of rice throughout the world was 10.1, being the second highest behind wheat. The geographical distribution of PI for rice is shown in Fig.5. Most countries where PI exceeds 4 were situated in the tropics and/or in the monsoon regions. In Central, Southeast and East Asian countries which bore Asian rice (*Oryza sativa*) from domestication of the Asian form of *O. perennis* [1, 9] and have a long history of rice culture, rice is, even now, the most important crop (for instance, 10.2 in Bangladesh, 9.6 in Vietnam and 7.5 in Cambodia). But, the highest PI (13.5) was detected in Guinea, West Africa. Guinea is the secondary variation-center of *O. glaberrima* which originated in the Central Niger Delta from domestication of its wild progenitor, *O. breviligulata* [10, 12]. Although the culture of *O. glaberrima* has been diminishing slowly with the introduction of *O. sativa*, there may be no gainsaying the role of *O. glaberrima* as a pioneer crop in making a rapid enlargement of rice cultivation possible.

(6) Maize

The PHA of maize throughout the world was 8.8, being third highest behind rice. The geographical distribution of PI for maize is shown in Fig.6. The countries where PI exceeds 4 were restricted within the tropics, reflecting that maize is native to tropical America between Mexico and Bolivia. In Guatemala and El Salvador, which have been regarded as one of the centers of origin [4], maize is the most important crop (4.2 in Guatemala and 4.8 in El Salvador). The PI of maize was also comparatively high in some temperate zones such as the Balkan States. This is a result of the steady effort of plant breeding which has made the cultivation of maize possible in cool temperate zone [11]. The same may be said of rice.

(7) Sorghum

The PHA of sorghum throughout the world was 2.9. Sorghum is native to tropical Africa (a tract of Ethiopia) [4]. Even now, most large PI values for sorghum were observed in African countries which have a short rainy season, particularly in the Sahel zone (26.1 in Mauritania, 21.6 in Niger, 12.6 in Sudan) (Fig.7). This seems to reflect the fact that sorghum is superior in drought resistance, though inferior in yielding ability, to maize [7, 14].

(8) Millet

Millet includes common millet, foxtail millet, finger millet and pearl millet etc.. Altogether, there are more than 13 species. The PHA of millet throughout the world was 2.4. The geographical distribution of PI for millets is shown in Fig.8. The countries where PI exceeds 4 were restricted within tropical Africa, particularly the Sahel zone. Of the millets described above, finger millet and pearl millet are native to tropical Africa [4]. Although both millets are inferior in yielding ability to sorghum, they can be harvested even in a drought year when sorghum yield will be nil because of their short growing duration and excellent drought resistance. Therefore, millet and sorghum are complementary to each other for farmers living in the peripheral region of the Sahara where the amount and distribution of rainfall are extremely uncertain and unreliable [14].

(9) Total

According to the FAO Production Yearbook, cereals were harvested in 178 countries and localities of the world, and the harvested area of cereals accounted for 47.6% of land under temporary and permanent crops in 1993. The geographical distribution of PI for cereals is shown in Fig.9. The PI ranged from 0.5 to 2.0 in most countries, and regional differences were, on the whole, small as compared to those observed for pulses and tuber crops. This seems to correspond with the fact

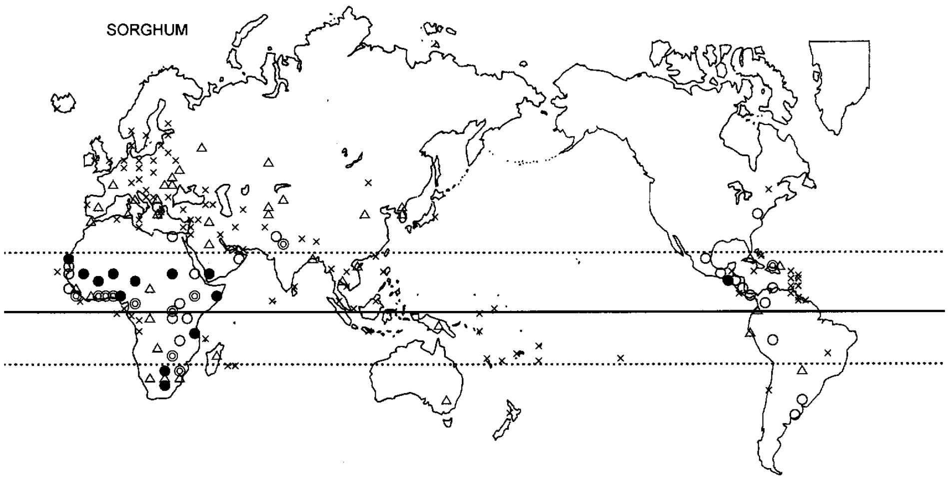

Fig. 7 Geographical distribution map of PI in sorghum.
Symbols are the same as those shown in Fig.1.

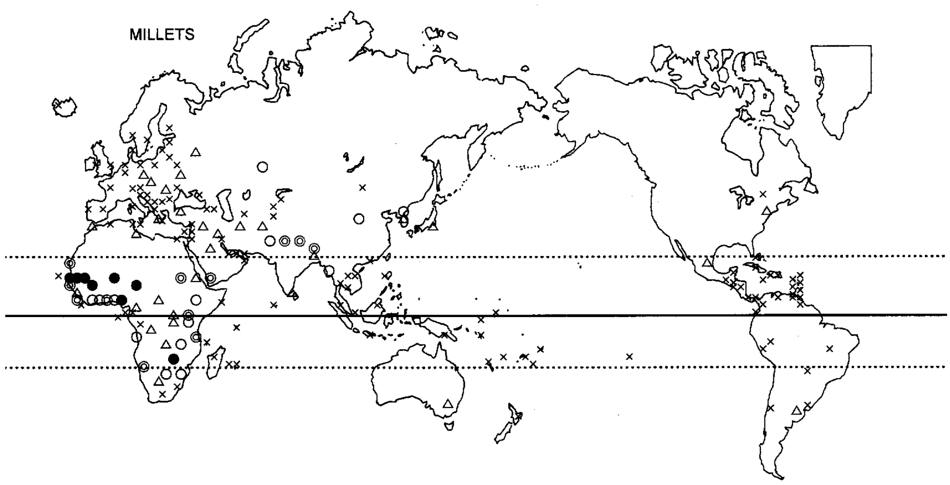

Fig. 8 Geographical distribution map of PI in millets.
Symbols are the same as those shown in Fig.1.

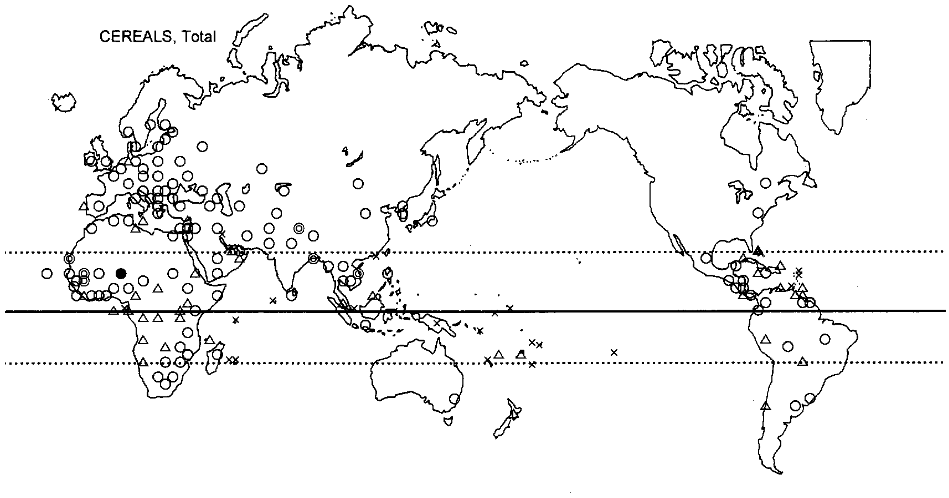

Fig. 9 Geographical distribution map of PI in total cereals.
Symbols are the same as those shown in Fig.1.

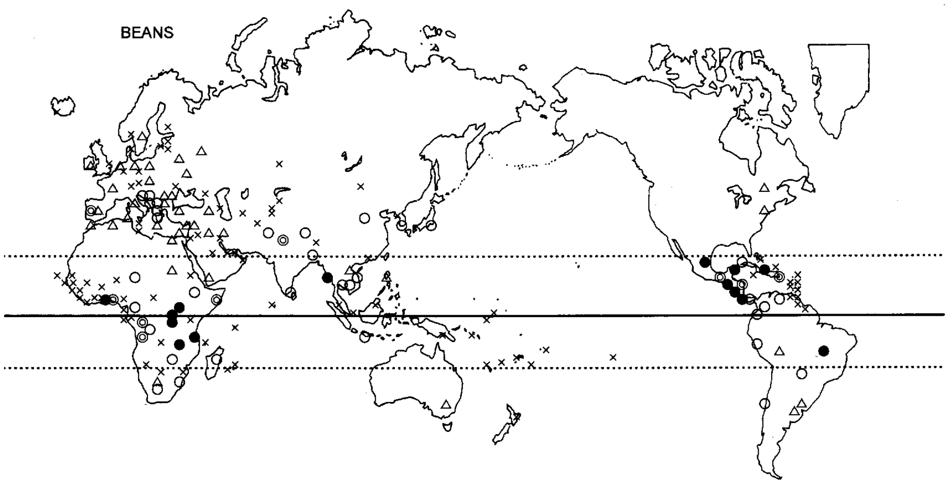

Fig. 10 Geographical distribution map of PI in beans.
Symbols are the same as those shown in Fig.1.

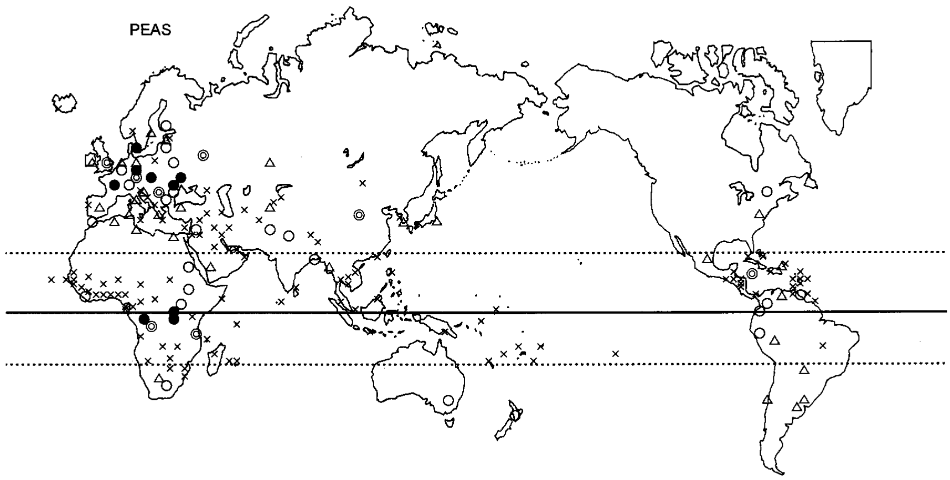

Fig. 11 Geographical distribution map of PI in peas.
Symbols are the same as those shown in Fig.1.

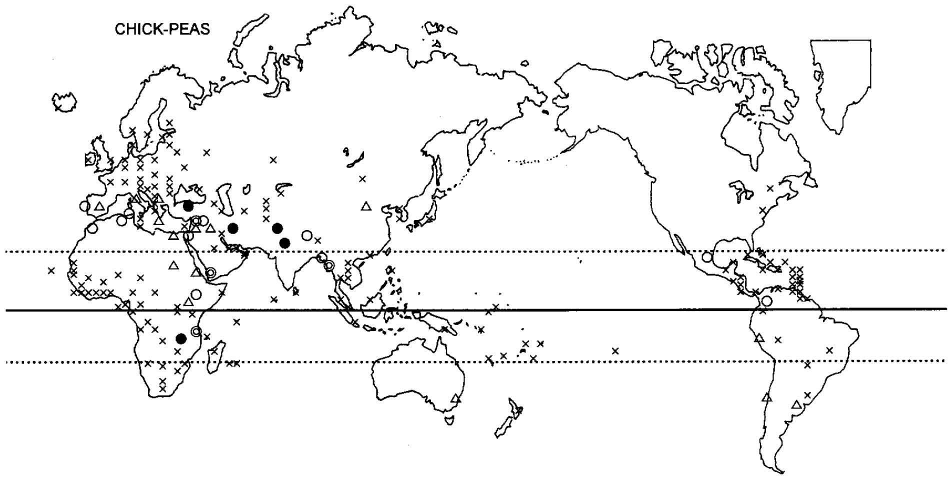

Fig. 12 Geographical distribution map of PI in chick-peas.
Symbols are the same as those shown in Fig.1.

that a great many people in the world live on cereals. However, a lot of island countries and localities scattered throughout the Pacific, Atlantic and Indian Oceans and central African countries which are characterized by a tropical rain forest climate, have a low PI value for cereals or no description of harvested areas devoted to cereals. Although the PI in Niger was 4.0, this seems to be because mixed- or inter-cropping and multi-cropping systems are popular there.

2. Pulses, Soybeans and Groundnuts

(1) Beans

The PHA of beans throughout the world was 1.7. The distribution map for the PI of beans is shown in Fig.10. The countries where PI exceeds 4 were restricted within the tropics centering, in particular, on Central America to which the bean is native [4] (6.4 in Costa Rica, 5.9 in El Salvador, 5.2 in Nicaragua, etc.).

(2) Peas

The PHA of peas throughout the world was 0.6. The higher PI values were found mainly in west and east European countries such as Denmark (8.5), France (6.7) and Ukraine (5.9), reflecting the fact that a cool temperate climate is suitable for peas [4] (Fig.11). However, peas were given an important position in tropical countries with highland regions, such as Burundi (8.2), Rwanda (4.8) and Jamaica (3.3).

(3) Chick-peas

The world average PHA of chick-peas was 0.7. The distribution map for the PI of chick-peas is shown in Fig.12. High PI values were found in Pakistan (6.8), India (5.4), Iran (5.2) and Turkey (4.0), reflecting the fact that chick-peas have their center of origin between the western part of the Himalayas and West Asia [4]. Because the chick-peas have excellent drought resistance, it is grown in the semiarid zone receiving an annual precipitation of less than 1000mm.

(4) Lentils

The PHA of lentils throughout the world was 0.2. The distribution map for the PI of lentils is shown in Fig.13. It is said that lentils have their center of origin in Southwest Asia [4]. Countries in this region such as Lebanon (8.3), Syria (7.7), Iran (5.6) and Jordan (5.2) showed remarkably high PI values. Because a cool temperate and semiarid climate suits lentils [5], they are grown as a winter crop in India and Bangladesh.

(5) Broad beans

The PHA of broad beans throughout the world was 0.2. The distribution map for the PI of broad beans is shown in Fig.14. High PI values were found in two main areas, namely, the countries along the shore of the Mediterranean (17.1 in Egypt, 10.9 in Morocco and 3.1 in Algeria) and China (8.8). The former area comprises the cultivated region of subsp. *faba* var. *minor* and the latter comprises the cultivated region var. *major* [5]. PI values in tropical countries were low excepting countries with highland regions, because a mild and subhumid climate suits broad beans.

(6) Total

Pulses were harvested in 163 countries and localities of the world. The world average PHA of pulses was 4.6. The distribution map for the PI of pulses is shown in Fig.15. Higher PI values tended to be found frequently in the tropical countries such as Niger (15.3), Malawi (5.8), Burundi (5.8), Rwanda (5.2) and Mauritania (5.2), excepting lots of island countries scattered throughout the Pacific Ocean.

(7) Soybeans

The PHA of soybeans throughout the world was 4.3. The soybean has its center of origin in

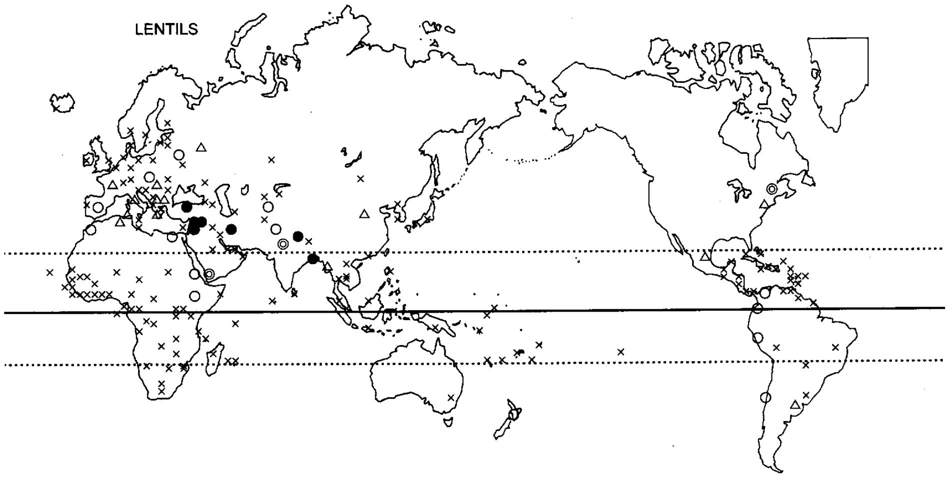

Fig. 13 Geographical distribution map of PI in lentils.
Symbols are the same as those shown in Fig.1.

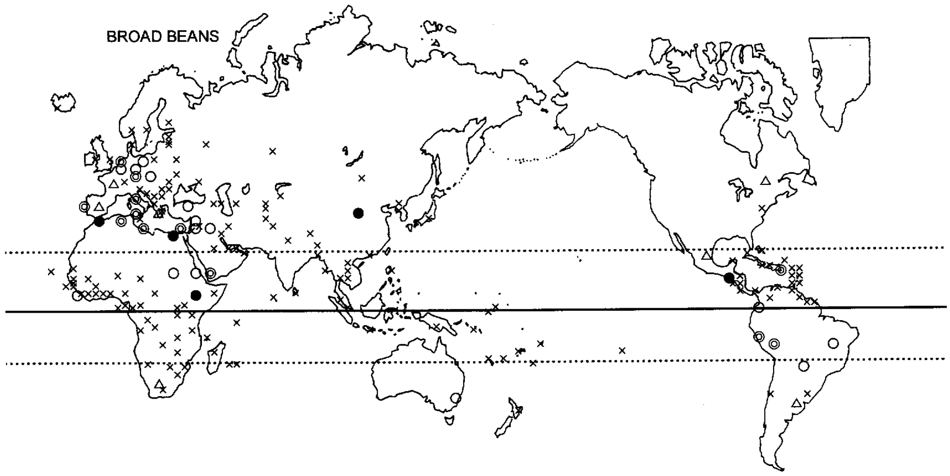

Fig. 14 Geographical distribution map of PI in broad beans.
Symbols are the same as those shown in Fig.1.

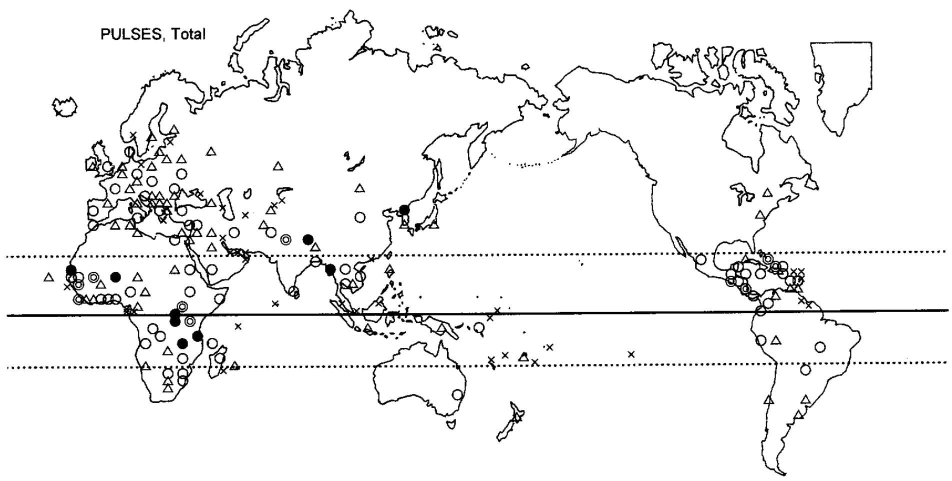

Fig. 15 Geographical distribution map of PI in total pulses.
Symbols are the same as those shown in Fig.1.

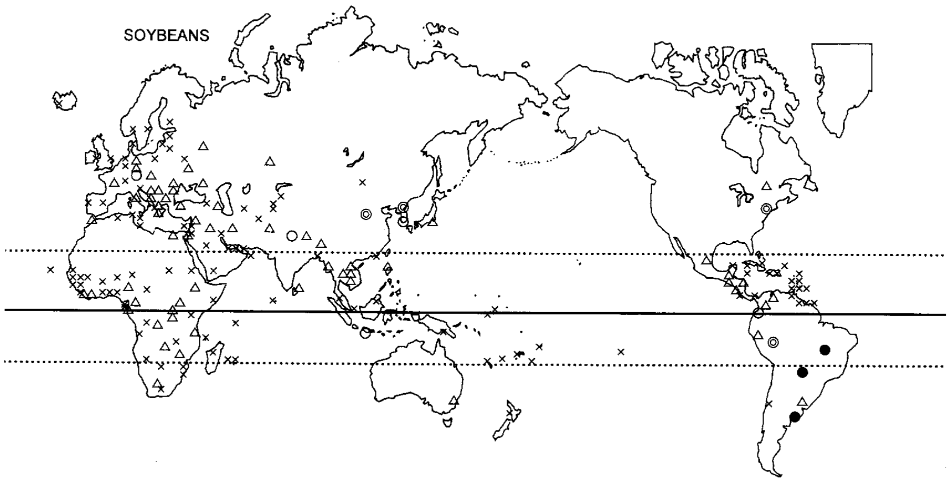

Fig. 16 Geographical distribution map of PI in soybeans.
Symbols are the same as those shown in Fig.1.

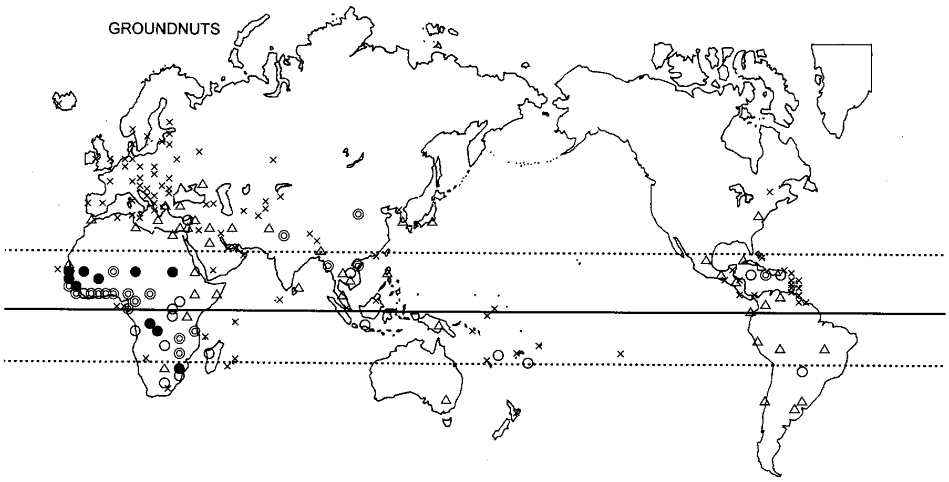

Fig. 17 Geographical distribution map of PI in groundnuts.
Symbols are the same as those shown in Fig.1.

East Asia [4] but the Americas account for 2/3 of the harvested area throughout the world now. There are seven countries where the PI exceeds 2, namely, Paraguay (6.5), Brazil (5.1), Argentina (4.4), Democratic People's Republic of Korea (3.7), China (3.0), USA (2.9), and Bolivia (2.1) (Fig.16).

(8) Groundnuts

The world average PHA of groundnuts was 1.4. The distribution map for the PI of groundnuts is shown in Fig.17. The high PI values were found in a concentric pattern in tropical Africa. In particular, a number of countries situated in the Sahel zone had remarkably high PI values (24.2 in Gambia, 21.7 in Senegal and 10.6 in Guinea, etc.), reflecting the excellent drought resistance of groundnuts.

3. Root and Tuber crops

(1) Potatoes

The PHA throughout the world was 1.3. Potatoes have their center of origin in the central Andes, and comparatively high PI values were found in countries in this region (4.8 in Bolivia, 4.7

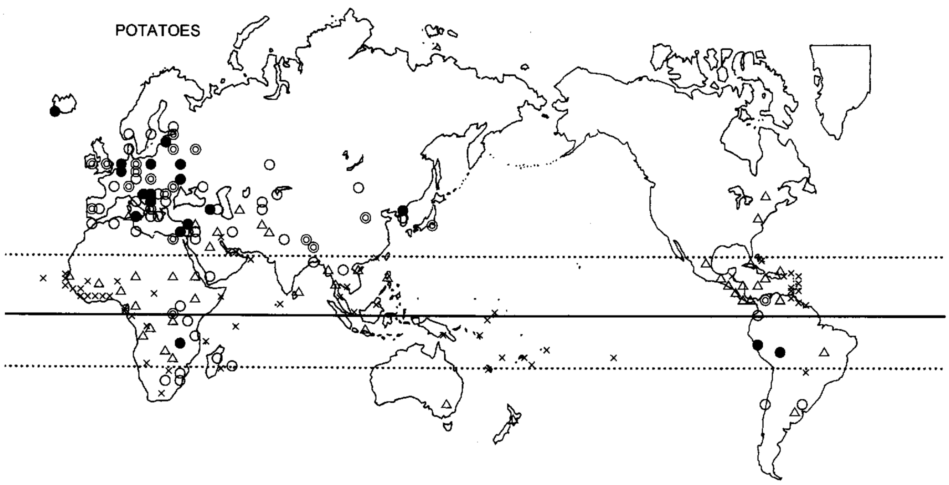

Fig. 18 Geographical distribution map of PI in potatoes.
Symbols are the same as those shown in Fig.1.

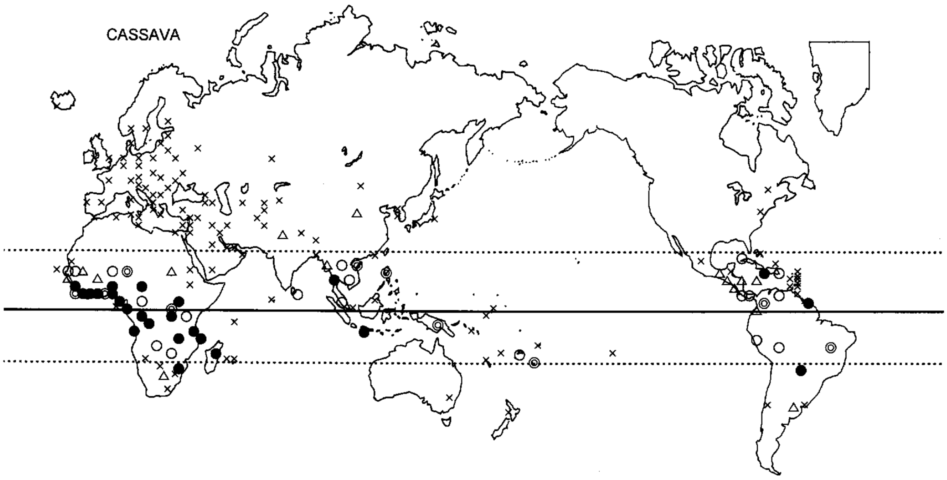

Fig. 19 Geographical distribution map of PI in cassava.
Symbols are the same as those shown in Fig.1.

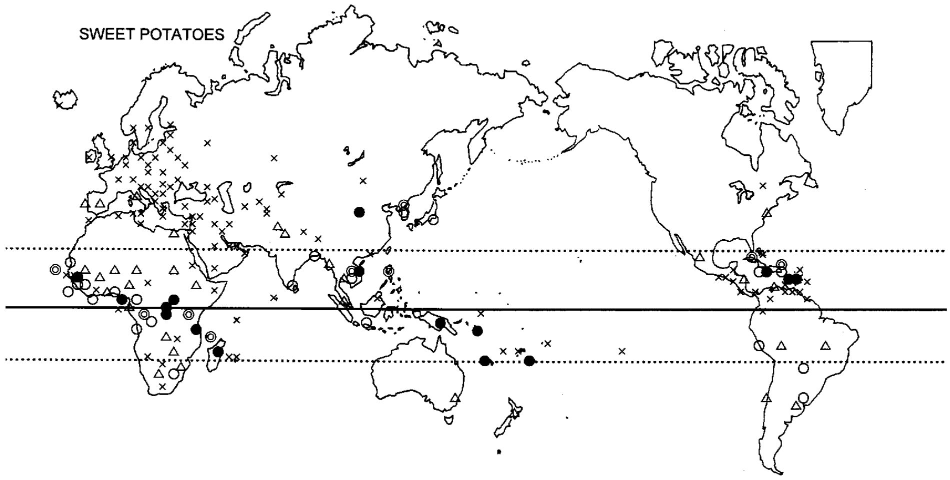

Fig. 20 Geographical distribution map of PI in sweet potatoes.
Symbols are the same as those shown in Fig.1.

in Peru and 3.1 in Colombia). In Europe, the positioning of potatoes was enhanced through experience gained during the severe famines that occurred there frequently in the 18th century. Even now, high PI values are found in many European countries (16.1 in Netherlands, 15.1 in Iceland, 10.9 in Poland and Belarus, etc.) (Fig.18).

(2) Cassava

The PHA throughout the world was 1.1. Cassava was disseminated from tropical America, its center of origin, to Africa by Portuguese in the 16th century [4]. Now, cassava is given considerably high positioning in lots of African countries (51.3 in Congo, 29.9 in Zaire, 24.1 in Mozambique, 17.3 in Tanzania and 15.3 in Guinea, etc.) (Fig.19). Excellent drought resistance, pest and insect tolerances and competitive power with weeds of cassava are reasons why cassava is estimated highly in tropical African countries [14].

(3) Sweet potatoes

The PHA throughout the world was 0.6. The positioning of sweet potatoes is low in their origin-center now, but as high as ever in some of the Caribbean island countries (28.9 in St. Vincent, 10.7 in Haiti and 5.3 in Guadeloupe, etc.). High PI values were also found in island countries and localities of the Pacific Ocean (40.6 in Papua New Guinea, 23.2 in Tonga, 12.2 in New Caledonia, etc.) and in African countries (22.2 in Rwanda, 12.9 in Burundi, 10.8 in Uganda, 9.1 in Tanzania, etc.). On the whole, high PI values were found abundantly within the tropical zone. China (10.2) was a solitary exception (Fig.20).

(4) Yams

The PHA throughout the world was 0.2. The distribution map for the PI of yams is shown in Fig.21. The countries where PI exceeds 4 were restricted within three tropical regions, West Africa which is the origin-center of *Dioscorea cayensis* and *D. rotundata* [4] (34.4 in Côte D'Ivoire, 28.8 in Nigeria, 28.2 in Benin, and 25.7 in Ghana, etc., known as the 'yam zone'), the islands of Oceania where *D. alata*, *D. bulbifera* and *D. esculenta*, etc. were disseminated from Southeast Asia [4] (75.6 in New Caledonia, 20.5 in Tonga, 15.4 in Papua New Guinea, and 8.6 in the Solomon Islands), and Caribbean island countries comprising the area which is the origin-center of *D. trifida* [4] (28.9 in Martinique, 27.3 in Saint Lucia, 26.9 in Jamaica and 19.4 in Haiti, etc.).

(5) Taro

Taro is a general term for genera *Colocasia* and *Xanthosoma*, which originated in tropical Asia and tropical America, respectively [6]. The PHA throughout the world was 0.06. High PI values were found widely in the tropical regions such as Africa (93.7 in Côte D'Ivoire, 59.2 in Ghana, 35.4 in Gabon, and 11.4 in Nigeria, etc.), Oceania (123.2 in Tonga, 117.6 in Papua New Guinea , 113.7 in New Caledonia and 72.7 in Samoa, etc.) and tropical America (123.2 in Fr. Guiana and 87.0 in Dominica) (Fig.22).

(6) Total

The PHA throughout the world for root and tuber crops was 3.3, being the lowest of the three groups of food crops. But, the number of countries and localities with harvested areas devoted to these crops was the highest of the three groups. Fig.23 shows the distribution map for the PI of roots and tubers. PI values were higher in the tropical island countries scattered throughout the Pacific, Atlantic and Indian Oceans such as Maldives (20.0), Papua New Guinea (12.9), Tonga (9.4) and Kilibati (9.2) and in African countries around the equator such as Congo (18.7), Zaire (10.4) and Ghana (6.8), which are characterized by a tropical rain forest and tropical savanna climates. But the PI values were comparatively high in European countries, too. In particular, it is worthy of notice that the PI in Iceland, which did not have any description of harvested areas for cereals and pulses

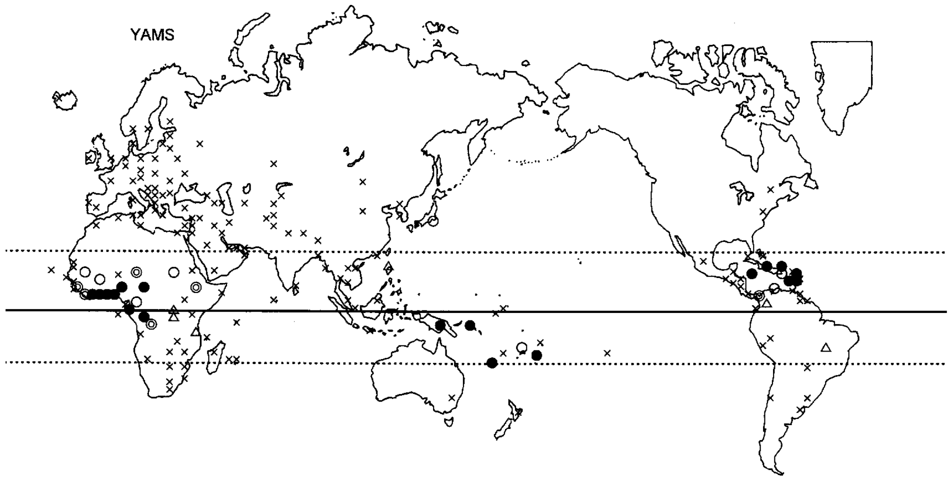

Fig. 21 Geographical distribution map of PI in yams.
Symbols are the same as those shown in Fig.1.

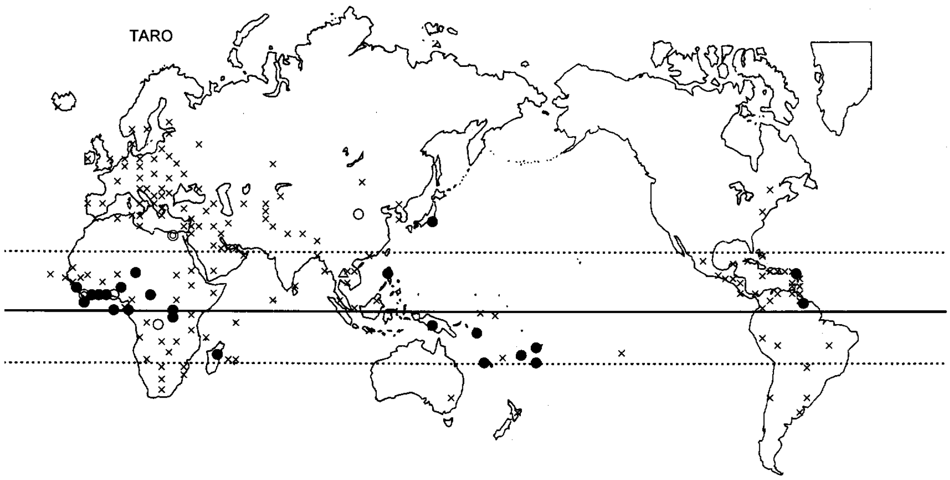

Fig. 22 Geographical distribution map of PI in taro.
Symbols are the same as those shown in Fig.1.

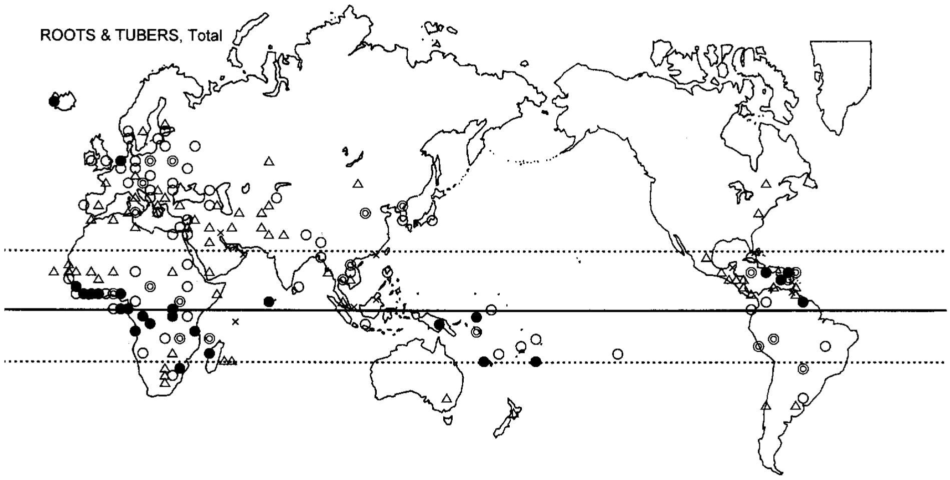

Fig. 23 Geographical distribution map of PI in total tuber crops.
Symbols are the same as those shown in Fig.1.

Table 1. Comparison among continents in consumption of wheat.

Continent	Self-supply[1] (%)	Consumption[2] (kg/person)	Energy intake[3] (MJ/person/day)	Energy intake[4] from wheat (%)
Africa	39	52	9.55	15
N.C. America	195	109	14.16	21
S. America	74	64	11.26	16
Asia	84	78	10.82	20
Europe	112	204	14.27	39
Oceania	986	49	13.10	10
World	100	98	11.38	23

[1] Production / consumption
[2] Consumption / population, Consumption = production+import-export
[3] Data in 1992 from FAO production yearbook (vol. 48)
[4] Consumption × 0.85(digestibility) × 0.8(coefficient of utilization) × 14.65MJ ÷ 365] / energy intake

Table 2. Comparison among continents in consumption of rice.

Continent	Self-supply[1] (%)	Consumption[2] (kg/person)	Energy intake[3] (MJ/person/day)	Energy intake[4] from rice (%)
Africa	81	27	9.55	7
N.C. America	113	22	14.16	4
S. America	97	59	11.26	14
Asia	101	144	10.82	35
Europe	64	7	14.27	1
Oceania	138	27	13.10	5
World	100	95	11.38	22

[1] Production / consumption
[2] Consumption / population, Consumption = production+import-export
[3] Data in 1992 from FAO production yearbook (vol. 48)
[4] [Consumption × 0.8(hulling rate) × 0.9(milling rate) × 0.9(yield rate) × 14.65MJ ÷ 365] / energy intake

Table 3. Comparison among continents in consumption of coarse grains.

Continent	Self-supply[1] (%)	Consumption[2] (kg/person)	Energy intake[3] (MJ/person/day)	Energy intake[4] from coarse grains (%)
Africa	96	107	9.55	31
N.C. America	112	670	14.16	129[5]
S. America	99	173	11.26	42
Asia	84	70	10.82	18
Europe	104	266	14.27	51
Oceania	375	47	13.10	10
World	100	157	11.38	38

[1] Production / consumption
[2] Consumption / population, Consumption = production+import-export
[3] Data in 1992 from FAO production yearbook (vol. 48)
[4] [Consumption × 0.85(digestibility) × 0.8(coefficient of utilization) × 14.65MJ ÷ 365] / energy intake
[5] The percentage of energy intake from coarse grain exceeds 100 in N.C. America. This is because the greater part of coarse grain is consumed as feed grain in N.C. America. Energy loss becomes large when coarse grain is consumed in order to produce animal products such as meat, milk, and eggs. On the other hand, most varieties of coarse grain such as maize, sorghum and millet have been consumed as human food in African countries.

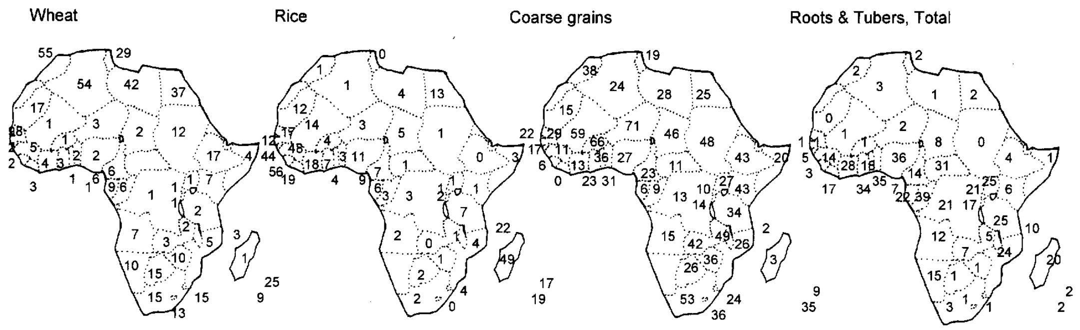

Fig. 24 The distribution map of percent of wheat, rice, coarse grain and tuber crops for energy intake, found in Africa

at all and is near the Arctic Circle, was 5.0 (potatoes).

4. General Discussion

It could be observed that the positioning of crops viewed according to PI was largely in correspondence with the temperature and water requirements of each crop (Figs.1-8, Figs.10-14 and Figs.16-22). However, there are regional differences in the positioning of cereals, pulses and tuber crops with such general principles.

From comparison among the PHAs of cereals, pulses, and tuber crops, it is obvious that man has come to rely most heavily on cereals as a source of food. There may be several reasons why cereals continue as dominant crops. Firstly, they satisfy basic dietary needs. Cereals, with high digestibility and 8-14% protein content and 60-80% carbohydrate, supply protein and energy as well as or better than other groups of plants [8]. Secondly, dry grain has high bulk density and is easily transported and stored [8]. Thirdly, they are abundant in genetic diversity and can be grown in a broad range of environments from cool temperate to tropical and from humid to semiarid climates. And, from diverse cereal crops, peoples in Europe, Asia and Africa picked out wheat, rice, and maize, sorghum and millet as the chief sources of energy intake (Tables 1, 2 and 3)*. In fact, the higher the PI, the higher the percentage of each crop for energy intake (Fig.24).

Although pulses are also abundant in genetic diversity (see Figs.10-14, 16 and 17), the relative importance of pulses was still more conspicuous in tropical countries (Fig.16). Pulses have high protein productivity per land area, though they are greatly inferior in energy productivity to cereals (Tables 4 and 5). This property gives the dietetic advantage to inhabitants in the tropics in combination with the culture of tuber crops. The relative importance of root and tuber crops, on the whole, was more conspicuous in tropical countries too (Fig.23). Root and tuber crops have high energy productivity (10.5 or 135.7GJ/ha), at 2.3 or 1.4 times as much as that of cereals (Table 6). However, it is difficult for people to take all the protein they require from root and tuber crops because their protein content is extremely low (and Kwashiorkor symptoms can result from protein deficiency). The culture of pulses has an important significance for people who have difficulty getting hold of animal protein. In this case, pulses and root and tuber crops are complementary to each other

* The percentage of energy intake from coarse grain exceeds 100 in N.C. America. This is because the greater part of coarse grain is consumed as feed grain in N.C. America. Energy loss becomes large when coarse grain is consumed in order to produce animal products such as meat, milk and eggs. On the other hand, most varieties of coarse grain such as maize, sorghum and millet have been consumed as human food in African countries.

Table 4. Difference in yields of cereals among countries.

Low-ranking countries	Mean yield[1] (kg/ha)	High-ranking countries	Mean yield[2] (kg/ha)	Ratio[5]
1 Cape Verde	284	1 Netherlands	7530	
2 Botswana	302	2 UK	6604	
3 Niger	305	3 France	6518	
4 Angola	370	4 Bel-Lux	6501	
5 Mozambique	426	5 Ireland	6474	
Average yield (kg/ha)[2]	338	Average yield (kg/ha)[2]	6726	19.9
Energy production (GJ/ha)[3]	4.5	Energy production (GJ/ha)[3]	95.7	21.1
Protein production (kg/ha)[4]	33.8	Protein production (kg/ha)[4]	672.6	19.9

[1] Mean yield for three years, from 1992 to 1994, of cereals in each country.
[2] Average yield for five countries of lower or higher rank.
[3] Calculated as 320kcal / 100g (coarse grain) and 340kcal / 100g (wheat) for low- and high- ranking countries, respectively.
[4] Calculated as 10g / 100g.
[5] Ratio of the value for high-ranking countries to that for low-ranking countries.

Table 5. Difference in yields of pulses among countries.

Low-ranking countries	Mean yield[1] (kg/ha)	High-ranking countries	Mean yield[2] (kg/ha)	Ratio[5]
1 Ghana	100	1 France	4885	
2 Niger	171	2 Ireland	4680	
3 Mali	217	3 Bel-Lux	4296	
4 Cape Verde	226	4 Netherlands	4074	
5 Togo	426	5 Switzerland	3750	
Average yield (kg/ha)[2]	190	Average yield (kg/ha)[2]	4337	22.8
Energy production (GJ/ha)[3]	2.7	Energy production (GJ/ha)[3]	61.7	22.8
Protein production (kg/ha)[4]	43.8	Protein production (kg/ha)[4]	997.5	22.8

[1] Mean yield for three years, from 1992 to 1994, of pulses in each country.
[2] Average yield for five countries of lower or higher rank.
[3] Calculated as 340kcal / 100g.
[4] Calculated as 23g / 100g.
[5] Ratio of the value for high-ranking countries to that for low-ranking countries.

Table 6. Difference in yields of roots and tubers among countries.

Low-ranking countries	Mean yield[1] (kg/ha)	High-ranking countries	Mean yield[2] (kg/ha)	Ratio[5]
1 Mauritania	1946	1 Netherlands	44099	
2 Swaziland	1954	2 Switzerland	43987	
3 Cayman Is	2073	3 Bel-Lux	43651	
4 EQ Guinea	2629	4 UK	42065	
5 Eritrea	2804	5 Denmark	36789	
Average yield (kg/ha)[2]	2281	Average yield (kg/ha)[2]	42108	18.5
Energy production (GJ/ha)[3]	10.5	Energy production (GJ/ha)[3]	135.7	12.9
Protein production (kg/ha)[4]	45.6	Protein production (kg/ha)[4]	842.2	18.5

[1] Mean yield for three years, from 1992 to 1994, of roots and tubers in each country, excepting in Eritrea where mean yield is for two years from 1993 to 1994.
[2] Average yield for five countries of lower or higher rank.
[3] Calculated as 110kcal / 100g (mean for sweet potatoes, yams and taro) and 77kcal / 100g (potatoes) for low- and high-ranking countries, respectively.
[4] Calculated as 2g / 100g.
[5] Ratio of the value for high-ranking countries to that for low-ranking countries.

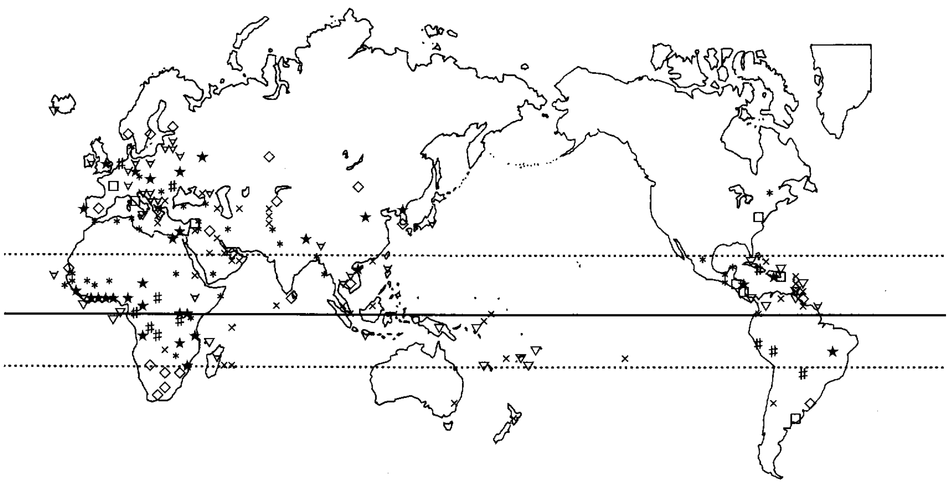

Fig. 25 Geographical distribution map of combination of crops showing PI ≧ 2.0. ×, no crop; ◇, only cereals; □, only pulses; ▽, only tuber crops ; ∗, cereals+pulses; #, pulses+tuber crops; ∀, cereals+tuber crops; ★, cereals+pulses+tuber crops

(Fig.25). According to Midorikawa [9], inhabitants living in a village of the Solomon Islands, Oceania, have made up for a lack of protein with intakes of fish and shellfish and partly of coconut. The positioning of pulses has been low in the islands of Oceania, circled with sea as they are (Fig.15). In view of growing pattern, pulses, with an inderterminate habitat, maintain vegetative apices and flower from axillary buds over protracted periods. Therefore, transient stresses may cause the loss of a particular age class of flowers and hence affect yield, but with the return of more favorable conditions, flowering continues and yield potential can be re-established. Consequently, pulses are generally superior in yielding stability to determinate crops [8]. This may be the second reason why pulses have been cultivated so successfully in tropical countries. In fact, pulses in common with cereals have been adopted frequently in cropping systems in the semiarid zone where the amount and distribution of precipitation are uncertain and unreliable (Fig.25). This introduction of pulses gives a step-up to yielding stability. Finally, it is conceivable that the culture of pulses has been a measure to preserve fertility in the developing countries of the tropics where farmers have never been graced with the luxury of chemical fertilizer.

The positioning of tuber crops tended to be high in tropical regions, as above mentioned. Another characteristic of tuber crops is that the yield difference between high- and low-yielding countries is small (Table 6). They can be regarded as indeterminate crops from the viewpoint of the yield-determining process. In the tropical regions where growing duration is not restricted by low temperature and water deficiency, the yield of tuber crops can easily become large as compared to that in a temperate region (assuming no difference in culture technique) where growing duration is checked by low temperature. In addition, because roots and tubers grow underground in an environment which is remarkably mild as compared to air, it is difficult for them to sustain damage due to extreme temperatures and water stress. This may be a reason why only potatoes have been cultivated with high positioning in Iceland which is near the polar circle. Tuber crops are hardy crops undoubtedly. Peoples in countries with a tropical rain forest climate or a tropical savanna climate with a long rainy season, rely on tubers as their major source of energy (e.g., 39% in Congo, 36% in Nigeria, 35% in Benin, 34% in Ghana, 31% in Central Africa, etc.) (Fig.24). According to Midorikawa [9], inhabitants in a village of the Solomon Islands depended for 70-80% of their energy intake upon tubers.

In short, it is concluded that crop utilization in the tropics has been characterized by key words such as 'yielding stability', 'combination of energy and protein production' and 'utilization of nitrogen-fixing crops'. However, the authors think at the same time that people's preference for certain foods is an important factor. For instance, the farmers of St. Vincent, St. Lucia and Trinidad and Tobago, countries scattered in the Caribbean Sea, have given only sweet potatoes, yams and taro, high positioning, respectively, and have shown little interest in other crops. Similarly, the farmers of Burundi and Rwanda who grow tuber crops have not given yams so high a positioning as compared to sweet potatoes, cassava and taro, while the farmers of Sudan seem to be willing to grow yams (Figs.20-22). In some countries in West Africa, the conventional foods such as millet, sorghum, maize, yams etc. have been steadily replaced by rice, if circumstances require, beyond the boundary of its climate requirements [11]. Changes in food preferences will, of course, continue to affect crop utilization in future.

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