Ecological Competition Among the Main Moisture Rich Starchy Staples in the Tropics and Subtropics

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Abstract

Cassava produces 67%, yam 9.2%, sweet potato 9%, plantain 7.1%, potato 4.7%, aroids 1.6% and sagopalm 1.3% of total food energy in the tropics and subtropics. Potential production per unit, time and surface is twice that of cereals.

Research should be aimed at lengthening the period of quick starch accumulation, in which partitioning of dry matter over sink and other plant parts appears to be constant with the possible exception of plantain. In crops that ripen, like sagopalm and plantain, lengthening might not be possible. Ripening in potato and yam received insufficient attention; it may be connected with early tuber development and dormancy of tubers.

Needs of plant nutrients differ considerably with cassava and sagopalm as the cheapest and sweet potato as the most expensive. Sagopalm and plantain especially in tropical lowlands possess the advantage of avoiding the problem of loss of organic matter and nutrients, through continuous recycling.

A distinction should be made between (i) fresh food crops: yam, plantain and potato, (ii) starch or energy-producing crops: cassava and sagopalm, and (iii) dual purpose crops: sweet potato and aroids.

Introduction

In a previous publication (De Vries, Ferwerda and Flach, 1967), a generalized calculation of the actual and potential production of a number of important food crops in the tropics was given. One of the main conclusions in this paper is that the potential yield of root and tuber crops is twice the potential yield of cereals. This yield potential, however, was not realized in root and tuber crops, due to the lack of research and the lack of dissemination of results. An updated calculation with respect to root and tuber crops is given in Table 1. This calculation is compared to the 1967 version in Fig. 1.

In general, we may conclude that the average world yields, has not changed much. Experimental highest yields of cassava, sweet potato and taro, however, are approaching the potential yields. This clearly reflects the interest taken in these crops in the last ten years. Only yam lags behind.

In Fig. 1, two other starch crops are included, i.e., the plantain (*Musa* spp.) and the sagopalm (*Metroxylon sagu*). In my opinion, such crops, that are also used as starchy staples, should also be included in our Society's regular crops. All of these crops and quite a number of others (Kay, 1973) serve as staples in parts of the tropics.

From a point of view of the production of energy foods, these starchy staples are mutually exchangeable. All can be and are being used for human nutrition, as an animal feed and for industrial starches. Moreover, interest nowadays is mounting because of the possibility of using these crops for energy. Of course, in looking at these crops as energy producers, certain aspects will be neglected. Not taken into account are such aspects as:

(1) contents and quality of protein in the products,
(2) storage quality of the products and,
(3) value and possibilities of additional products of the same crop, such as leaves.

These aspects are mainly important in places where these crops are used as human food or animal feed. For industrial purposes, it might be important to consider the starch quality.

It appears, nevertheless reasonable to consider these crops as a mutually exchangeable complex with regards to their uses. In doing so, one also neglects differences as taste preferences, food habits, local customs which, no doubt play an important role in the spread of these crops over our world.

There exists a very common prejudice that the use of these crops for human nutrition is a sign of poverty. Provided some precautions are taken in using additional food stuffs, these crops are fully acceptable as human food. And for all other purposes they probably are better than most other crops.

These starch crops do, however, possess one serious disadvantage: their high moisture content. Due to the moisture content of between 60 and 80%, the produce are difficult to store and expensive to transport.

In general, these crops provide sufficient food for some 13% of total world population. However, the relative importance of these crops in the tropics is somewhat less; here they provide food for approximately 10% of the population (Table 3). Ranking of importance in the tropics is quite at variance with world ranking: cassava, yam, sweet potato, plantain, potato, aroids, sagopalm.

Research efforts on our crops apparently are governed by the

1. importance of the crops in non-tropical countries. This holds for potato and for sweet potato. Most of the researches on the latter crops were done in the United States of America.
2. commercial interest in the crop. This especially holds for cassava. All other crops are of mainly local interest. Only if research is developed locally, will these crops receive the attention so badly needed. This is clearly shown by the research on taro in Hawaii. And it should point the way for the other root crops.

Ecological Competition

With regard to starch production, each crop may be substituted for each of the others; one could say that such crops have an approximately equal value as food, feed and also for industrial purposes. They, however, differ with regard to ecological zone of optimal growth. Agronomists often bring crops into such ecological competitive groups, e.g. cereals or oil crops or pulses. It is therefore important to describe and compare the ecological possibilities of these moisture-rich starchy staples.

Our principal problem is defining the range of optimum conditions for a high production of starch per unit time and unit area. In addition, an idea should be formed on starch production beyond these optimum ranges.

In general, one may distinguish ecological conditions into the following categories:

1. **Not or only slightly modifiable**
    a. temperature;
    b. light; light may be diminished, e.g. by shade
    c. soil texture
2. **Partly modifiable**
    a. water; water may be modified by irrigation and/or drainage
    b. soil; soil structure, organic matter
3. **More easily modifiable**
    a. pH
    b. nutrients

Of course, many of these factors are interrelated, e.g. temperature, water and soil, pH and nutrients.

Some information on ecological conditions has recently been compiled by Wilson (1977) on optimal conditions and by Plucknett (1978) on sub-optimal conditions. Especially for yams the recent book of Onwueme (1978) is useful.

Growth and Duration of Growth

All crops mentioned in this paper are usually propagated vegetatively; some by means of stem part or suckers; others by means of a part of the produce harvested. This presents a disadvantage for production of the latter category.

In general, the growth cycle of these crops can be distinguished into the following phases:

1. Establishment; the plant parts used for propagation to establish themselves.
2. Development of leaf area; the plant produces its leaf area.
3. Starch accumulation; after formation of leaf area, the plants form their sink and start accumulation of starch.
4. Ripening; not all crops show the phenomenon of ripening: a diminishing of the leaf area, accompanied by a slackening starch accumulation.

We may assume that these phases follow each other. In *Dioscorea* and in *Solanum* sink formation and starch accumulation may start before the optimum leaf area is attained. But starch accumulation is quickest after the optimum leaf area is reached. A careful survey of various literature data on root and tuber crops is given by Wilson (1977). They are presented in Table 4. It should be noted that these data are not generalized for the crop but represent one special variety only;

Wilson's (1977) survey was supplemented by data on sagopalm given by Flach (1976). This crop follows the same pattern during a much longer life span. With *Musa* the situation is quite different, however, due to the dual nature of its sink; first the pseudostem acts as a sink; later on this function is taken over by the fruits. In Ehtiopia, the pseudostem of *Ensete ventricosum* actually is used as a starchy staple.

The following remarks on ecological conditions in these growth phases can be made.

In 'establishment', water should be locally available. High sunshine usually is not favorable because of its effect on drought and high temperatures.

In 'development of leaf area', water, sunshine and nitrogen should be adequate. Here, weed competition might be important.

In 'starch accumulation', high sunshine is favorable. But for translocation to the sink, somewhat lower night temperatures and a sufficient supply of potassium are considered beneficial.

A phase of 'ripening' can often be discerned. But it is not certain (except for plantain and sagopalm) whether we are confronted by a phenomenon caused either by external factors, e.g. climate – an exogenous rhythm, or by internal factors of the plant and endogenous rhythm. For the time being, I suppose that both rhythms exist and that the ideal situation is that both rhythms are adapted to each other.

Usually, the phenomenon of ripening can be described as an imbalance between the functions of roots, leaves and the sink. Root function becomes too limited to provide nutrients and/or water for both sink and photosynthetic apparatus. A choice then is made usually in favour of the sink. It is clear that such a phase of ripening would be heavily influenced by a water shortage and should be called exogenous.

On the other hand, a programmed destruction of both photosynthetic apparatus and roots may exist, as the case of *Dioscorea,* and in *Solanum.* This form of ripening I would call endogenous.

The phases of establishment and development should be made as short as possible, whereas lengthening of the phase of starch accumulation might be advantageous, (if possible). If an endogenous factor of ripening exists, lengthening probably is impossible. Such an endogenous rhythm exists in plantain and sagopalm. In both crops, starch accumulation is ended by flowering and/or fruiting. Potato and yam probably possess an endogenous rhythmicity. The duration of growth in these crops probably is a varietal characteristic. A connection might exist between the dormancy before germination in these tubers, and the start of sink formation before full leaf area is attained. In sweet potato, aroids and cassava, the situation is less clear and needs further research. If such endogenous rhythmicity does not exist in these crops, their production could be increased by lengthening the phase of starch accumulation.

The figures given in Table 4 suffer from some severe limitations. First, they concern one special variety only. Second, they are only estimates. These limitations are less important in cases where the common name adheres to only one species. But they may be very important in those cases where the common name is used for a number of species (yam) and even a number of genera (aroids). In these cases quite a number of differences may exist.

The possibility of lengthening the phase of starch accumulation needs further attention in research. This problem is closely interconnected with the possibly existing phenomena of ripening. For research into this complex matter, the crops need to be grown under carefully controlled circumstances. Such research therefore, should be done in larger, well-equipped experiment stations.

Partitioning of dry matter

Boerboom (1978) showed the constant partitioning of dry matter in cassava over the storage organ and the other plant parts. Comparable results were found by de Bruijn, elsewhere in these proceedings. Soetono *et al* (1980) found the same phenomenon. The basic system of dry matter partitioning in cassava is given in Fig. 2.

Tsuno (1977) show the same pattern of partitioning. His data are presented in Fig. 3. The crops probably were a *Solanum* - potato (cv Danshakuimo) and the other cv Norin no. 1, in another publication (Tsuno & Fujise; 1964) is a sweet potato. One may therefore assume that this pattern of partitioning is usual in our moisture-rich starchy staples. It at least holds true also for the sagopalm, as the leaf scars are spread evenly along the length of the trunk.

Fig. 3 shows clearly that the regular pattern of partitioning does not hold for the phases of establishment and development. But during 'quick starch accumulation' it probably holds true. It is however not certain, how ecological conditions will influence partitioning. On the one hand, adverse ecological conditions may influence the speed of dry matter production. On the other, partitioning of dry matter might be influenced as well.

The regression coefficient of the straight line might be useful in comparing starch crops. Boerboom (1978) gave this regression coefficient the name of efficiency of storage root production (ESRP). One should realize, however, that in such a graph the time factor is not used. This is made clear in Fig. 3.

The intercept with the axis of useful dry matter production Boerboom named initial start starch accumulation (ISS). But from Fig. 3, it becomes clear that the intercept only is a claculated point, an apparent initial start of starch accumulation (AISS)

Boerboom's (1978) calculations on cassava show ESRP's (regression coefficients) ranging from 0.70-0.36; Soetono *et al* (1980), 0.74 and 0.68. The figures of Tsuno (1977) show ESPR's of 0.98 in potato and sweet potato. These coefficients give an indication of the dry matter diverted to the storage organ. This especially seems close to maximum useful dry matter production when AISS becomes a relatively small part of total dry matter production.

The phenomenon needs further research as it could be a useful tool, for instance in development of simple growth models for comparing productions, especially for starch crops with a long duration of growth.

Light

Light intensity and daylength are interrelated to each other in the term total radiation received.

Daylength is treated by Wilson (1977). He cited literature that short days stimulate tuberization in cassava, yams and *Colocasia,* as well as in potato. Such influence is unlikely in sweet potato as this is a summer crop in the subtropics. In sagopalm, such an influence is also unlikely, due to its year round production. This holds also for plantain.

Total radiation of course is rather important for all the crops mentioned. All highest yields obtained already approach the possible maximum (Fig. 1). This indicates that the plant is at its highest productivity during the growth phase of starch accumulation. This probably also holds true for the plantain where a large part of the starch has to be accumulated in relatively short period of fruit development.

In literature statements like "aroids are tolerant to shade" are often found. The results of the highest experimental yields (Table 1: Fig. 1) do not warrant such a statement. It might well be that the growth pattern of such a crop is more temperature-controlled than light-controlled.

Outside the phase of starch accumulation, the crops may differ with regard to their needs of light. Some shade in the phases of establishment and development may have only little detrimental effect on yield with plants that usually tiller, i.e., propagate vegetatively in the shade of motherplants, e.g. plantain, sagopalm and the aroids.

Temperature

As Wilson (1977) already stated, experimental data on temperature requirements are lacking almost completely. Exceptions have to be made for potato (Bodlaender,

1963) and for banana (Champion, 1963). A generalized survey of literature statements is given in Fig. 4 with respect to average temperatures. These temperature ranges mainly are based on Kay (1973) and on Purseglove (1974 & 1975). Also the altitudinal ranges of the crops were taken into consideration e.g. Westphal (1974).

One should bear in mind that in yam, the temperature ranges of the various species differ considerably. In Fig. 4, the trajectory of tropical yams is presented. But *Dioscorea opposita* (Kay 1973) is reported to be able to withstand even frost.

Some general lines concerning the influence of temperature on growth can be drawn.

a. Transpiration of crops increases with temperature.
b. A decrease of temperature below the optimal trajectory usually leads to an increase of the duration of growth.
c. Differences between day and night temperatures within the optimal trajectory usually are advantageous for storage of dry matter in the sink. This probably is caused by two factors: (1) favorable circumstances for development of sink (Tsuno, 1970) and (2) diminishing of respiration.

The positive influence of differences in day and night temperatures is not proved for both sagoplam and plantain. Of course temperature influences in the moisture rich starchy staples are far more intricate than mentioned here. A good literature survey for the potato is given by Wilson (1977).

Water

Water requirements of crops may be given in comparison to the potential evapotranspiration (Eo). The actual water need of a crop, (Et) usually differs from Eo because the evaporating surface differs from an open water surface. For instance, a tropical rain forest Et may exceed Eo because of the well spread and dense leaf canopy. And in young crops Et may be considerably lower than Eo.

Potential evapotranspiration in the tropics is 3-5 mm water per day with a mean of 4 mm/day (Monteith, 1977). Much higher rates, up to 10 to 15 mm/day, are reported for irrigated crops in the semi-arid tropics and sub-tropics, due to advection of energy. The latter situation is excluded in this treatment. So, in general, we may conclude that only in well spread and dense canopies, among which a good circulation of air is possible, Et can exceed Eo. This situation occurs in a mature canopy of sagoplam, where the LAI may reach a value of 6.5 (Flach, 1977) and also in a mature canopy of banana like 'Gros Michel' (Moreau, 1965). None of the other crops LAI normally exceeds 4 (Wilson, 1977) moreover, their architecture is either too low or too dense or both to allow the necessary air circulation. We may therefore assume that only mature plantings of sagoplam and banana may exceed Eo in their water use. In all other crops Et is at the most of the same level as Eo and often smaller than Eo.

In a situation where excess water that does not run off, the plant has to be adapted to a high water level. A crop that is adapted to such a situation is taro (see e.g. Plucknett & de la Peña; 1971). This crop may be cultivated in fields closely resembling wet rice fields. The crop is supposed to be able to transport oxygen to its roots. The sagopalm also is adapted to extremely wet situations and also to fluctuating water levels. But the palm appears to produce somewhat better under less extreme conditions (Flach et al 1976). It was noted in our hothouses that the palm may produce pneumatophores above a regularly occurring water level. This probably is a means to supply oxygen to submerged roots. None of the other crops is adapted to high water levels. Of course, all crops will do well in a situation where the water available approximately equals Et. In this respect the storage of water in the soil especially is important. But a situation of water shortage is of more interest.

According to May & Milthorpe (1962) drought-resistance is the ability of a crop to grow and produce adequately under circumstances of water shortage. They distinguish the following categories:

1. the ability to end growth and production before a serious water shortage develops;
2. the ability to survive a water shortage and resume growth:
   a. through deep rooting, in order to use otherwise unavailable water in the soil,
   b. through a temporary diminishing of transpiration,
   c. through a temporary lowering of water content of tissue.

An effort to classify mechanisms of drought resistance in our crops along these lines is shown in Table 6. But this classification does not even do justice to the differences between the crops with respect to behavior under drought.

Moreover, the ability to survive dry conditions may be influenced by methods of cultivation. For instance, in 'establishment' all crops need water but the quantity needed and the urgency of a timely availability is influenced by the size of the parts used for vegetative propagation, the placement above or under ground level and the presence of leaves at planting.

A comparison of agronomic practices is given in Table 7. It is clear that planting of large setts underground without leaves is an advantage under dry conditions. In cassava, the differences in planting methods probably are an adaptation to water conditions.

Only yam may really survive drought for 2-3 months (Onwueme, 1978). The sett may remain dormant; at germination the plant first develops roots and only later its still xerophytic vines. But it is very clear that even such adaptations will not prevent a loss, at least in production per unit time, if compared to optimal conditions.

During 'development of leaf area, shortages of water will at least result in slower growth leading again to a decrease in production per unit time. But results of drought may be somewhat retarded for the deep rooting crops.

The mechanism in cassava to shed its leaves at drought and to resume growth later on is an adaptation to drought. But such an adaptation will result in lower yields, both through a diminishing photosynthesis and the use of reserves from the sink at regrowth.

It is a general belief that in 'starch accumulation,' a slight water shortage is advantageous. Plenty of water would promote vegetative development. The advantage of a slight water shortage probably might be explained by the fact that in drier periods the cloudiness is limited. And, without clouds there usually is more radiation, whereas night temperature tends to be lower.

From the description of the phase of ripening, it is clear that ripening usually is hastened by a water shortage and may be retarded by plenty of water.

A generalized presentation of water requirements and tolerances is given in Fig. 5.

Temperature and Water

In Fig. 6, the data on temperature (Fig. 4) and water (Fig. 5) are combined. Of course the actual value for crop selection for a certain region is very limited. Moreover, the figure only shows the present optimal possibilities and not any possible trend for future development. Despite these limitations, it becomes very clear that ecological competition only exists in a very limited part of the tropics. Most of the crops have their own specialized zone for optimal growth.

pH

A survey of literature on pH requirements is given in Fig. 7. Data on the aroids is rather incomplete. On yams, only one literature statement was found, i.e. that the optimum pH is around 6-7 (Memento, 1974). Coursey (1979) gave his opinion during the conference. Usually, with careful consideration like the publication of Cock & Howeler (1978) on cassava, tolerances widen, in this case to an upper limit of approximately 8, with varietal differences. It is very clear from this survey that further research especially on yams and aroids is badly needed.

Nutrients

The use of plant nutrients will be distinguished into two broad categories: (i) the nutrients taken up in the storage organs: the sink. These nutrients usually are removed from the site of cultivation and thus lost during cultivation. (ii) The nutrients used for production of all other plant parts are immobilized and therefore except for a small amount of fallen leaves not available for recycling during crop growth. The latter, situation is at variance in crops with a longer duration of growth. In plantain leaves and stems nutrients are recycled continuously after the crop is established. The same holds for the leaves of the sago palm.

Nutrient removal. The removal of plant nutrients in the produce harvested of root and tubercrops was estimated by one of our advanced MSc. students through a literature survey (de Blaeis; 1979). His figures were completed for (i) potato by means of the figures of Burton (1966), (ii) plantain by means of the figures given by Montagut *et al* (1965) on banana and (iii) sagopalm by the figures of Woodman *et al* (1931). The figures are presented in Fig. 8. In Table 8 the averages are presented, recalculated on the basis of potassium in the sagoplam pith =10. In Table 8 rice is presented also, for comparison.

The value of the figures is rather limited as they were compiled from all types of research, e.g. studies on value of foods for human nutrition and animal nutrition, also from various studies on plant nutrition. In this first approach, which necessitated evaluation of some 75 literature sources, no attempt was made to weigh the literature. Averages are simply arithmetical, whereas highest and lowest figures are those found in literature, In the higher figures we may have to do with luxury consumption, whereas low values may be caused by underconsumption. Luckily these possible trends are countervalued by the fact that at high production levels plants use the nutrients usually more economical.

Despite these limitations some general trends may be distinguished. The crops remove considerable amounts of plant nutrients from the soil, also if compared to a cereal (Table 8). Their use of potassium reaches a high level. In general, the production of these moisture-rich starchy staples poses a heavy drain on plant nutrients in the tropics and subtropics. The uptake as a percentage of fertilizer production in the tropics and subtropics amounts to 40% for N, 20% for P and 335% for K (Table 9). Here we are faced with a problem that needs attention. For instance, exports of cassava in 1970 from Brazil, Thailand and Indonesia of 4.4 x 10^6 tons included an export of 58 x 10^3 tons of potassium, or 7.25%, of the potassium production in the complete tropics and subtropics. Even if this subject falls outside the scope of this paper, agronomists should be aware of the problem.

Nitrogen contents show a relation to the protein contents (Table 2) as expected. Moreover, the crops where the produce can be used for vegetative propagation, show a nitrogen level of two or three times that of the other crops and approximately the same level as that of rice of which the product also is meant for propagation. This reasoning also holds for phosphorus although either yam is too low or cassava too high.

Mutual relationships between the averages of removal per crop are shown in Fig. 9. Figures and relations are hard to explain. But it should be noted that the results are in accordance with the results of Edwards et al (1977) and Cock & Howeler (1979) on cassava. It is clear that some differences in removal of nutrients exist. The sagoplam appears to be cheapest, in nearly every respect.

Nutrient immobilization

Literature data on immobilization of plant nutrients is rather scarce. And if such studies have been done, they do not follow the same pattern and thus have to be recalculated, which nearly always results in some doubt. Literature found on cassava, banana and sweet potato is presented in Table 10.

It appears that in the root and tuber crops, approximately 35 of N and 65 of K and P is taken up in the sink. The remainder of the nutrients is immobilized in the other plant parts. For N this holds true also for banana, but for P and K only some 25% of the total is taken up in the fruit bunches.

The figures in Table 10 for removal of plant nutrients fall within the limits of Figure 9.

Based on the partition of dry matter in Table 10 and the average nutrient removal figures of Fig. 8, Table 11 was developed, using the top yields of Table 1. Table 11 therefore can be considered to be a first approximation of nutrient removal and nutrient immobilization at a top yield level. In their order of magnitude the figures found roughly agree with actually used fertilizer applications in unrelated experiments e.g. (Plucknett & dela Peña (1971).

Especially with respect to immobilization, important differences exist between the crops. In the root and tuber crops, leaves and stems usually are left in the field after the period of cultivation; stems and leaves decompose and the nutrients return to the soil. This usually happens in a period when the soil is bare. In the high tropical temperatures, decomposition is rapid, which leads to losses of part of the nutrients, especially N and K. The initial investment in such a crop is comparatively low, but largely lost to the farmer.

In banana and even more so in sagopalm, a relatively large amount of nutrients is invested in the crop. But these nutrients are exactly recycled in the crop. In these crops, nutrient needs will approach the nutrient removal through the produce harvested.

We may conclude from Table 10 that considerable differences in nutrient needs between our crops probably exist. These differences are as yet largely unexplained. Further research into this matter is needed, especially because of the continuous rise of energy prices that strongly influence the prices of fertilizer.

The nutrient need per ton of dry matter in product and per day of vegetation in US $ is presented in Table 12.

It appears that, if the investment on sagoplam is calculated with an interest, cassava is the cheapest, whereas sago, taro and yam are at approximately the same level.

One should however, keep in mind that perennial crops in the lowland tropics have the advantage of continuous recycling of organic matter and nutrients. This seems to be more important as permanent annual cropping in the lowland tropics is still an unsolved problem. In this respect, an exception has to be made for taro, under the flooded cultivation as practiced in Hawaii.

Conclusion

In Europe, two types of potato are cultivated (1) a potato for direct consumption and (2) a potato for industrial uses (starch, feed etc.). Distinction among our starch crops along the same lines leads to Table 13.

Ecological competition among our crops is only very limited, as shown in Fig. 6. And in this figure it is not taken into account that the crops differ in duration of growth, which on one hand increases ecological competition but on the other limits it.

Use of nutrients differs also. These differences will become over more important Research on these crops should always include nutritional value.

As energy crops, attention should be paid to cassava and sagopalm. Cassava has the disadvantage of its short duration of growth in connection with the problem of permanent cropping in the tropical lowlands. Sagopalm has the disadvantage of its long juvenile period. But both problems might be solved by research. For sagopalm, it might be possible to harvest in the vast natural stands in southeast Asia and while doing so to change those natural stands into regular plantings. Moreover, the eight years unproductive period might be shortened through a research effort, as was done with oil-palm and rubber.

Taro and sweet potato may offer possibilities as dual purpose crops. Their relatively high protein contents however, may cause difficulties in processing. And the sugar content of sweet potato may pose additional difficulties.

Through research, each of the limitations mentioned may be overcome in principle. But careful consideration is needed whether choice of another crop may lead to the same result.

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Table 1. Comparison of high experimental yields and average world production in 1974 of moisture-rich starchy staples.

Literature reference	Reported high yield	% edible	Kcal per kg	High prod. in Kcal. $ha.^{-1}$, day^{-1} of vegetation	Average world production (1974)	Average prod. in Kcal ha. $^{-1}$ day^{-1} of vegetation
Cassava CIAT 1969	100 tons in 305 days	83	1530	416	9.2 tons in in 330 days	35
Sweet Potato IITA 1976	43.1 tons in 122 days	88	1140	354	9.2 tons in 135 days	68
Taro Plucknett et al 1971	128.7 tons in 365 days	85	1130	339	5.4 tons in 120 days	43
Sagopalm Flach 1976	25 tons waterfree starch in 365 days	100	4000	275		
Yam Rehm & Espig 1976	60 tons in 275 days	85	1040	193	9.8 tons in 280 days	31
Banana Purseglove 1972	75 tons in 365 days	59	1280	155	12.5 tons in 365 days	26

*After FAO-statistics.

Table 2. Comparison of composition[1] of moisture-rich starchy staples

	Cassava	Sweet Potato	Aroids	Yam	Potato	Sago[2] Palm	Plantain	Rice
Kcal per 100 g fresh product	153	114	113	104	75	76	128	350
Dry matter content of % fresh product	40	30	30	27	20	20	33	88
% Carbohydrates on D.M.	92.5	85.5	85.8	88.8	85.0	92.5	93.0	88.6
% Protein on D.M.	1.8	5.0	6.6	7.4	10	1.5	3.0	8.0
% Fat on D.M.	0.5	1.0	0	0.7	0	0.5	0.6	1.7
% Fiber on D.M.	2.5	3.3	1.7	1.9	2	1.5	0.9	0.2

[1] Calculated by Platt (1962)

[2] By LIM (1967)

Table 3. Distribution of production of the main starchy staples over the main climatic zones in relation to the population of these zones[1]

	Total production			% Of total production			
	10^6 tons	4.2 10^{12}KJ or 10^{12} Kcal	% of energy	In mainly trop. and sub. trop. countries		In other countries	
				in weight of crop	in energy of total	in weight of crop	in energy of total
Potato	134	208.4	40.7	4.5	1.8	95.5	38.9
Sweet Potato	134	134.4	26.3	12.8	3.4	87.2	22.9
Cassava	103	130.8	25.6	99.3	25.4	0.7	0.2
Yam	20	17.7	3.5	99.3	3.5	0.7	0.0
Aroids	4	3.8	0.7	89.6	0.6	10.4	0.1
Plantain	18	13.9	2.7	100	2.7	0	0
Sagopalm[2]	3	2.4	0.5	100	0.5	0	0
Total	579	511.4	100	–	37.9	–	62.1
Population	4.10^9			1.9×10^9		2.1×10^9	

[1] FAO Statistics

[2] Own rough estimate

Table 4. Growth of the starchy staples

Crop	Sink	Duration of growth in weeks and in percentage of total					Vegetative propagation by means of
		establishment	development	quick starch accumulation	ripening	total	
Potato	Stem Tuber	2 wks 15%	3 wks 23%	6 wks 46%	2 wks 15%	13 wks 100	Tuber– (Parts)
Sweet Potato	Root Tuber	1 wk 4%	4 wks 17%	18 wks 78%	?	23 (?) wks 100	Stem– (Parts)
Yam	Root Tuber Stem Part	6 wks 13%	11 wks 24%	14 wks 31%	14 wks 31%	45 wks 100	Tuber– (Parts)
Aroids	Root Tuber with Stem Part	3 wks 9%	5 wks 16%	8 wks 25%	16(?)wks 25%	32(?) wks 100	Tuber– (Parts)
Cassava	Tuberous Root	4 wks 10%	13 wks 30%	25 wks 60%	(?)	42(?) wks 100	Stem– (Parts)
Sagopalm[1]	Stem	14 wks 4%	90 wks 22%	300 wks 75%	150 wks	400 wks 100	Suckers
Plantain[1]	Fruit	4 wks 8%	30 wks 62%	12 wks 25%	2 wks 4%	48 wks 100	Suckers

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[1] first crop; in the following crops the phase of establishment and development coincide with rapid starch accumulation.

Table 5. Estimated duration of each phase at a high level of production

	Establishment	Development	Quick Starch Accumulation	Ripening
Sweet Potato	1 week 6%	4 weeks 24%	12 weeks 70%	
Yam	6 weeks 15%	11 weeks 28%	8 weeks 20%	14 weeks 36%
Taro	3 weeks 6%	5 weeks 9%	44 weeks 85%	
Cassava	4 weeks 9%	13 weeks 30%	26 weeks 61%	
Sagopalm	14 weeks 4%	90 weeks 22%	300 weeks 74%	(150 weeks)
Plantain	4 weeks 8%	30 weeks 62%	12 weeks 25%	2 weeks 4%

Table 6. Mechanisms of drought resistance

Crop	End growth (1)	Survive water shortage through		
		Deep rooting (2.1)	Diminishing transpiration (2.2)	Lowering of water content (2.3)
Yam	X	X	X	–
Cassava	(X)	X	X	–
Sweet potato	(X)	X	–	–
Potato	(X)	–	–	–
Aroids	(X)	–	–	–
Sagopalm	–	–	–	–
Plantain	–	–	–	–

Table 7. Survey of agronomic practices for vegetative propagation

Crop	Size of setts	Placements of setts	Leaves present
Yam	Large	underground	none
Cassava	medium	in drier conditions underground	none
Sweet potato	small	above ground	present
Potato	large	underground	none
Aroids	large	partly underground	partly present
Sagopalm	very large	largely above ground	present
Plantain	very large	largely above ground	present

Table 8. Comparison of average removal of plant nutrients in produce harvested, calculated for potassium in sago palm pith = 10

CROP	N	P	K	produce used for vegetative propagation
Potato	28	4	39	yes
Sweet potato	16	4	21	yes
Aroids	24	5	41	yes
Yam	21	3	27	yes
Cassava	8	3	24	no
Plantain	10	1	29	no
Sago palm	6	1	10	no
Rice	26	5	6	yes

Table 9. Average removal of plant nutrients as compared with fertilizer production with plant nutrients in the same region in 1974 (x 10^6 ton)

	TROPICS AND SUBTROPICS		OTHER	
PRODUCTION	177.2		334.2	
	REMOVED	PRODUCED	REMOVED	PRODUCED
N	1.6	4.1	3.0	38.2
P	0.3	1.4	0.5	9.8
K	2.7	0.8	5.1	18.9

Table 10. Estimate of the uptake of major plant nutrients as divided over plant parts in cassava, banana and sweet potato

CROP		CASSAVA 14 months				BANANA 10 months			SWEET POTATO 65 days		
		calculated after NIJHOLT ((1973)				calculated after MONTAGUT et al (1965)			calculated after TSUNO (1968)		
Plant Parts		Roots	Stems	Leaves	Total	Bunches	Stems & Leaves	Total	Tubers	Stems & Leaves	Total
Tons fresh		64.5	41.9	4.2	110.6	40	48.5	88.5	–	–	–
% of D.M.		25.8	18.8	15.5	22.7	22	18	19.8	–	–	–
D.M.	tons	16.6	7.9	0.6	25.1	8.7	8.8	17.5	7.8	5.5	13.3
	%	66.1	31.5	2.4	100	50	50	100	58.6	41.4	100
N	kg	45.2	60.5	18.7	124	80	170	250	31.2	58.3	89.5
	%	36.3	48.6	15.0	100	32	68	100	35	65	100
P	kg	28.1	15.2	1.9	45.2	7	19	26	10.2	9.1	19.3
	%	62.1	33.6	4.2	100	27	73	100	53	47	100
K	kg	315.5	158.6	10.6	484.7	200	630	830	84	44	128
	%	65.	32.7	2.2	100	24	76	100	66	34	100

Table 11. Estimate of removal and immobilization per ha of plant nutrients at top yield level

Crop	Useful D. M. in tons	Duration of growth (days)		% In sink D.M.	Total in sink kg	% In other D.M.	Total in other plants parts (kg)	Total nutrients (kg)
Cassava	40	305	N	35	180	65	335	515
			P	65	60	35	32	92
			K	65	540	35	292	832
Sweet Potato	12.9	122	N	35	113	65	211	324
			P	65	36	35	20	56
			K	65	148	35	80	228
Taro	38.6	365	N	35	521	65	969	1490
			P	65	116	35	63	179
			K	65	895	35	484	1379
Yam	16.2	275	N	35	188	65	350	538
			P	65	23	35	13	36
			K	65	243	35	131	374
Sago Palm (fully grown)	37.6	365	N	50	128	50	128	256
			P	35	19	65	35	54
			K	35	211	65	392	603
Plantain	24.7	365	N	35	141	65	262	403
			P	25	15	75	44	59
			K	25	398	75	1193	1591

Table 12. Nutrients needed per day of vegetation and per ton of dry matter product, calculated at world market prices 1978 (N 0.60; P 1.70; K 0.40 US $/kg).

Crop	N	P	K	Total
Cassava	2.5	1.3	2.7	6.5
Sweet potato	12.4	6.0	14.5	32.9
Taro	6.4	2.2	3.9	12.5
Yam	7.3	1.4	3.4	12.1
Sago*	1.1	0.7	1.8	3.6
Plantain	2.7	1.1	7.1	10.9

*sagopalm without slowly increasing, but completely recycled, investment over 8 years of N 614,= P 367, =K 965, = Total 1946,= US $ (interest not calculated in).

Table 13. Comparison of quality for different purposes of the main moisture rich starchy staples

FRESH FOOD	(FOOD) ENERGY (STARCH)
1 *Quality*	1 *High Production* Per Unit
Protein content Palatability Taste	of surface, time, labor, input
2 *Storage Quality*	2 *Easy Harvesting*
3 *High Production*	*3* *Easy Processing* e.g. Low Protein Content
	3 *Starch Quality*
FRESH FOOD CROPS	ENERGY CROPS
Yam Irish Potato Plantain	Cassava Sagopalm
DUAL PURPOSE CROPS	
TARO (AROIDS) SWEET POTATO	

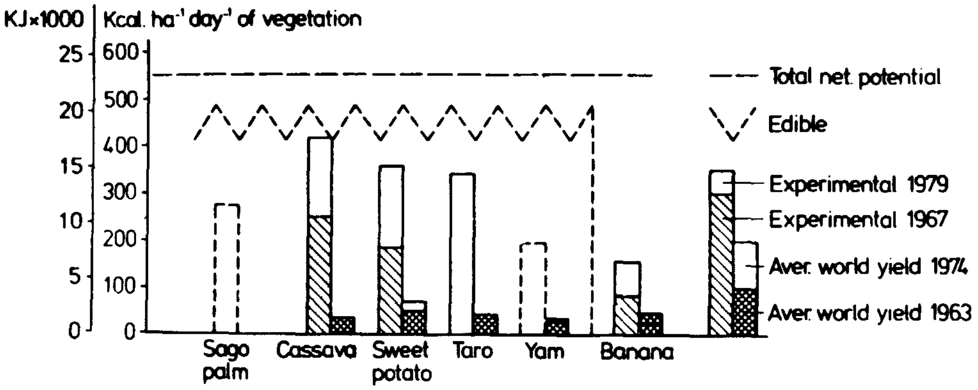

Fig. 1. Average world yields (1963 and 1967), maximum yields obtained in experiments (1967 and 1979) and potential production of both dry matter and edible dry matter in KJ (Kcal) per hectare and per dry of vegetation. For sagopalm an experienced good farmer's yield is given; for yam, an estimate

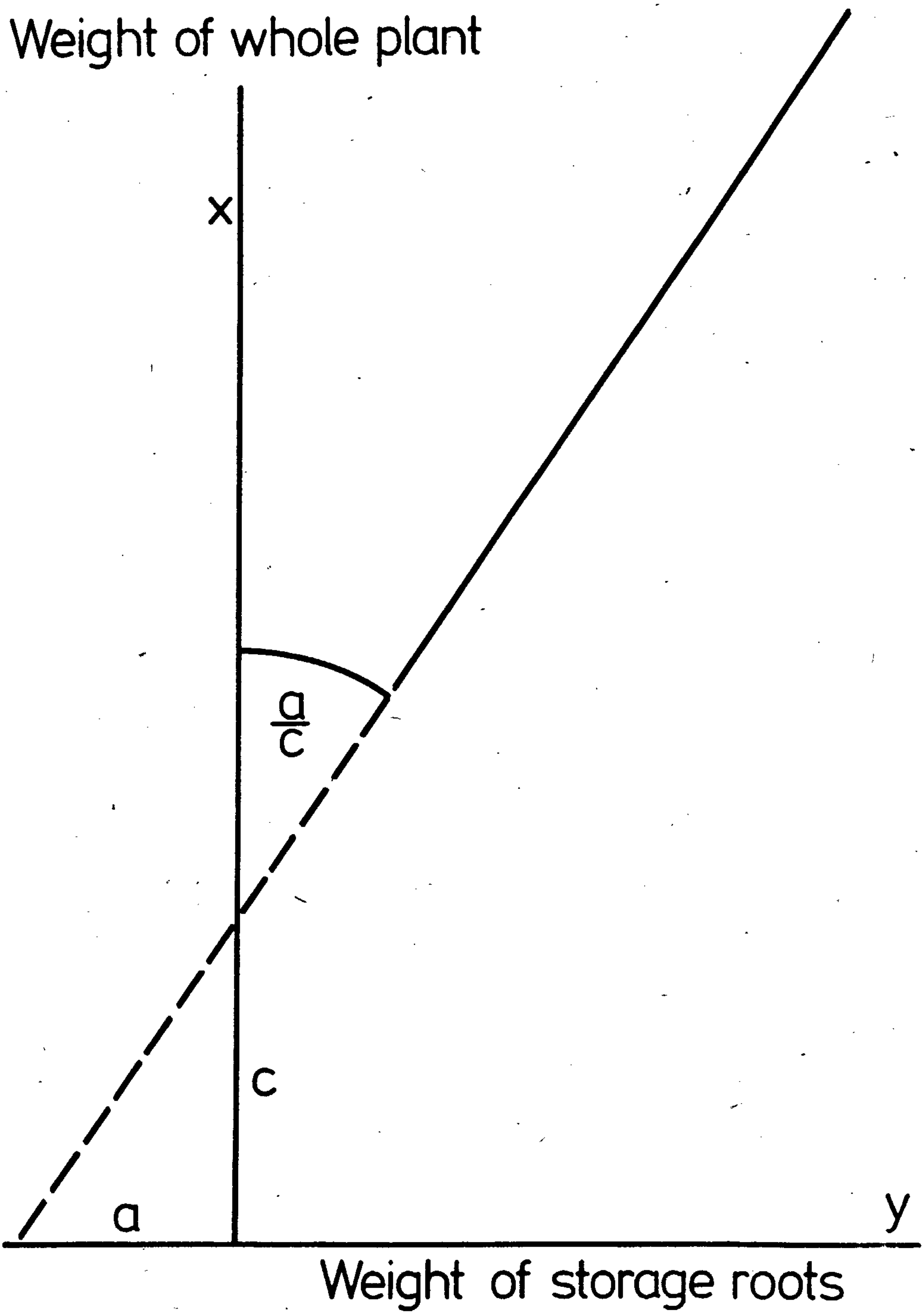

Figure 2. Partitioning of dry matter in cassava after Boerboom (1978)

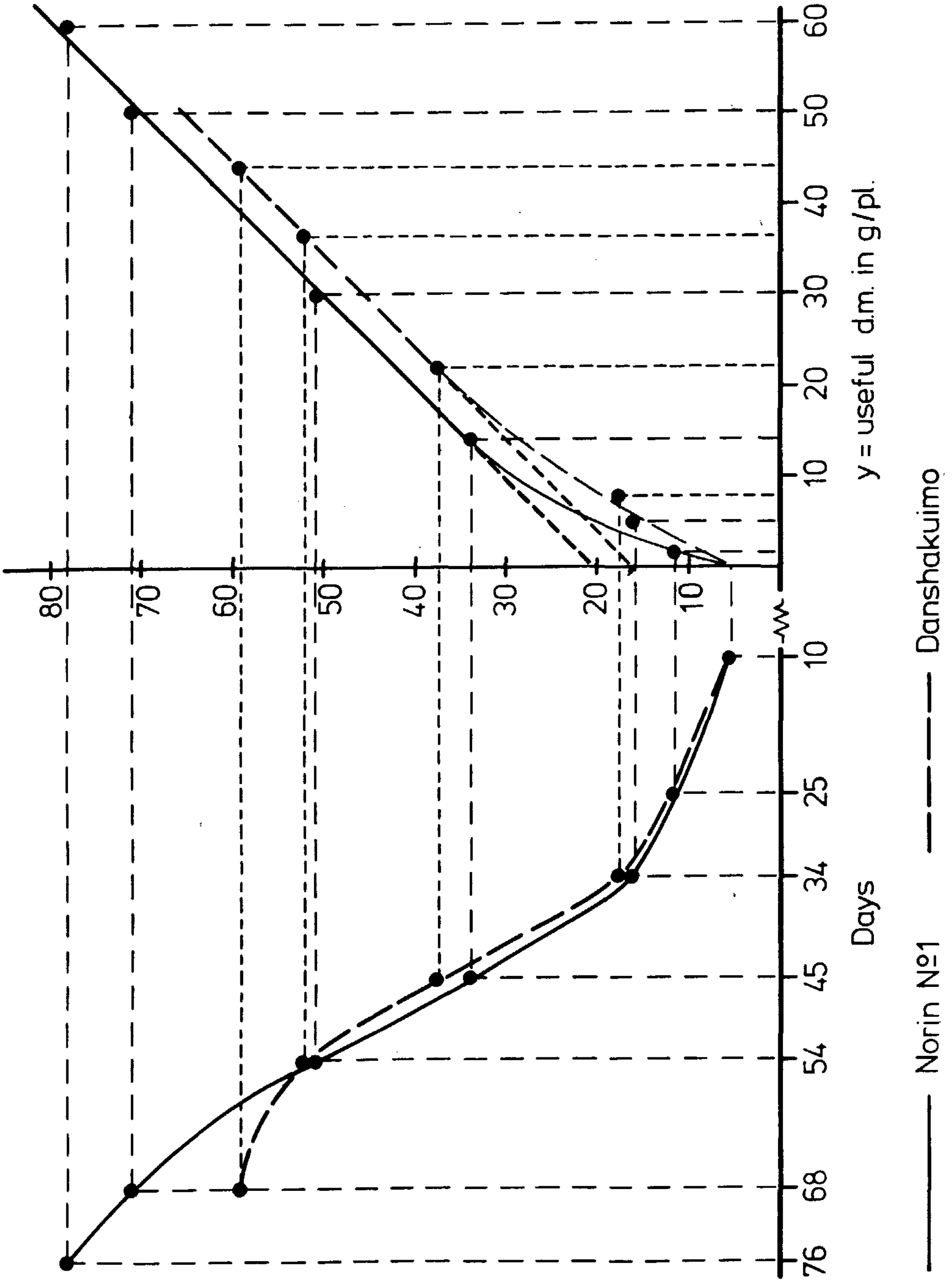

Figure 3. Partitioning of dry matter in sweet potato and irish potato as derived from data of TSUNO (1977), as related to dry matter production per unit of time

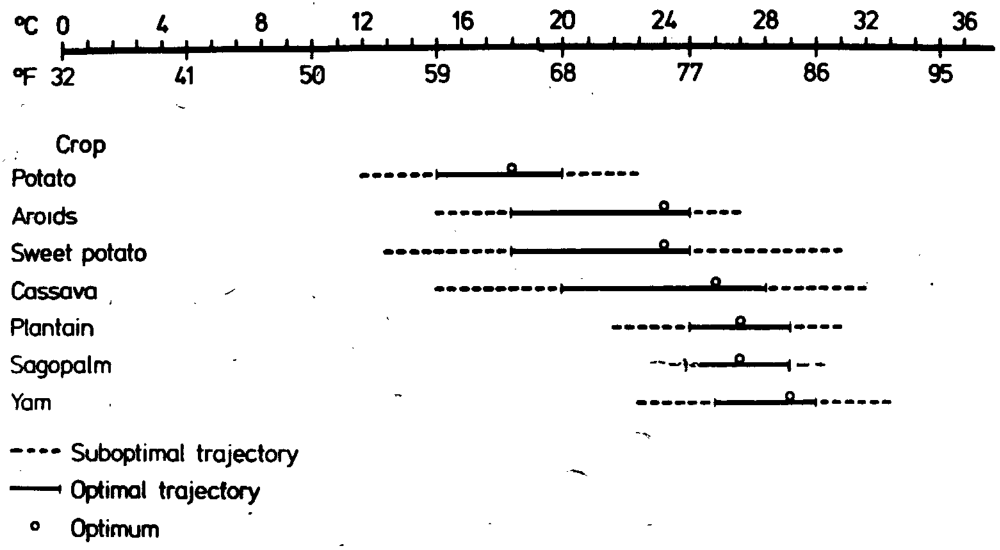

Fig. 4. Temperature ranges of the moisture-rich starchy staples

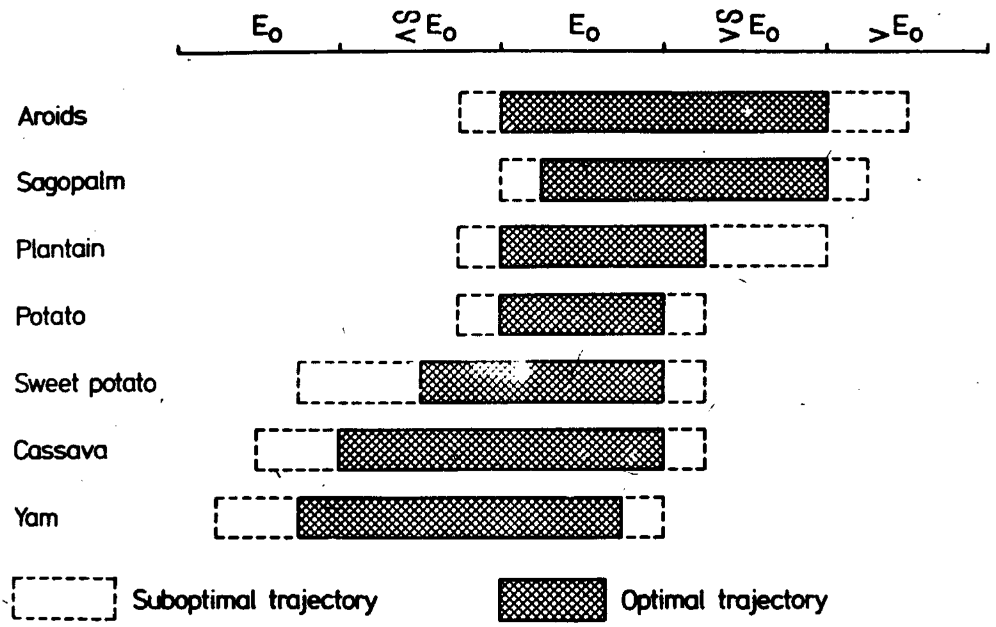

Fig. 5. Qualitative comparison of water requirements and tolerances of the moisture-rich starchy staples

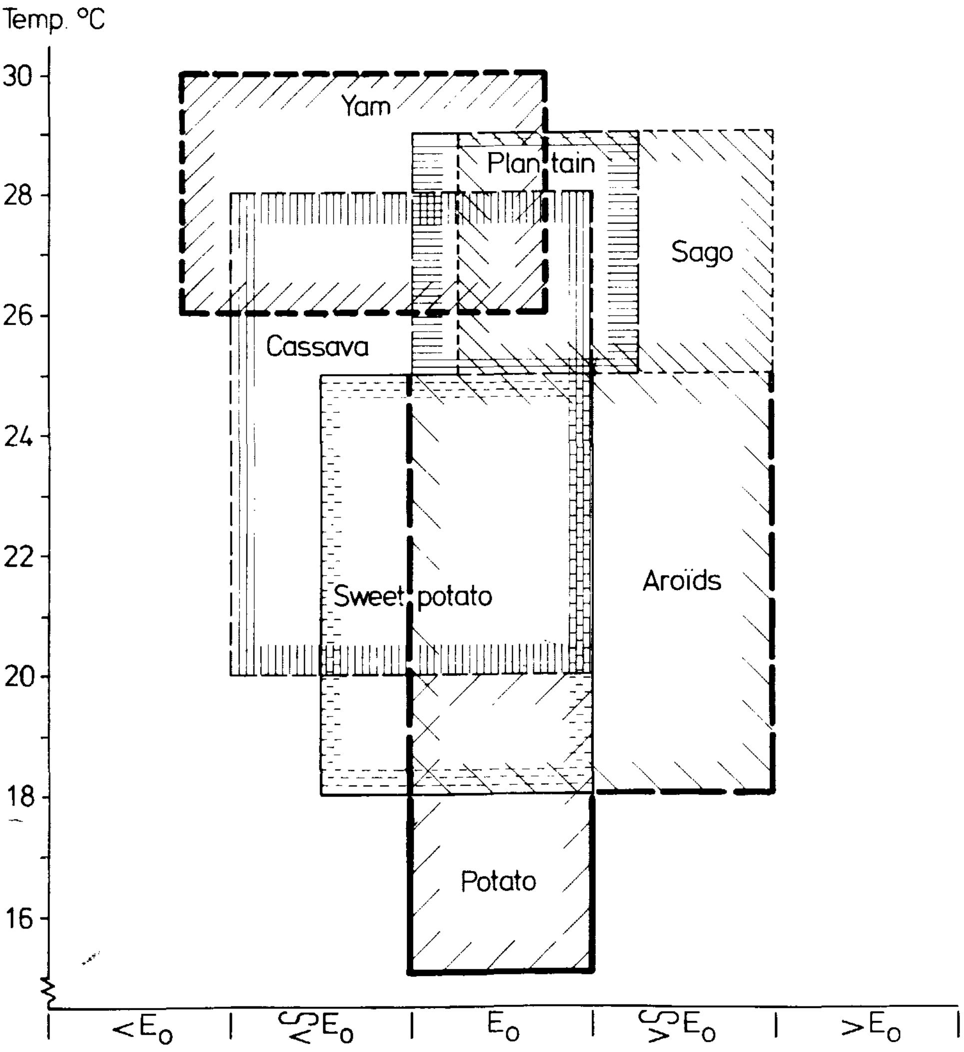

Figure 6. Combination of water requirements and temperature for optimal growth

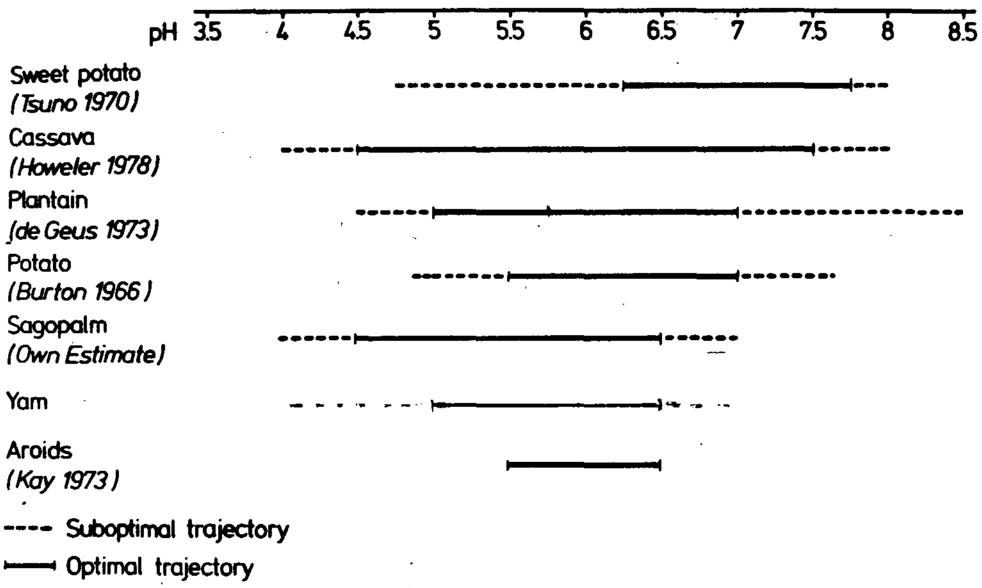

Fig. 7. pH ranges of the moisture-rich starchy staples

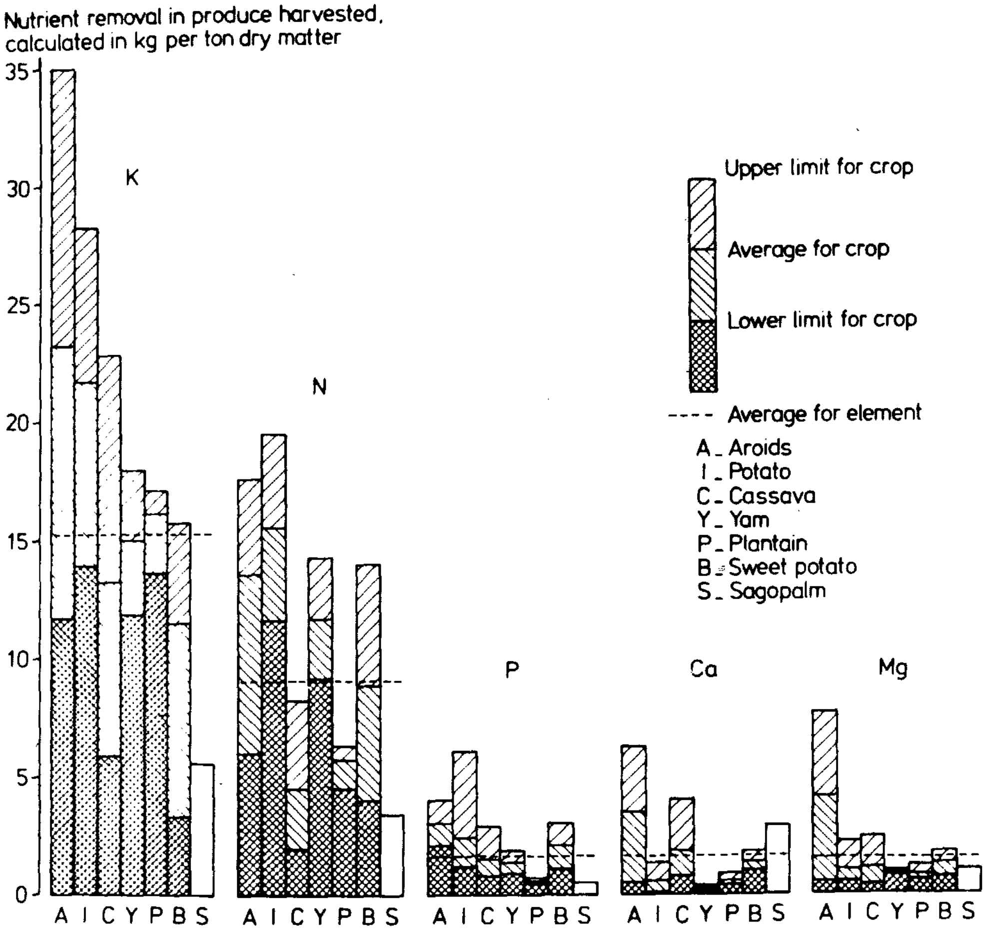

Fig. 8. Plant-nutrients removed per ton dry matter in product

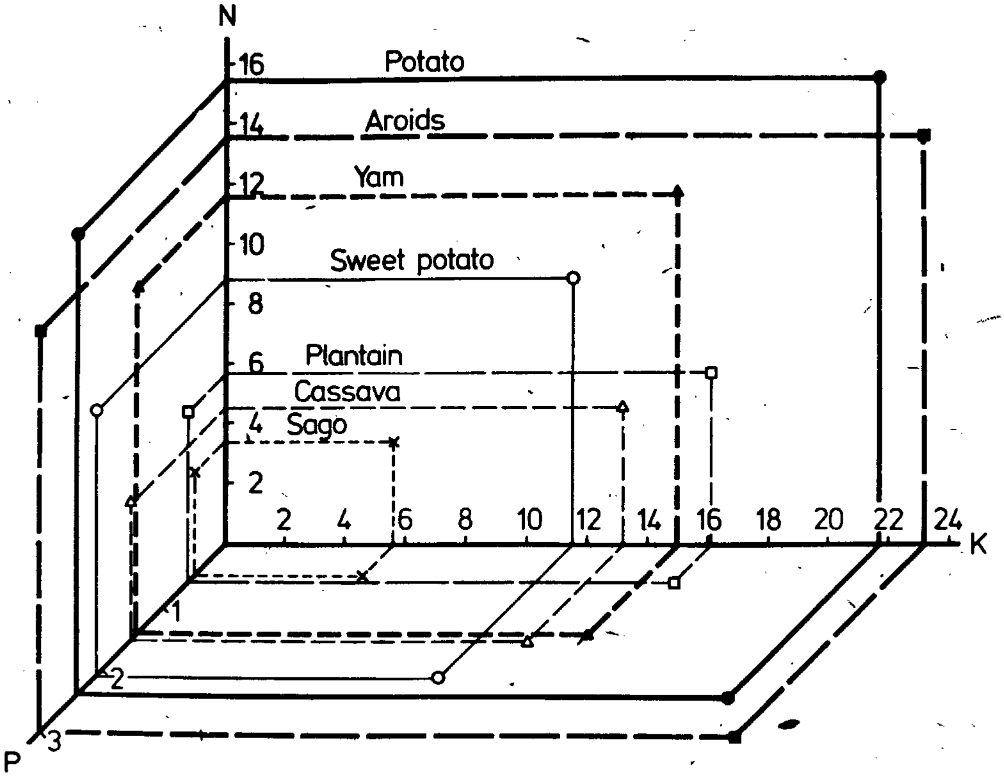

Fig. 9. Relation between nitrogen (N), phosphorus (P) and potassium (K) in plan