THE SWEET POTATO IN SUBSISTENCE AGRICULTURE

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ABSTRACT

It is generally accepted that the sweet potato (Ipomoea batatas *(L.) Lam.) originated in the Americas and was transported westwards across the Pacific, but there is as yet no firm evidence as to when or how it was introduced into Papua New Guinea.*

The significance of sweet potato varies according to an ecological partitioning of Papua New Guinea into six natural regions, but taking the country as a whole, it is quantitatively the most important crop in subsistence agriculture.

A very wide range of morphological variation has been found to exist. Propagation, maintenance of gardens and harvesting are, with some exceptions, similar in all regions, but there are notable differences in mixed cropping practices and methods of land preparation, especially in the broad intermontane valleys of the main cordillera.

Storage practices are not well developed, as there has generally been no necessity for this, and aspects of cooking and eating quality are fairly uniform throughout the country. As a subsistence crop, the sweet potato is relatively free of pests and diseases, though there are some exceptions.

Sweet potato plays a major role in maintaining the domestic pig population and because of this it is important in the accumulation of wealth and in the establishment of prestige in subsistence social systems.

INTRODUCTION

This article is based upon a survey by mailed questionnaire and of relevant literature, together with information from the author's field studies, of sweet potato (*Ipomoea batatas* (L.) Lam.) cultivation in subsistence agriculture in Papua New Guinea. The survey was carried out in order to obtain background material from as many localities as possible, to assist in agronomic research into the crop. In the mailed survey details were obtained from almost 60 localities, and these are listed and mapped in Appendix 1. The localities cover all the main climatic variations in the country.

Some of the information is only incidental to agronomic research, but it provides material which is essential to the understanding of a plant which is of major importance in subsistence agricultural systems and which has wider potential as a cash crop. Other staple foods, such as bananas (*Musa* spp), yams (*Dioscorea* spp.), taro (*Colocasia esculenta*), *Xanthosoma* spp. and cassava (*Manihot utilissima*) may be almost as widespread as sweet potato in subsistence agriculture, but none of them has assumed the role of a main staple for as many people as has sweet potato and none of them has reached the altitudinal limit of sweet potato. There are other crops, notably some cereals and other root crops, which could extend the limits of subsistence farming, especially when one considers altitude, but these have been unknown to the people until relatively recent times. So far they have had comparatively little impact on subsistence agricultural patterns.

The following table gives some idea of the quantitative importance of the various staples in subsistence agriculture in Papua New Guinea

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(*Table* 1). It is extracted from the "Survey of Indigenous Agriculture and Ancillary Surveys, 1961-62", carried out by the Bureau of Statistics (1963). This contains the only comprehensive information which is at present available, and although not very recent, the situation has probably changed very little since the survey was made.

Crop	Papua New Guinea		Papua New Guinea
Bananas (*Musa paradisiaca* and *M. sapientum*	160	460	620
Taro (*Colocasia esculenta* and *C. antiquorum*	93	224	317
Xanthosoma spp.	10	138	148
Yams (*Dioscorea* spp.)	92	144	236
Cassava (*Manihot utilissima*)	16	37	53
Sweet potato (*Ipomoea batatas* (L.) Lam.)	241	979	1220

Evidence from the questionnaire shows that subsistence gardening is changing in many areas. The most widespread changes are, of course, caused by the introduction of cash crops, but there are other changes, caused by more widespread and more frequent communications, resulting in an exchange of knowledge and planting material. Allied with this is the adaptability of the sweet potato. Massal and Barrau (1956) say that throughout the South Sea Islands generally, sweet potato is becoming more important in indigenous agriculture because it is easy to grow and it grows rapidly, compared to most other traditional staple food crops. In addition it is a comparatively high yielder and can be progressively harvested, thus eliminating the need for lengthy storage. All of these factors allow more time to be devoted to cash cropping or to outside employment.

The survey has shown that as a general rule, there is no ritual associated with the cultivation or consumption of sweet potato, a feature which contrasts with other subsistence crops such as yams or taro.

ORIGIN AND VARIETIES OF SWEET POTATO IN PAPUA NEW GUINEA

The introduction of all parts of the sweet potato plant into Papua New Guinea is prohibited (Plant Quarantine Regulations). Some years ago, a number of varieties were officially introduced from the United States of America, for testing and crossing with local types. The well-known American varieties 'Nancy Hall' and 'Puerto Rico' were reported to have been introduced into the Zenag area in 1945 (Massal and Barrau 1956).

Most evidence supports an east-west movement of sweet potato from the Americas, where it is thought to have originated, into the Pacific (Dixon 1932; Brass 1941; Barrau 1958; Conklin 1963; Nishyama 1963; Yen 1963). In those studies historical, lexical, botanical and cytological evidence is presented.

There are various ideas regarding the mode of introduction into Papua New Guinea and in discussing this it is often necessary to discuss also the time of introduction. Massal and Barrau (1956) say the most plausible theory is that the sweet potato was introduced recently from Indonesia whence the Portuguese had brought it. Yen (1963) concludes from botanical evidence that it is unlikely that the sweet potato was introduced from Polynesia. The mode of introduction into the Highlands*, where it is the most important subsistence crop, is unknown, but suggestions would be along trading routes known to have been kept free of internecine warfare, or even through the migrations of people. Such migrations have been suggested, largely on botanical evidence (Robbins 1963).

The question of the time of introduction of sweet potato into Papua New Guinea is of major ethnological importance in view of the theory of what might be termed a quite recent social and cultural revolution in the Highlands, following the suggested appearance of sweet potato between two hundred and three hundred years ago (Bulmer, S. and R. 1964; Watson 1965a, 1965b). The subject is somewhat controversial and is beyond the purpose of this article to examine in detail, except for recording the need for further evidence from other fields of study. For example, a study of the linguistic evidence on the origin and varieties of sweet potato would be of value, especially if done in conjunction with an investigation on morphological variation.

* Highlands in this article refers to the valleys and mountains of the main cordillera of Papua New Guinea.

It would appear from the present survey that people in Papua New Guinea often think of sweet potato as being native to their area. In other cases, however, people remember where sweet potato came from, and when, its appearance in these cases usually being associated with Christian missions, or with German, Japanese or Angau administrations. Unfortunately the evidence is not always clear, however, whether informants are talking of sweet potato in general, or of particular varieties.

On the basis of the limited collection of sweet potato varieties at Aiyura (about 300 in all) it is evident that many areas in former times had varieties distinct from those in neighbouring areas. Many of these varieties are now being replaced by a more limited number which are finding more popular acceptance over larger areas.

The ability of sweet potato to set seed under local conditions was first reported by Yen (1963). The germination of seed in the field has been found by the author to occur frequently, indicating that the vegetative propagation of chance seedlings in subsistence agriculture could lead to the appearance of new varieties in a relatively short period of time, even allowing for discriminatory selection by the propagators. It is also possible that bud mutation, common in the sweet potato plant, has been a source of varieties in the many isolated valleys of Papua New Guinea.

Some examples of the existence of a number of sweet potato varieties in various areas are worth mentioning. The people of the Lake Ipea area recognize 13 distinct types, 11 of which they knew before European contact (Walker 1966). The Enga people of the Western Highlands District recognize at least 31 different kinds, 25 of which they believe are indigenous to the region (Meggit 1960). Brookfield and Brown (1963) record the people of the Chimbu as growing at least 30 varieties.

In the Aiyura collection the most noticeable variations are in the leaf shape (*Plate* I) hairiness of stems, pigmentation of leaf veins and of stems and pigmentation of skin and flesh

Plate I.—A representative range of leaf shapes of sweet potato in Papua New Guinea

Plate II.—Some variations in tuber shape and size and of pigmentation of skin and flesh. The varieties are, left to right, beginning from the top: Yakat, Baromba, Nama; Bonangen, Hagesafa, Ngulugu; Domambo, Pora, Markham; Wanmun, Conmayam, Kia

(*Plate* II). Most of this variation is not very significant from an agricultural point of view, but in initial observation plots the variation in tuber shape and size and especially also in yield, have been found to require further investigation.

SUBSISTENCE AGRICULTURAL ENVIRONMENTS

Subsistence agriculture in Papua New Guinea is based upon the production and consumption of the starchy staples sweet potato, yams, bananas, sago, taro and cassava. Depending on the environment and with the exception of cassava, one of these becomes the main staple, with the others assuming varying degrees of secondary importance. The diet is otherwise supplemented by sugar-cane and by various greens and pulses (Conroy and Bridgland 1947; Massal and Barrau 1956; Barrau 1958).

The natural regions, as given by Barrau (1958) are used as a basis in this study and they are given in Appendix II, slightly modified, together with examples and along with other details relevant to this study. Barrau's scheme is very broad so as to accommodate conditions in Melanesia as a whole and in the present modifications, one of his regions, 'Rainforest foothills and mountain ranges', has been divided into 'Rainforest lowlands and foothills' and 'Lower montane forests'. They have been separated because the survey shows that it is at about the lower level of the lower montane forest that sweet potato becomes the most important staple in the subsistence economy. The natural regions used here are, therefore:—

1. Non-swampy coastal areas;
2. Swampy lowlands;
3. Grassland, scrub, savanna and savanna woodland;
4. Rainforest lowlands and foothills
5. Lower montane forest; and
6. Inter-montane valleys of the main cordillera.

In environments 1 to 4 it is unusual to find any one staple comprising as much as 50 per cent of the bulk of the diet and in many areas two staple root crops, or even three, may assume equal quantitative importance. In environment 5 sweet potato is the main staple. In environment 6, sweet potato never provides less than 50 per cent of the bulk of the diet and can provide over 90 per cent. The proportions mentioned are estimates only, but their magnitude serves to emphasize the role of sweet potato in subsistence agriculture in Papua New Guinea.

In environments 1, 2, 4 and 5 all subsistence gardening is characterized by a slash and burn technique, short cropping periods and a long bush fallow. A particular subsistence technique can therefore be used to advantage in a number of environments, but it is the environment, including population pressure, which will determine which crops are grown from those available. The scheme as presented here is intended only as a means of establishing the importance of sweet potato in relation to the environment and for this reason the environment has been considered more important as a basis to the study than the type of subsistence agriculture. As in all such schemes, there will always be buffer areas between sharply contrasting natural environments, but this does not detract from the importance of the main divisions.

CULTIVATION OF THE SWEET POTATO

Grown in each of the natural environments, sweet potato can also be found grown over a wide range of soil types (Haantjens *et al* 1967). Soil type is not a limiting factor to growth, as provided sufficient free-draining top-soil is available, the sweet potato plant will usually produce a reasonable crop. Where the top-soil layer is shallow, sufficient is usually provided by the practice of mounding, which also assists drainage requirements.

As with other subsistence crops, sweet potato can be grown all the year round in Papua New Guinea. In all environments there is only a minor seasonal temperature variation throughout the year, and with certain exceptions, rainfall is not limiting. The exceptions are environment 3 and the Bena-Korofeigu area of environment 6, where rainfall is very limited for a certain period each year.

Irrigation of sweet potato has not been documented and if it occurs must be very rare. Mulching also is rare, though weeds may be left lying on top of the ground once they have been pulled.

The remainder of this section on cultivation of the sweet potato has been divided into separate subheadings dealing with the various aspects of propagation, preparation of land, maintenance, harvesting and yields and finally, relationships with other crops.

Propagation

Propagation is universally from vine cuttings because, it is said, of the ease with which they strike and the rapidity of their development. Tubers may be used for propagation when new varieties are brought into an area, or when cuttings are in short supply. They are first sprouted and the sprouts either broken off when they are long enough for planting, or a piece of tuber may be cut off with the sprout still attached, and then planted. The only case of propagation from seed was in environment 4 in the Gazelle Peninsula, New Britain, where seed may apparently be the medium of bringing in new varieties. It is not certain, however, whether it is known by the people that the sweet potato is a cross-pollinating plant and that an established variety cannot therefore be propagated from seed. The use of seed in this case could well be an innovation since European contact. Apart from variability of seedlings, the reasons for seed not being used as a means of propagation include low germination, difficulty of collection and time needed for establishment.

Cuttings are almost always taken from the apical portions of the vines, but lengths of ordinary stem may be used if apical portions are in short supply. When this occurs, cuttings which have a new shoot in a leaf axil are preferred. Apical portions are generally recognized as giving quicker establishment and an earlier yield. In environment 2 this is not often recognized and preference is not always made. Cuttings vary in lengths, but the usual is around 30 cm.

There is widespread recognition of the desirability of taking cuttings from mature plants only. The reasons are that cuttings from immature plants are liable to die or strike more slowly after planting. Taking cuttings from immature plants is also thought to lower the yield of the plants from which they were taken. The truth of this would depend on the stage of growth of the plant and severity of pruning for removal of cuttings. There are usually no objections to taking cuttings from plants which are in the process of being harvested and this is often done, as one can see the crop, and cuttings can then be selected from individual plants according to their yield of tubers.

Cuttings are mostly planted straight away, but if convenience dictates, they may be left for up to a week. If pre-treatment of cuttings is carried out, it is always to promote the initiation of adventitious roots. This may be done by leaving the cuttings in a heap in the shade and covered with grass and banana leaves. At Yanyi village in the Lae Highlands and in places in the Wonennara Subdistrict of the Eastern Highlands, one practice is to place cuttings in a shallow pool of water for a few days to initiate roots, but this practice is not widespread. As a rule, such pre-treatment practices are not regarded as essential.

There is widespread variation in the depth of planting, from about 6 cm to as deep as 30 cm or more in some cases. The most widespread is about 6 to 15 cm. There are various reasons for the planting depths adhered to, as no doubt they are best thought to suit local conditions of climate, soil and drainage. However, there is widespread recognition in most environments that planting too deep reduces yield and makes tubers hard to harvest, while planting too shallow exposes cuttings to drying out, reduces successful establishment and results in smaller tubers and reduced yield. There is a tendency to plant at shallower depth in heavier soils than in lighter soils, no doubt because the latter dry out more quickly.

All angles of planting are employed, from horizontal to vertical. The usual is between 30 and 60 degrees from the horizontal. Proponents of planting at 60 degrees and below are usually quite firm in their belief that these angles promote a more even spread of tubers and increase yields. Followers of vertical planting, however, though not so numerous, also believe their method to increase yields.

In all environments, cuttings may or may not be bent underground. Bending, if practised, is usually carried out by simply placing the

underground portion of the stem in an horizontal position and curving it at an angle as it protrudes from the soil. Where cuttings are bent underground like this, the reason is always said to be to promote greater tuber growth from a greater number of nodes. Where bending of cuttings is not practised, the usual reason given is to avoid their rotting.

The usual number of cuttings per planting point lies in the range two to five. In environment 1 it is sometimes only one cutting, but in other environments it can be as many as eight to ten. The reasons given for planting a number of cuttings are to obtain a greater number of tubers per planting position and as an insurance against some not striking. This is often evidenced by more being used in the dry season than in the wet season. In many cases, however, it is an obvious overinsurance and its value in increasing yields is very doubtful, yet it is often believed in all environments that more than one cutting per hole will increase yields. An additional reason, however, is to obtain a quick ground cover. Only in environment 6 is one cutting per planting point more widely used, a practice which no doubt is followed because of the ability of sweet potato to maintain fairly constant yields over a wide range of plant density.

Preparation of Land

The ability of sweet potato to yield good crops in a range of environments has been assisted by the use of horticultural methods developed by subsistence gardeners. This mainly involves earth-moving to assist drainage and tuber development, usually by forming mounds, and where so-called 'hot-beds' are used, at higher altitude, to create a soil temperature more suitable to growth.

In environments 1 to 5, mounds may or may not be used, but where they are used there is almost always an appreciation of their value in increasing yields. In each of these environments, the range in size of mounds appears to be fairly constant. They may vary from about 25 to 90 cm in diameter and from between 15 to 40 cm high (*Plate* III). Wherever mounds are used in environments 1 to 5 the main recognition of their function is in providing good drainage for the crop, but they are also useful in making harvesting easier. In many cases in environment 2, the use of mounds is a recent innovation. Where mounds are not used, the soil is merely loosened before the cuttings are inserted into the ground, a typical slash and burn subsistence practice. However, it is also often recognized that one can vary

Plate III.—Shown in the foreground are sweet potato cuttings planted in mounds of a size common in environments 1, 2, 3, 4, and 5 (see Appendix II)

practice according to soil type. If the soil is loose and friable, a reasonable production can be obtained without going to the trouble of forming mounds. In isolated instances where mounds would obviously give an improvement in yields, their value is not recognized. For example, at Yoliapi village in the Telefomin Subdistrict, where soil profiles are dominated by a very shallow top-soil and by a heavy clay subsoil, mounds are not used and although a soil loosening technique may be employed, it is no different to that of growing other food crops. At Ketskets in the Buka Passage Subdistrict on Bougainville, where sweet potato is planted both on flat ground and in mounds, the former is said to produce a quicker crop than the latter. At Timini village, in the Mumeng Subdistrict of the Morobe District, there are initially no mounds, but during growth soil is heaped up to about 15 cm high to cover developing tubers. This practice is probably also followed elsewhere.

Digging sticks are still widely used in all environments, mainly to break the soil down to a finer tilth than is possible with a spade, should this be needed. The spade is, however, universally used, and it is the main implement in ground preparation. It has been instrumental in environment 6 in encouraging the drainage and cultivation of fertile areas which previously could not be used for cultivation because of excess moisture.

One often finds that where sweet potato is the dominant staple, planting may be carried out in established gardens throughout the whole year and new gardens are prepared just before the beginning of the wet season. In most areas of environment 6, therefore, there is a tendency to seasonal activity, with clearing, burning and land preparation reaching a peak late in the dry season and with wet seasons marked by lower activity, mainly harvesting, maintenance and replanting.

The preparation of land in environment 6 is distinct from that in all other environments, except that it shares the features of tillage and orderly garden lay-out with environment 3. Within environment 6, the methods of providing a medium for sweet potato growth vary. Leahy (1936) provided the first general account of some of the techniques and the areas where they are practised. Other observers have given both general and more detailed accounts of practices in particular localities (Schindler 1954; Barrie 1956; Reay 1959; Kingston 1960; Meggit 1960; Montgomery 1960; Brookfield and Brown 1963; Walker 1966; Watson 1967). These authors also usually provide details of cropping procedures, fallow periods and subsidiary crops. Brookfield (1962) in a valuable study, developed a systematic approach and defined the areas of 'distinctive agricultural methods' within the Highlands and gave explanations in terms of rainfall distribution and temperature, at the same time emphasizing that all variations could not be explained by physical factors alone. Appendix III outlines these agricultural methods used in the Highlands and gives examples of their use. The methods are illustrated in *Plates* IV to VIII.

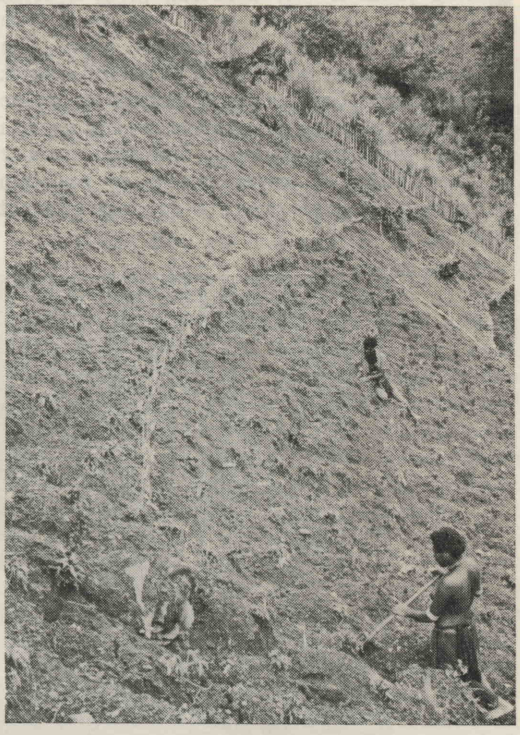


Plate IV.—Technique of growing sweet potato on very steep slopes, common in the inter-montane valleys of environment 6. Of particular interest are the small terraces, which are slightly oblique to the contour, and the small mounds made by accumulating soil uphill of the spot to be planted

Plate V.—Typical cultivation method of the Upper Ramu Valley and the Asaro and Bena Valleys. For description see Appendix III

Attributing the widespread grasslands of the Highlands region solely to the cultivation of the sweet potato cannot be categorically accepted. Even though cultivation has obviously contributed to the reversion of forest to grassland in some areas, this is not so for most of the Eastern Highlands, for example, where large uncontrolled fires each dry season are probably the main reason for preventing a reversion to montane forest.

Maintenance

Weeding practices vary—some people only weed until the vines cover the ground, but others carry on periodical weeding up until harvest, because it is said to improve yields. Once the ground is covered, weeding is easily and quickly done and depending on climatic conditions, two to five weedings are required before this stage is reached. In the Lake Ipea area of the Western Highlands District, where large composted mounds are used, for the first 5 or 6 months after planting, mounds and spaces between them are carefully hand-weeded and any earth that has fallen down is replaced on the mound. After vines have covered the ground, the spaces between the mounds are allowed to become overgrown (Walker 1966).

Vine pruning may or may not be carried out, irrespective of the environment. When it is carried out, the reasons for doing so may differ. Vine pruning to encourage tuber development instead of top-growth is seen, for example, at Wabunum (Woodlark Island) and at Tauta (Madang District). At Mendamen (East Sepik District) on the other hand, vine tips are removed to encourage spreading. Vine pruning in these lower altitude gardens may also be carried out to prevent encroachment upon a neighbour's garden. In environment 6 vine pruning is more common and again is usually done to encourage tuber development. In this environment also, tuber pruning is common, and this is done by discarding smaller tubers during progressive harvesting, together with the removal of any excess roots which are not developing tubers.

Harvesting and Yields

Ideal climatic growing conditions are considered to be adequate rain in between periods of sunny weather. It is generally agreed that excessively wet or dry periods will produce a poor crop.

In all environments, the most common method of determining a garden's readiness for harvesting is by inspection of tubers in the ground. Additional signs are appearance of flowers, hardening and thickening of vines, discolouring and abscission of leaves, length of time the crop has been in the ground and by the protrusion of developing tubers above ground level. Tubers are almost always harvested with digging sticks and hands to keep damage to a minimum. Knives may be used occasionally, but never a spade.

There is a wide range of periods to maturity between environments and a lesser range within. Aside from local variations in temperature and cloud cover, caused mainly by surrounding terrain, time to maturity increases with altitude. In environments 1, 2 and 3 the usual time to the first harvest is between 2 and 4 months, while in environment 4, which extends up to about 900 m, it can be up to 6 months. In some instances there is an acknowledged variety effect. In environment 5 the period to first harvest ranges from as little as 3 months to as long as 8 or 9 months, the usual being around 6 months. In environment 6 the period to first harvest is usually no less than 5 months and can be longer than 9 or 10, depending on the elevation and season. At 2,000 to 2,200 m for example, it is usually 7 to 8 months, compared to 5 months at 1,500 m. In some Chimbu areas, for example at Kone village at 1,590 m, first harvest is at 3 to 4 months, but this is probably a reflection of favourable climate and soil, together with a high level of technical ability resulting from the necessity to maintain a high level of production from a limited area of land.

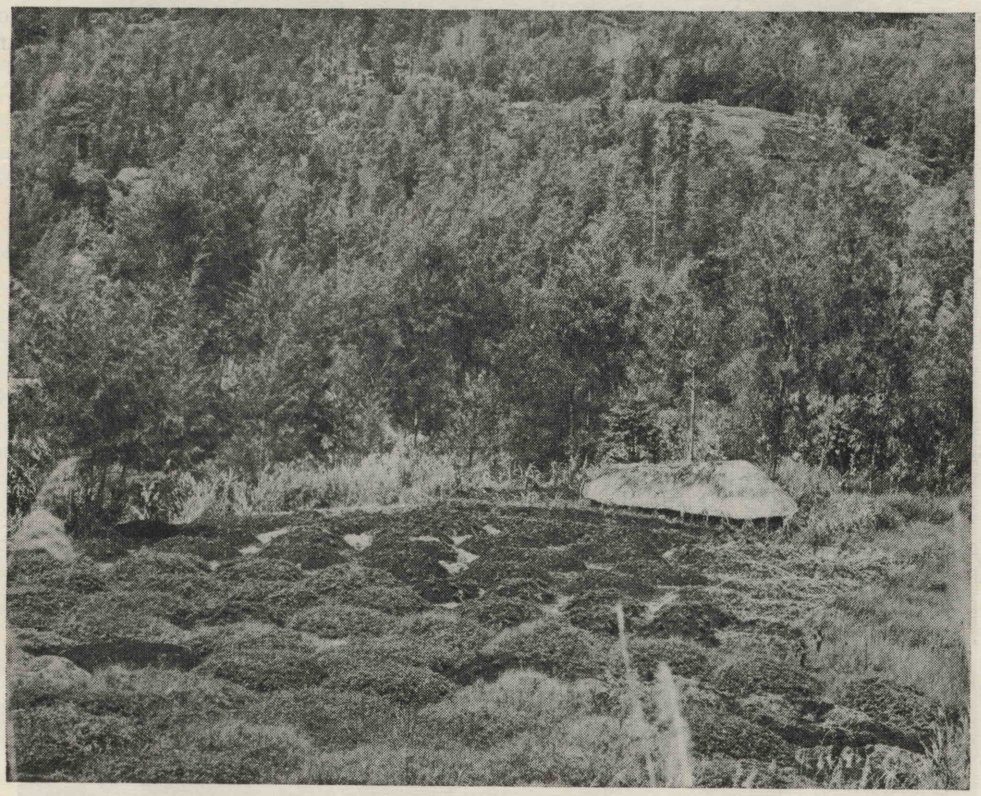
Plate VI.—Method of cultivation found most commonly in the lower Chimbu Valley and the Wahgi Valley. For description see Appendix III

Progressive harvesting is carried out in all environments, irrespective of variety, but it is not always found, especially in environment 2. Progressive harvesting involves exposing individual tubers to view to determine if they are large enough or mature enough for harvesting. If a tuber is considered not to be ready, it is re-covered, with inspection at a later date. In environments 5 and 6 it is a universal practice and is of course facilitated by mounding. In

these two environments, the crop can last for up to 6 months from the first harvest, but normally it is harvested over a period of 2 to 3 months before replanting is carried out, or a new garden made.

Being a somewhat specialized method of growing, the so-called 'hotbed' mounds found in parts of the Western Highlands are often harvested so as to facilitate their rebuilding for the next planting (Walker 1966). At the final harvest, the ground is worked down and out, a shallow hole being left beneath the centre of the position of the old mound. Old sweet potato vines and weeds are then put back into the hollow. Meggit (1960) reports a similar procedure, but he says that the second crop is not a large one, unless the ground is of good quality, and it is usually fed to pigs or kept for emergencies.

Although reliable yield figures for subsistence production are not available, it is believed that yields from the Soil Exhaustion and Crop Rotation Trials at Aiyura are a fair reflection of what subsistence gardeners achieve in the Highlands (DASF Annual Reports, 1959-60 to 1965-66). These have been around 20,000 kg per hectare, although the Soil Exhaustion Trial yields have dropped well below this in recent years. Allowing for an approximate 31 per cent loss as inedible tubers (unpublished results) for the variety 'Akaio', which is at present being used in the Exhaustion Trial, an estimate of



Plates VII and VIII.—Cultivation of sweet potato in the Lai Valley of the Western Highlands District. This method is found also in other areas of the Western Highlands and in the Southern Highlands. The Casuarina trees in the background are planted as part of the fallow rotation. Refer to Appendix III for a description

average yields of edible tubers for Highlands subsistence sweet potato growers would be about 14,000 kg per hectare. However, one proviso is that in subsistence production, if there is a temporary shortage of food, tubers which would normally be fed to pigs are quite acceptable for human consumption. A Soil Exhaustion Trial at Keravat (DASF Annual Report, 1959-60) initially gave a yield of approximately 29,000 kg per hectare, and this would probably be a good estimate of subsistence yields in environments 1 to 4. This yield includes all grades, however, and the yield of tubers acceptable for human consumption would probably be 18,000 to 20,000 kg per hectare.

Relations with Other Crops

Mixed gardening is the usual practice in subsistence agriculture and one finds that in all environments sweet potato is grown intercropped with other food crops such as maize, taro, yams, bananas, sugar-cane, cassava, beans, peas and cucumbers, the emphasis on other crops depending upon the environment (*Plate* IX). At the same time, however, sole plantings of sweet potato are common in all environments and not infrequently people have reservations of growing sweet potato mixed with other crops. Some believe that the intercropping of sweet potato with yams or taro reduces the yield of the latter two, especially that of taro. Examples are at Nunamai and Tatupiti villages in the Central District. In the Highlands some people prefer not to mix taro and sugar-cane with sweet potato.

In the lower altitude environments gardening cycles are quite short and the land is usually cropped only once. In environments 5 and 6, gardening may be continued on the one site for 3 or 4 years, especially if sweet potato is the crop concerned. In environment 6 in partic-

Plate VIII

ular, where population densities are higher and land availability on the whole lower, some land may be cropped almost continuously, depending on its quality; some may be cropped for 3 or 4 years, with short fallows of varying length of time between croppings and then the land abandoned to long fallow, and some may be cropped only once or twice before long fallow, which may be up to and over 20 years. Examples of land classification, cropping systems and land enclosure have been described for the Chimbu (Brookfield and Brown 1963) and for other areas in the Highlands (Barrie 1956; Montgomery 1960; Meggit 1960; Walker 1966; Schindler 1954).

There is ample evidence from the survey and from published literature that in environments 5 and 6 the ability of sweet potato to yield worthwhile crops from relatively depleted land is well known. For example, the Wain people of the Lae Highlands (Morobe District) grow sweet potato on poor land near the village and yams on less frequently cropped land some distance away. The yam areas may also be used for sweet potato, but only as a second crop (Jackson 1965). The North Fore people of the Okapa area (Eastern Highlands) may crop a mixed garden of taro, yams and winged beans, then sweet potato and maize and then sweet potato only, before the land is fallowed (Loh,

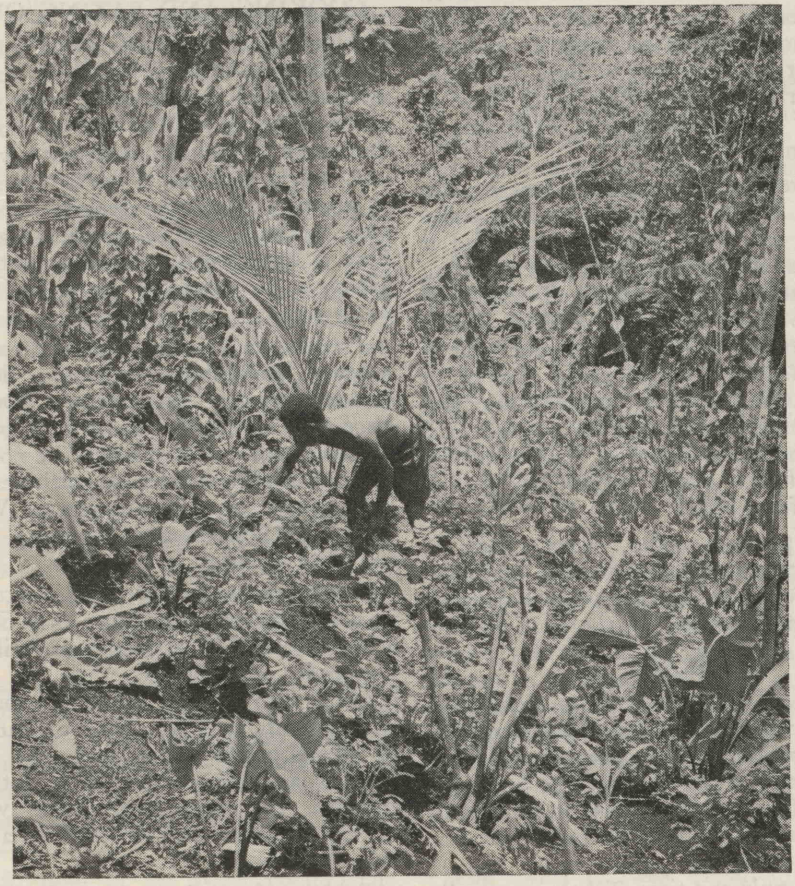


Plate IX.—A typical mixed cropping garden in a Lowlands environment. Some of the food plants which can be seen are sweet potato, taro (Colocasia), maize, banana, yam and coconut

pers. comm.). Various gardens would be in different stages of such a cycle and there would be variations according to the quality of the land. At Usa village, in the Southern Highlands, sweet potato may be grown up to six times in succession before the land is fallowed.

The relationships of sweet potato with cash cropping are also worth noting. In environments 1 and 4 it is common for an area of ground to be used as a subsistence garden before planting to coconuts, cocoa or rubber. After that, the use of sweet potato as a cover-drop in young coconuts is a widespread practice up until palms are 5 or 6 years old. Sweet potato may also be planted as a subsistence crop concurrently with coconuts to make double use of the land. When it is used as a cover-crop in coconuts, cocoa or rubber, it is not likely that much effort is made to maintain it, but rather it is allowed to fend for itself, perhaps after initial care. The actual value or otherwise of sweet potato as a cover-crop is not yet known.

In those areas of environment 5 where coffee is grown, it is not uncommon to find coffee planted into old sweet potato gardens and it is not unusual to find also sweet potato being planted into and harvested from well-established coffee groves. Much the same situation applies in environment 6, with the exception that it is rare to find sweet potato being cropped in established coffee. However, sweet potato and coffee in environment 6 may be planted in a garden at the same time, so that after the harvesting of the sweet potato the garden becomes a coffee grove.

When it precedes coffee, sweet potato is thought by some to assist the coffee by breaking up the ground, or in some other way which the people cannot define.

STORAGE

There are no elaborate storage techniques. These have probably not been developed because sweet potato can be grown at all times of the year, and it can therefore be harvested as required. In all environments it is unusual for sweet potato to be stored for more than 2 or 3 weeks. The normal pattern is to harvest 2 or 3 days' supply at a time. Tubers are usually kept on a table, or on the floor, in a bilum hanging in the house, or even under the house, but in environment 3 may be stored in a yam food house. In one instance, storage of tubers in holes in the ground was reported, but this would be similar to leaving plants unharvested in the ground. Storage in holes filled with sand is also found in some cases. Leaving edible tubers unharvested in the ground is a good storage method, provided moisture is not excessive. If this is done, tubers which are known to be ready for harvest become more satisfying when eaten, mainly because of the lower moisture content which develops.

There is a general recognition of the desirability of retaining the skin intact and preventing bruising, so that rotting of tubers is avoided.

COOKING AND EATING QUALITY

Although it would seem that little attention is paid to it, storage for a few days is often recognized by the people as improving eating quality. This is due to loss of moisture from the tuber, given a greater energy value per unit weight and also to the hydrolysis of starch to sugars. Only on the desirable aspects of lowered moisture content, sweetness and lack of fibre is there any agreement on eating quality. There is no expressed preference for dry or moist types.

Preferences for size vary, although in subsistence horticulture there is a definite bias towards growing large tubers. Despite this, large size is regarded as of little practical importance, and provided tubers are not too small, they are readily consumed, particularly if there is a danger of a food shortage. Where preference for flesh colour is expressed, it is usually for white or cream.

Sweet potatoes are prepared for consumption in a number of ways. They may be baked in ashes, steamed in a mumu, or boiled. In the Lowlands environments they are sometimes mashed with coconut milk. Although in all environments it is not hard to find examples of sweet potato leaves and vine tips being used as an item of diet, it is not a general practice. The more usual habit, when it is carried out, is to use the leaves as a flavouring with some other foods.

Evidence from the survey suggests that varieties can be supplanted in favouritism by others, but whether this is a process which has been

accelerated by improved communications in recent years is not known. Many people use sweet potato varieties of relatively recent introduction to their area. Along main roads in the Highlands, for example, three or four varieties have become widespread during the last 15 or 20 years. Older varieties are often retained, though they may not be eaten very often.

Finally, yield is not the main criterion of desirability. One variety, commonly known as 'Gonimi', is very widespread and popular though of relatively low yield.

SWEET POTATO AND LIVESTOCK FEED

Pigs are the largest and most important domestic animal in subsistence agriculture in Papua New Guinea. Their use lies mainly in their value as a source of wealth and prestige. The date of their introduction into Papua New Guinea is not known exactly, though their first discovered remains are reported to be five to six thousand years old (White 1968).

Pigs may or may not be allowed to forage in old sweet potato gardens, depending on what the local social custom is and also upon local ideas of allowing the animals to acquire the taste of fresh garden food. In environments 5 and 6, where pigs tend to be socially more important than in other environments, only a small minority prevent pigs foraging in old gardens and occasionally, when the supply of sweet potato is plentiful, they may even be allowed to forage in unharvested gardens.

Regardless of forage practice, it is common in all environments to feed pigs sweet potato by hand. This is usually in the form of discarded tubers and peelings, from the household, but when there is an abundance available, better quality sweet potato is also fed to them.

Free foraging pigs in environments 5 and 6 are the cause of a great deal of soil loss from steep slopes, where their rooting habit in recently abandoned gardens exposes the soil to water erosion.

It would be true to say that the pig population in environment 6 would not be so high, but for the cultivation of the sweet potato. The pig population of the Highlands is not known, but there are probably as many pigs as people, if the observations of Schindler (1954) and the estimates of Brookfield and Brown (1963) can be taken as a guide. However the pig population in the Highlands is known to vary in accordance with a cycle, coinciding with a periodic spate of feasting, dancing and exchange, which activity generally lapses until the pig population builds up again. The length of the cycle, and the particular stage encountered would no doubt vary from area to area. In his study of land use at Aiyura village in the Eastern Highlands, Schindler says that about half the production of sweet potato goes to feeding the family pigs. This emphasises the relative efficiency of Highlands gardening methods and emphasises the role of the sweet potato in the accumulation of accepted standards of wealth.

PESTS AND DISEASES

In subsistence agriculture, much reliance is placed upon natural predators in controlling insect pests. In addition, however, both disease and insect pests are usually kept in check by the practices of mixed cropping, crop rotation and garden fallowing.

There are three insect pests of some consequence in sweet potato subsistence crops, despite the practices mentioned above. The three major pests are the sweet potato weevil (*Cylas formicarius* F.), the sweet potato hawkmoth (*Herse convolvuli* (L.)) and the sweet potato leaf miner (*Bedellia somnulentella*). The life history, alternative hostplants, damage caused by and recommended control measures of these are given by Smee (1965) and O'Connor (1969).

In the field of sweet potato diseases, virus-infected sweet potato has been found on the Gazelle Peninsula of East New Britain. Movement of any part of the sweet potato plant from this area is therefore prohibited, as virus diseases could have serious implications for sweet potato in Papua New Guinea, through possible dissemination by insect vectors and vegetative propagation.

CONCLUSIONS

The ability of sweet potato to sustain good yields in subsistence agriculture from sea level to altitudes of up to 2,600 m is reflected by the fact that quantitatively it is the most

important food crop in Papua New Fuinea. Although it achieves this position largely through its cultivation in the inter-montane valleys of the Highlands region, it has been shown to be of considerable importance in other environments as well. Of all the staple root crops available to the people, it appears to be the most adaptable to a range of environments, an attribute which is probably based upon a large degree of genetic heterozygosity. Its relative freedom from pests and diseases in subsistence agriculture is an additional factor accounting for its widespread acceptance in all environments and growing importance in some.

The significance of sweet potato in the Highlands lies in the fact that it appears to be the only crop which has, until recently, been available to the people, which will support relatively dense populations at altitudes above 1,400 m. The importance of sweet potato in supporting the pig population of the Highlands, and to a lesser extent of the Lowlands, has already been mentioned as a major factor in the establishment of wealth and prestige in subsistence economies.

The last 50 years has seen the introduction of a variety of food crop plants—legumes, roots and grains—which may become more acceptable with the passage of time and which will, if more widely accepted, be able to extend the limits of cultivation further than at present, especially in terms of altitude. Already maize and potatoes are relatively common items in the subsistence diet, the former in both coastal and elevated areas, the latter in elevated areas only.

The various agronomic and horticultural aspects studied in the survey have provided basic information on sweet potato cultivation which will be of value to research into methods of commercial production.

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APPENDIX I

Locality details of villages from which information was obtained during the mailed survey

Environment	Village	Number of Village on Map	Elevation (m)	Administrative Subdistrict	Administrative District
1. Non-swampy coastal	Merani	5	15	Abau	Central
	Nunamai	6	30	Abau	Central
	Wabununu	10	15	Samarai	Milne Bay
	Amele	25	not given but<150	Madang	Madang
	Baranis	26	sea level	Madang	Madang
	Kaliku	28	sea level	Madang	Madang
	No name given	33	not given about 30	Lae	Morobe
	Ketoketo	56	61	Buka Passage	Bougainville
2. Swampy lowlands	Bibriari	11	430	Amanab	West Sepik
	Wagu	17	60	Ambunti	East Sepik
	Karanio	22	15	Angoram	East Sepik
3. Grassland, scrub, savanna and savanna woodland	Gnarowein	30	180	Kaiapit	Morobe
4. Rainforest lowlands and foothills	No name given	1	<150	Kerema	Gulf
	Bakoiudu	2	488	Kairuku	Central
	Serove	7	30	Popondetta	Northern
	Kiorata	8	150	Popondetta	Northern
	No name given	12	<150	Lumi	West Sepik
	Nuku	13	230-300	Lumi	West Sepik
	Yoliapi	14	450	Telefomin	West Sepik
	No name given	18	150-300	Maprik	East Sepik
	Mendamen	19	460	Maprik	East Sepik
	Kmoluik	20	107	Maprik	East Sepik
	Waigakam	21	180	Maprik	East Sepik
	Bembei	24	300	Madang	Madang
	Narer	27	300	Madang	Madang
	Timini	31	610	Mumeng	Morobe
	Bai	52	30	Rabaul	East New Britain
	Tanaka	53	335	Rabaul	East New Britain
	Illugi	54	30	Kokopo	East New Britain
	Tabuna	55	46	Kokopo	East New Britain
5. Lower montane forest	Tatupiti	3	1006	Goilala	Central
	Efogi	4	1220	Port Moresby	Central
	Kakaia	9	915-1220	Baniara	Milne Bay
	No name given	15	7915	Telefomin	West Sepik
	Drelingan	16	1200-1530	Telefomin	West Sepik
	Bundi	23	1530	Ramu	Madang
	Tauta	29	1280	Saidor	Madang
	Mapos	32	1460	Mumeng	Morobe
	No name given	34	1530-1830	Lae	Morobe
	Konge	35	1530-1830	Finschhafen	Morobe
	Mobuta	50	915-1070	Wonerara	Eastern Highlands

Appendix I—*continued*

Locality details of village from which information was obtained during the mailed survey

Environment	Village	Number of Village on Map	Elevation (m)	Administrative Subdistrict	Administrative District
6. Inter-montane valleys of the main cordillera	Usa	36	1530	Kagua	Southern Highlands
	Kone	37	1585	Gumine	Chimbu
	Nonambaro	38	1830	Goroka	Eastern Highlands
	Wanima	39	1585	Goroka	Eastern Highlands
	Korofeigu	40	1585	Goroka	Eastern Highlands
	Rana	41	1830	Henganofi	Eastern Highlands
	Kanampa	42	1830	Kainantu	Eastern Highlands
	Hena-agaru	43	1830	Okapa	Eastern Highlands
	Kopena	44	2075	Kainantu	Eastern Highlands
	Kainantu	45	1585	Kainantu	Eastern Highlands
	Tuempingha	46	1585	Kainantu	Eastern Highlands
	Ibusa-Kagu	47	1980	Okapa	Eastern Highlands
	Punano	48	1615	Kainantu	Eastern Highlands
	Omomunta	49	1707	Kainantu	Eastern Highlands
	Yanyi	51	1646	Wonerara	Eastern Highlands

APENDIX II

Subsistence Agricultural Environments

Environment and Examples	Characteristics	Details of Subsistence Agriculture	Details of Staples in Diet
1. Non-swampy coastal areas. Parts of north coast of New Britain, west coast of New Ireland and parts of Bougainville.	Narrow coastal strips of herbaceous beach and strand vegetation. Mostly sandy and coral-derived soils. Coconut palms have replaced most of the natural vegetation.	Subsistence economy greatly modified by production of copra and employment on large plantations. The subsistence economy is basically slash and burn, with a fallow period which is relatively short. Fallows are often only long enough to allow regeneration to a high secondary brush. Gardens can extend into the hinterland and fishing remains an important source of protein and subsidiary income.	By and large, sweet potato assumes the place of a secondary staple behind taro, yams and sometimes bananas. Quantity of sweet potato in diet however, varies from 10 to 50 per cent and in some cases can be more than 50 per cent. Sweet potato becoming more important because of ease of cultivation and relative freedom from pests and diseases—factors important to people who have greatly modified their subsistence economy.
2. Swampy lowlands. Deltas of Fly and Purari Rivers; mouths of coastal creeks and rivers; inland swamps of Sepik.	Freshwater swamp and tidal swamps mainly covered by *Rhizophora* and *Bruguiera* spp. mangrove and stands of Nipa palms. Sago palm (*Metroxylon* spp.) occupies large areas of shallow freshwater swamps.	Fishing and sago collecting are the main activities, with gardening assuming varying degrees of importance, depending on how much sago is available. When carried out, gardening is slash and burn, usually with only dibbling of vegetative cuttings.	Mextroxylon (sago palm) the main starchy staple. When gardening is practised sweet potato is of very little importance and is often only one of a number of subsidiary dietary items. In some areas only those who like it bother to plant it. Yams can achieve considerable importance.
3. Grassland, scrub, savanna and savanna woodland. Extensive areas of coastal and subcoastal Papua, especially the rain shadow Moresby area, the Gona-Popondetta-Oro Bay-Tufi area and the broad rift Markham-Ramu valley.	Typical of areas receiving a marked seasonal rainfall of 1,000 mm a year or less or where rainfall may be higher, but dry season is still very pronounced. Forest can occur along river valleys.	Vegetative characteristics believed to have been formed mostly by man through destruction of original vegetation by shifting agriculture and by burning for hunting. Agricultural techniques have been developed to suit the conditions, the main feature being tillage to retain soil moisture. Gardens are usually rectangular and the soil is turned over carefully in large clods.	Yams and bananas are usually the most important crops and cassava also often rates more importantly than sweet potato.
4. Rainforest lowlands and foothills. Occupies large tracts of country throughout Papua New Guinea, from sea level to about 915 m.	As well as rainforest, includes monsoon (semi-deciduous) forest where there is a marked dry season and where, through man's activity, patches of grassland tend to appear. Local variations in terrain affecting climate can extend the limits of this environment to alitiudes considerably higher than 915 m.	Typical slash and burn economy with bush fallow rotation involving a long fallow period and short cropping period of 1 to 2 years, with semi-foraging of bananas and other foods as the bush regenerates. Fallow after main cropping periods varies from 10 to 20 years, depending on the availability of land. Soil preparation mainly confined to scraping and loosening patches of ground with a digging stick and spade at the sites of individual plants.	Taro is the staple food and sweet potato assumes varying importance as a supplementary staple, varying from about 10 to 20 per cent of the bulk diet. At altitudes approaching 610 m, sweet potato becomes more important and may even become the main staple. The approximate limit of 915 m to this environment is also a rough estimate of the altitude where sweet potato assumes the role of the main starchy staple.

APPENDIX II—*continued*

Environment and Examples	Characteristics	Details of Subsistence Agriculture	Details of Staples in Diet
5. Lowland montane forest. Areas of Papua New Guinea mainland and islands which are not part of the inter-montane valleys of the main cordillera, e.g., Lae Highlands, many parts of the Southern Highlands and elevated valleys of the mainland and islands.	This zone is usually taken to extend from 915 to 2745 m, though there are local variations. Where grasslands have not been induced, vegetation consists mainly of forests of oaks (*Quercus* and *Castanopsis* spp.) members of the family Lauraceae, klinki pine (*Araucaria klinkii*) and southern beech (*Nothofagus* sp.).	Very similar to environment 4.	Sweet potato is the dominant staple, with few exceptions, e.g., Telefomin area of the Western Highlands District where taro supplants it.
6. Inter-montane valleys of the main cordillera. Upper Ramu, upper Purari Valleys. (Lai River, Upper Yuat and Strickland Valleys)	Except for steep valley sides, these are predominantly grassland areas. Two types of grassland occur: "short grass", dominated by *Imperata cylindrica*, *Themeda*, *Arundinella* and *Ischaemum* spp.; and "long grass", dominated by *Miscanthus* spp. In swamp areas, vegetation is dominated by *Saccharum spontaneum* and *Phragmites kaka*. Theoretically a part of environment 5, these grasslands appear to have been formerly forested (Robbins 1963, and others)	Separated from environment 4 because of more advanced and more orderly garden techniques. More advanced localized aspects are composting and planting of Casuarina trees in the fallow. Land tilled, in direct contrast to all other environments except 3. Gardens extend from about 1,220 to 3,050 m for cultivated Pandanus. Upper limit of sweet potato cultivation around 2,400 to 2,600 m, depending on local conditions, especially frost and cloud occurrence.	Sweet potato is by far the most important staple. Crops typical of lower environments (yams, aroids, cassava and bananas) are still grown, but usually in spots especially favoured to suit their growth. Content of sweet potato in diet ranges from 50 per cent to over 90 per cent. Dependence upon it increases with altitude, modified by local conditions. What amount to monocultures with sweet potato occur in certain areas such as Upper Chimbu and Okapa. Different tillage techniques are used in different areas (see Appendix III).

APPENDIX III

Environment and Agricultural Techniques in the Inter-Montane Valleys of the New Guinea Highlands (Environment 6)

Conditions and Examples	Other Characteristics of Environment	Details of Agricultural Methods
1. Areas of marked seasonality of rainfall. Lack of rainfall at a certain time each year imposes a limitation on plant growth. Upper Ramu Valley, Asaro and Bena Bena Valleys.	Seasonality of rainfall has encouraged the use of fire in agriculture to such an extent that fires are largely indiscriminate and uncontrolled in the dry season. Landscape now dominated by large areas of short grassland in which *Imperata cylindrica*, *Themeda*, *Arundinella* and *Ischaemum* spp. occur, their proportion depending upon local conditions of soil and climate. Use of Casuarina in fallows not as widespread as in 2 and 3, except in more locally heavily populated spots.	Gardening methods determined by seasonality of rainfall. Field layout of sweet potato gardens is one of long narrow parallel beds separated by shallow drains, 1 to 1.5 m apart, dug down to the often stiff clay subsoil. Drains run up and down hillsides, or on a lesser slope, may be at an oblique angle. Their main function is disposal of excess water and prevention of gully erosion and large-scale soil movement downhill, which occur if drains are dug across the slope. Sweet potato planted throughout the year, but the more seasonal the rainfall the more there is a peak of activity in garden preparation some weeks before the commencement of the wet season. After burning, land is given a complete tillage and fallowed until planting time. In between periods of light showers the land is tilled to prevent formation of a surface crust and to conserve moisture. When soil moisture is sufficient planting is carried out. This is usually accomplished by the beginning of the wet season, because of the difficulty of working ground once the wet season has commenced. The bare fallow is, apart from moisture conservation, recognized as improving the yields of the subsequent crop, though the technical reasons for soil aeration and mineralization are not understood by the people. Variations of preparation of beds between trenches include one or more rows of small mounds, or no mounds at all. On occasions no drains are necessary and the tilled ground is merely small-mounded. If after planting general rains do not commence, the soil is dug over at intervals to prevent a crusty surface forming.
2. Areas of lower seasonality of rainfall such that growth is not limited by seasonality, or only to a relatively minor extent. Chimbu Valley, Lower Wahgi Valley.	Landscape dominated by sweet potato gardens and fallowed areas planted to Casuarina trees. Grasses also occur (*Miscanthus floridulus, Imperata cylindrica, Themeda, Ischaemum* and *Arundinella* spp. In Upper Chimbu slopes of 35 degrees commonly cultivated.	No definite planting season, but may be a peak just before commencement of less obvious wet season or even just before it ends. Complete tillage as in 1, together with bare fallow technique, but more conscious incorporation of debris (burnt grass, Casuarina leaves and twigs) into tilled soil. Layout of garden beds may be square or rectangular (2 to 3 m wide by about 3 to 5 m long) separated by shallow drains which, however, usually go to greater depth than in 1. This type of land preparation governed by need for more adequate drainage than in 1 and it is this that governs the distance between drains. Small mounds are usually constructed on the beds. In areas where large-scale steep slope cultivation is carried out, ditching is often not used and a system of semi-terracing is employed, using split Casuarina saplings pegged across the slope. These retaining walls are made permeable to prevent build-up of water and massive soil movement downhill.

APPENDIX III—*continued*

Conditions and Examples	Other Characteristics of Environment	Details of Agricultural Methods
3. Seasonality of rainfall not marked, but climate such that these areas are exposed to lower temperatures than is usual elsewhere in the Highlands. Large areas of high altitude in the Western Highlands and Southern Highlands Districts, e.g., Lai Valley, Lagaip Valley.	Again widespread use of Casuarina. Fallowed areas, if not planted to Casuarina tend to be dominated by the long sword grass *Miscanthus floridulus*. Short grass communities composed of *Imperata cylindrica*, *Themeda*, *Ischaemum* and *Arundinella* spp., however still occur.	Complete tillage, but ground formed into very large mounds whose size appears to increase with altitude and decreasing soil temperatures. Variation is approximately as follows (Kingston 1960): at 1,680 m, 2 m diameter and 60 cm high; at 1,980 m, 3.7 m diameter and 90 cm high; at 2,286 m, 3 m diameter and 122 cm high. Mounds may also be oval to oblong in shape. Plant debris is incorporated into mounds and composted inside to raise soil temperature. Mound saucer-shaped at first (concave at top) and all weeds and old sweet potato vines are thrown into the saucer and then covered to complete the mound. Only topsoil is used in construction. A light incomplete burning of grass is often practised before mounds are constructed and the actual filling in with plant debris and tilled earth may take place over a period of 8 weeks. This constitutes a bare fallow similar in effect and purpose to those in 1 and 2. Grass may often be cut and incorporated into the mound with only stubble being burned. Any soil washed down from the mounds is returned to the top. In these areas yield and size of tubers is often reduced and shape tends to be inferior.
4. Swampy areas. Parts of Wahgi. However, more developed in Wissel Lakes area of West Irian.	Peaty swamp soils built up over time from trash of tall grass which constitutes the swamp vegetation (*Phragmites kaka* and *Saccharum spontaneum*.	Fairly similar to grid-iron pattern of 2, and in a way difficult to separate from it apart from necessity for more adequate drainage in these swamp soils. However, in its usual pattern this method does not involve tilling of the original surface. Ditches are deeper and subsoil from them is thrown onto intervening beds, is broken down and then becomes the plant medium. In the Wahgi Valley ditches may be 60 cm deep, but this is shallow compared to the necessity for greater depth in the Wissel Lakes areas.

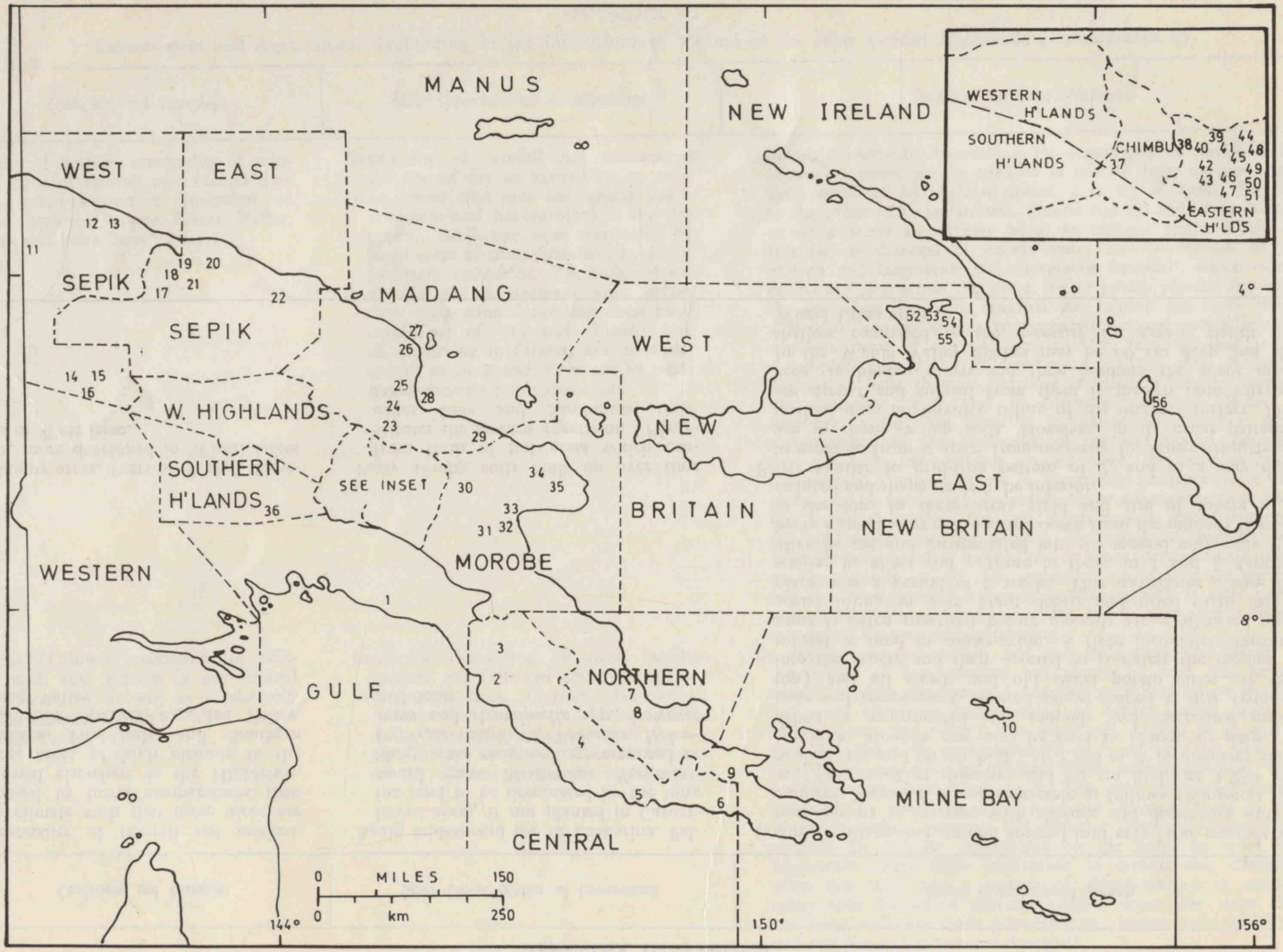

Figure 1.—Location of Districts and villages listed in Appendix I.