The

Papua and New Guinea

Agricultural Journal

Vol. 20. JULY-SEPTEMBER, 1968 * Nos. 1 and 2

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*Due to delays the actual publication date of this Journal was May, 1969.**

Deer in New Guinea.

PART I: NOTES ON THE FIELD IDENTIFICATION OF CERTAIN DEER SPECIES LIKELY TO BE ENCOUNTERED IN PAPUA AND NEW GUINEA.

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ABSTRACT.

The presence of two species of deer, the rusa (Cervus timorensis) *and axis* (Axis axis) *have been confirmed in the Territory of Papua and New Guinea.*

The more useful observations which can be made when deer are seen are listed, and the signs made by deer in the bush are described.

The points by which the two Territory species of deer may be identified when seen in the field are listed and compared with four other species, which, although not recorded in the Territory, may have been introduced.

INTRODUCTION.

Of the species of deer detailed in the following notes, only two, rusa (*Cervus timorensis*) and axis deer (*Axis axis*) are known to be established in the Territory of Papua and New Guinea (Downes 1968). Details of four others, fallow deer (*Dama dama*), sambar (*C. unicolor*), red deer (*C. elaphus*), and the sika deer (*C. nippon*), are included for comparison. Although there is no evidence to support it, they were probably introduced to the Territory at the time acclimatization of the other species took place.

It is reasonable to assume that many characteristics of both appearance and behaviour of the deer in the Territory will be no different from those of the same species in their native habitats. Because very little is known of their precise origin or how many varieties were imported, and because of the innate difficulty of identifying female deer at a distance, positive identifications will await the collection of adequate specimens. Sightings by any but the most experienced observers will be of doubtful value unless the animals can be studied at comparatively close quarters and adequate notes taken at the time of observation.

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However, it is important to record all sightings of deer, particularly in new country, and to notify the Wildlife Laboratory in the Department of Agriculture. If possible, skins, samples of hair, skulls with jawbones and antlers should be sent to the Laboratory.

These notes are intended for use by field officers of the Department of Agriculture, Stock and Fisheries, Territory of Papua and New Guinea. They are not an exhaustive key to the species. But much could be gained from chance observations of deer in the bush if the hunter knew what to look for. Detailed identification notes are provided in a number of books which should be used for the final identification of specimens. The available sources of information are listed under each species.

POINTS TO LOOK FOR.

The technique of deer-stalking can be developed by observing some basic requirements. Extremely slow movement, with frequent stops, is most likely to produce sightings since in a country which has any type of cover, the range of vision changes at every step. The animals should be approached from a downwind and, if possible, a downhill direction. Having the sun behind is also an advantage.

When deer are seen.

Note the shape of the antlers (*Figure* 1). Record the details of colour patches, etc.

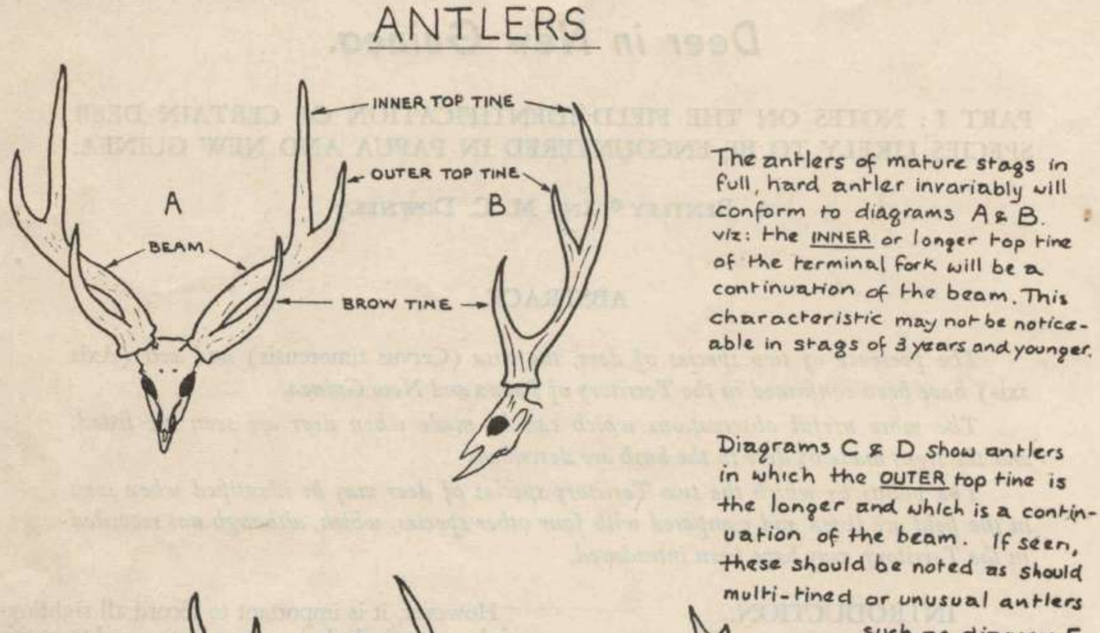


Figure 1.

Note the relative sizes and numbers of the different animals in the group.

Classify into stags, yearlings, hinds, calves (see '*Age Groups*').

Fill in a Deer Sighting Report Sheet as in *Appendix* 1 and send to the Wildlife Laboratory, Department of Agriculture.

When deer are shot.

Note details of antlers, sex organs, foetus, etc.

Fill in a Deer Specimen Report Sheet as in *Appendix* 2.

Measure body size (*Figure* 2).

Collect the lower jawbones and some hair. For complete identification, the complete skull, the whole skin including the tail, hoofs and head are required.

Collect about $\frac{1}{2}$ lb. of food from the rumen and preserve in 10 per cent. formalin.

Label specimens and send with report to the Wildlife Laboratory, Department of Agriculture.

SIGNS COMMON TO ALL DEER HABITAT.

Hoofprints.

These are the signs which are the first thought of by most observers. Confusion can occur between well-formed tracks of goats and, say, fallow and other smaller kinds of deer. To a lesser extent the same can be said of the tracks of young cattle and red deer. Information on approximate track sizes is given in the following notes. The edges of clearings and native gardens, swamps, ridge saddles, trails used by other game, logging tracks and unfrequented foreshore, are the most likely places in which to find deer sign.

Rubbing trees.

All male deer use trees and shrubs for antler play, the removal of the velvet on the completion of antler growth, and for the marking of their territory. Rubbings can be seen from ground level to two or three feet above ground level. There is usually a centre of damage to the bark at a height of about two to three feet. A particular species of tree is frequently favoured, or isolated trees uncommon in the area. Stag territory is often marked by several rubbed saplings of one to three inches in diameter. These are easily seen because there are usually several examples visible from the one viewpoint.

Droppings.

Usually deer faeces are in pellet form, similar to those of goats and sheep. The size varies with the size and species of animal. Spring growth or other lush feed can cause droppings to become similar to a small 'cow pad'. The droppings of very young fawns are, on occasion, elongated and not unlike those of a young dog. Pellets are by no means a reliable factor in identification unless supported by other evidence. Pellets disintegrate rapidly when exposed to heavy rain, but if in a dry or sheltered location they remain recognizable for a much longer time.

Wallows and rutting scrapes or holes.

Sambar, red deer and rusa make wallows which the hinds also use. In country frequented by wild pigs their wallows can be distinguished by the droppings thereabout and the height of mud rubbings on nearby trees. In the case of deer the rubbings may be more than six feet above ground level. Rutting scrapes—holes of varying depth depending on soil type—are made by fallow deer and sika using forefeet and sometimes antlers. There is an odour about these holes which, in the case of the sika, is "strong, penetrating and musk-like" (Kiddie 1962).

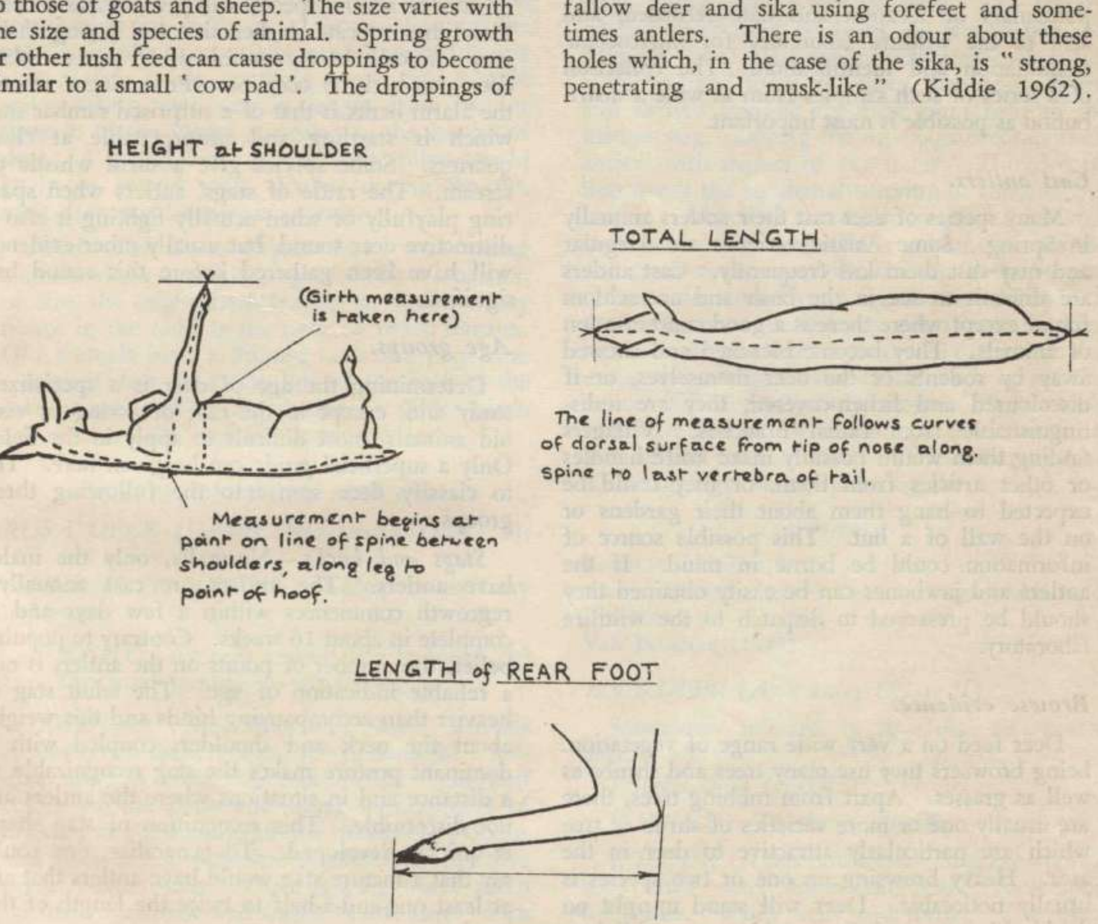


Figure 2.

There is usually an odour in most stag territories which becomes recognizable with experience.

Hair.

Samples of hair may be found on rubbing trees, caught in splinters or rough bark ; where an animal has passed under a hanging tree or limb ; in the mud of a wallow ; in the wire about a garden or plantation, or in high grasses where there is an impression of an animal having lain down. In a situation similar to the last mentioned, a sample of hair can usually be taken by wetting the palm of the hand and pressing it firmly over the area ; hair will readily stick to the palm. Skins or pieces of skin may be in the possession of villagers. Any samples of hair should be collected, taped to a white card, the particulars of location and date recorded, and sent to the wildlife laboratory for microscopic examination and identification. The collection of a series of such samples from as wide a distribution as possible is most important.

Cast antlers.

Many species of deer cast their antlers annually in Spring. Some Asiatic varieties are irregular and may cast them less frequently. Cast antlers are difficult to see in the bush and are seldom found except where there is a good concentration of animals. They become bleached and chewed away by rodents or the deer themselves, or if discoloured and lichen-covered, they are indistinguishable from fallen branches. Villagers finding them would possibly make knife handles or other articles from them, or they could be expected to hang them about their gardens or on the wall of a hut. This possible source of information could be borne in mind. If the antlers and jawbones can be easily obtained they should be preserved to dispatch to the wildlife laboratory.

Browse evidence.

Deer feed on a very wide range of vegetation. being browsers they use many trees and shrubs as well as grasses. Apart from rubbing trees, there are usually one or more varieties of shrub or tree which are particularly attractive to deer in the area. Heavy browsing on one or two species is usually noticeable. Deer will stand upright on the hind legs to reach favoured browse and lighter branches may be broken down from a height of six to seven feet in the case of the larger deer. They will also eat many aquatic plants, mosses and lichens, fungi and seaweed.

Voice.

It is not possible to convey an accurate impression of the great variety of sounds made by deer. Some deer are more vocal than others but only a most experienced observer could identify a deer by this evidence alone. Most male deer are more vocal during the breeding season, or rut, as it is more usually termed. Any call closely or even vaguely resembling the bellow of domestic cattle is worth investigating. Stags will show varying degrees of interest in human imitations of their calls during the rut. In cover and unseen, hinds or does of several species will give an alarm bark, sometimes repeated. Females and young make very soft calls barely audible at 50 yards. Male deer also bark on occasion. Pre-eminent among the alarm barks is that of a surprised sambar stag which is startling and unforgettable at close quarters. Some species give a shrill whistle or scream. The rattle of stags' antlers when sparring playfully or when actually fighting is also a distinctive deer sound, but usually other evidence will have been gathered before this sound has significance.

Age groups.

Determining the age of deer is a specialized study and, except in the case of young or very old animals, most difficult to apply in the field. Only a superficial guide can be given here. Try to classify deer seen into the following three groups :—

Stags and bucks.—Normally, only the males have antlers. The antlers are cast annually ; regrowth commences within a few days and is complete in about 16 weeks. Contrary to popular belief, the number of points on the antlers is not a reliable indication of age. The adult stag is heavier than accompanying hinds and this weight about the neck and shoulders coupled with a dominant posture makes the stag recognizable at a distance and in situations where the antlers are not discernible. This recognition of stag shape is quickly developed. To generalize, one could say that a mature stag would have antlers that are at least one-and-a-half to twice the length of the head.

Apart from the general impression of age, a salient feature to observe is the neck line of the undisturbed animal. As age increases, so the head is carried lower and the graceful curve of neck is lost. In a very old animal the neck line becomes practically a prolongation of the line of the back.

At close quarters, antler pedicles may be studied, and it will be noticed that the pedicles of older stags are short and the coronet or burr of the antler closer to the skull than that of a young animal. After a stag reaches maturity, its antlers are said to go back, i.e., lose length, weight and tines.

Yearlings.—At about eight months, the growth of the antler pedicles is noticeable. They appear as lumps on the skull and the growth of the first year antlers or spikes is a continuation of the pedicle development. It is most unusual for first year antlers to be anything more than simple spikes which will vary in length from two or three to fifteen inches according to the species of deer. A young looking stag with spikes would be in its second year. Except during the rut, male deer may be seen in groups.

Hinds and does.—Apart from very young animals which can be distinguished by comparison of size, the only salient feature an observer may notice in the field is the neck of older females. Old animals have a thinner neck and may have a marked drop from the line of the back to the base of the neck at the shoulder. Older hinds and does usually lead any group of deer.

NOTES ON DEER SPECIES.

RUSA DEER (*Cervus timorensis*) (*Plate* I).

SHOULDER HEIGHT. Thirty-six to forty inches.

WEIGHT. Average mature stag to about 220 lb. The hind perhaps to 40 lb. lighter.

COLOUR. Greyish-brown ; some animals appear much darker (age ?). In sunlight a reddish tinge is most noticeable. The light buff colour of the belly and inner legs appears to extend more generally into the darker body colour and provides a remarkably effective protective colour combination. There is a light-grey patch on the under-neck and throat to the chin which is prominent in good light.

EARS. Not strikingly large (6 in.) and inclined to be pointed.

TAIL. Appears thin and is not bushy.

HOOFPRINT. Rarely larger than $2\frac{3}{8}$ in. × $1\frac{1}{2}$ in.

HABITAT. Appears to be adaptable to a wide range of habitat. Tends to live in herds, and groups of several animals are often seen.

HAIR CHARACTERISTICS. (Neck and back.) Individual hairs flattened.

SIGHTING UNDER 50 *YARDS*. Often three or more animals. The neck appears long and craning and the head small in comparison with the body—particularly so with large-antlered stags. Stag groups may be seen. The antlers, when viewed from the front, are lyre shaped and have six tines. The top-most tine on each antler is vertical and these two tines, thrusting upward and carried upright are most prominent in the mature stag. During the rut, stags decorate their antlers with masses of vegetation. This decoration is not the accidental carrying of rubbing tree matter. Although a reddish tinge is sometimes quite noticeable in the body colour, this should not cause confusion with the red deer, because the rusa does not have a light-coloured patch on the back, above the tail. A retreating rusa does, however, display a prominent area of light colour under the tail, and between the back legs. The animal has a particularly rangy, 'leggy' look, and after the initial alarm may stand again at 100 or 200 yards' distance. These deer wallow. The stags fight savagely during the rut.

References.

BENTLEY (1967) : 67-69.

RINEY (1955) : 15-17 includes comparison with sambar.

VAN BEMMEL (1949).

AXIS DEER (*Axis axis*) (*Plate* II).

Sometimes referred to as chital or spotted deer.

SHOULDER HEIGHT. To 36 in.

WEIGHT. To about 200 lb.

COLOUR. Chestnut-brown, brightly spotted with white ; dark stripe along spine evenly spotted white. White belly and throat. The white spots remain throughout the year.

(*a*)

(*b*)

(*c*)

(*d*)

Plate I: RUSA DEER.—(*a*) Rusa stag. Note the straight and vertical inner or rear tines of terminal fork. This head has not uniform structure in both antlers. (*b*) Rusa hind and fawn (four months old). Note long neck, light-coloured legs and patch at throat. (*c*) and (*d*) Rusa stag.

[Photographs are of specimens of deer from Australia, *not* New Guinea].

Plate II : AXIS DEER.—Axis stag.
[Photograph is of a specimen of deer from India, *not* New Guinea.]

EARS. Not noticeably large. Pointed.

TAIL. Long, with bold, white fringe.

HOOFPRINT. Rarely larger than 2 in. × $1\frac{1}{8}$ in.

HABITAT. Open forest at lower levels.

SIGHTING UNDER 50 *YARDS*. This deer has a strong herd instinct and except for lone stags, will usually be seen in groups ; 50 animals or more if the country is quite undisturbed. Axis deer are among the most beautiful of deer, and are comparatively easily identified by their bright markings. The white throat is a striking characteristic. The antlers are usually six-tined (brow and terminal fork) and are quite slender. The velvet of the growing antlers is reddish-brown. The tail is raised on alarm and the white underside is most conspicuous, particularly when several animals move off. These deer do not wallow, but are not likely to be found far from water.

References.

BENTLEY (1967) : 63-66.
RINEY (1955) : 11-13.

FALLOW DEER (*Dama dama*) (*Plate* III).

SHOULDER HEIGHT. Thirty-four to thirty-six in.

WEIGHT. Buck to about 200 lb. ; doe considerably less.

COLOUR. Usually light-brown or fawn, sometimes with a reddish tinge flecked with large white spots. This is the usual summer colouration but there are many variations ; sometimes white or black animals are seen. The winter colour is grey or dark-brown without spots or the spots barely discernible. A black, or very dark, line of hair runs along the spine to the tail. Underparts creamy-white. Young are spotted.

EARS. Five in. and pointed.

TAIL. Fairly long, often black, with fringe of long, white hairs. When animal is not alarmed the tail is flicked constantly.

HOOFPRINT. Rarely larger than $2\frac{1}{4}$ in. × $1\frac{1}{2}$ in.

HABITAT. Prefers lighter country at lower levels to mountainous forest. Adult buck has a most noticeable tuft of long hairs on the penis sheath.

SIGHTING UNDER 50 *YARDS*. Two or three animals or sometimes more, in open country, may be seen together. The palmated or flattened antlers of the adult male are a positive identification. The general glimpse of a grey-with-white, smallish animal (summer) is the usual sighting in bush. A single animal unsure of the danger will move off with a bounding, stiff-legged gait with the tail held over the back, all four feet off the ground together. In this situation, the animal will stop after about 50 yards to again locate or confirm danger. Fallow are not often vocal, but very occasionally they may bark once or twice if suddenly alarmed. During the rut the bucks give a throaty rattle but they do not roar. In open country, a group of fallow should be fairly easily seen, particularly if an adult buck is present. These deer do not wallow.

References.

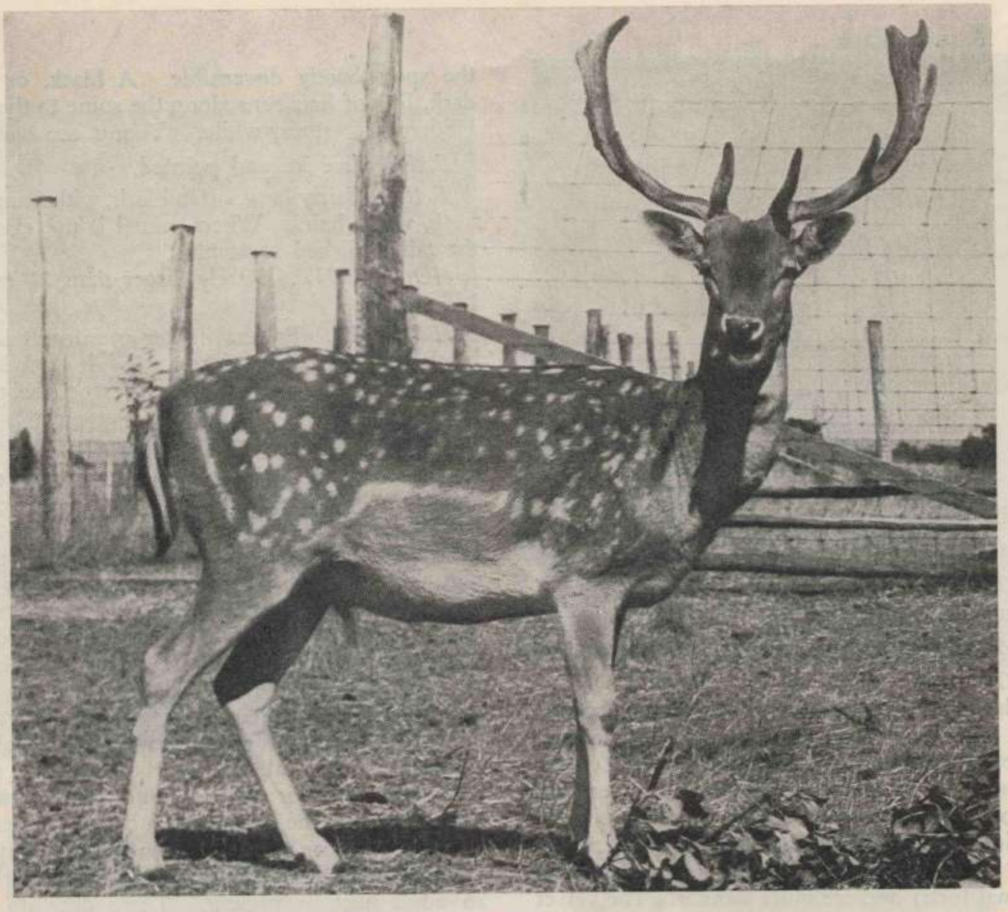
BENTLEY (1967) : 54-61.
CADMAN (1966).
CHRISTIE AND ANDREWS (1966) : 82.
PAGE (1962).
PRIOR (1965).
RINEY (1955) : 20-22.

SAMBAR DEER (*Cervus unicolor*) (*Plate* IV).

SHOULDER HEIGHT. To 50 in.

WEIGHT. To 600 lb., but average adult stag 350 to 400 lb. Adult hind 250 to 300 lb.

COLOUR. Uniform dark shades of brown, almost black appearance in certain lights. Hinds frequently lighter in colour than the stags. Light buff colour on the belly, inner legs, buttocks and chin. Often an orange-coloured fringe of hair surrounds the light patch on the rump. The young are not spotted.



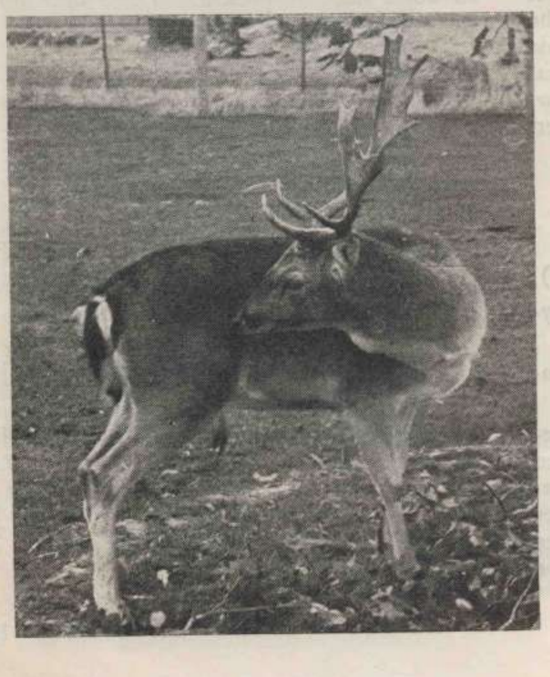


Plate III : FALLOW DEER.—(Above) Fallow buck, summer coat, antlers still in velvet but fully grown. Note long hairs on sheath, black tail with white underside, white tail patch, flattening of antlers. (Left) Fallow buck, winter coat (same animal as above). Note no spots although sometimes these may be carried all year round.

Plate IV : SAMBAR DEER.—(Above) Sambar stag. Note raised tail and fringe of longer hair at throat. (Left) Sambar hind about 2 years old. Note star of turned hair on base of neck common to all Sambar. Small area of bare skin here sometimes. Note size of ears. (Below) Sambar hind.

EARS. Strikingly large (7 in. +), round and bat-like.

PROMINENT GLANDS. In front of the eye, these are everted in alarm and are most noticeable.

TAIL. Varies in length, but frequently long (to 12 in.) and bushy.

HOOFPRINTS. Rarely larger than $2\frac{3}{4}$ in. × $1\frac{7}{8}$ in.

DROPPINGS. Usually in groups.

HABITAT. Heavy forest on the fringe of settlement or natural clearings. Readily adaptable to lighter country where adequate cover is available.

SIGHTING UNDER 50 *YARDS*. Very round ears with a surround of grey often noticeable. Large gland in front of the eye distended in alarm. Fringe of longer hair about the neck and throat erected. Compact, dark body ; head held low when moving in cover ; rump appears higher, nose thrust forward, antlers along back. Sambar may allow a very close approach if they are in cover or very close to it and they feel they have not been seen. The hearing of a short, heavy, crashing run with or without a glimpse of the light-coloured under-tail patch is frequently the observer's first indication of the presence of sambar. Unless the animal is injured, the tail is always raised on alarm and one of the most usual views of a sambar in cover is the flesh-coloured skin on the underside of the raised tail and the large, light-coloured rump patch. In the case of the stag, this sighting may sometimes be preceded by a most startling honk, quite unique in deer sounds in its intensity. Hinds may bark repeatedly at a distance. A hind with a very young calf may stand momentarily and stamp the forefoot before moving off. Sambar prefer to go under obstacles rather than jump them. The stag's antlers are six-tined and the velvet of the growing antlers is grey. These deer wallow.

References.

Bentley (1967) : 19, etc.

Riney (1955) : 14 and 17.

RED DEER (*Cervus elaphus*) (*Plate* V).

SHOULDER HEIGHT. To 48 in.

WEIGHT. Up to 500 lb. has been recorded, but the adult stag weighs 300 to 350 lb., the hind about 200 lb.

COLOUR. Invariably the red shade, from which this deer gets its name, is visible but in winter they are a duller brown. There is a large straw-coloured patch about the buttocks and this extends onto the back above the tail. During the rut, the stag develops a conspicuous mane and in common with many deer, the neck thickens. Young calves are spotted white.

EARS. Rather long (7 in.), but narrow and pointed.

TAIL. Very short.

HOOFPRINT. Round-toed and large, about 3 in. × 2 in.

DROPPINGS. Often in groups but frequently found in lines, being dropped as the animal walks.

HABITAT. Adaptable but prefers mountainous or undulating forest.

SIGHTING UNDER 50 *YARDS*. The red deer is an animal with a strongly developed herd system. Usually four or more animals are seen, depending on the density of population. Groups of stags and groups of hinds and young may be seen. The stag marshals a number of hinds during the rut. The most noticeable characteristic is usually the reddish colour and the light-coloured rump patch which extends over the tail. Hinds will frequently bark on alarm and may continue to do so as they move off. The antlers of the adult stag are often multi-tined. The colour of the velvet of the growing antler is grey. During the rut, the stags roar frequently in the early morning and late afternoon. The roar is a cattle-like bellow or shorter variations. A reasonable imitation will usually be answered readily by the stag, followed by a closer approach to the 'caller'.

REFERENCES.

Bentley (1967) : 43, etc.

Page (1962).

Riney (1955) : 6-8.

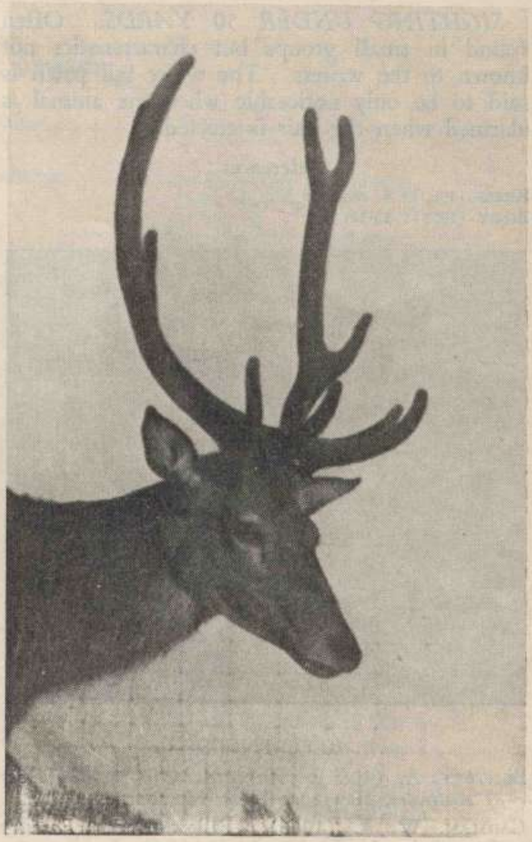


Plate V : RED DEER.—(Above and right) Red stag. (Below) Red Deer hind. Note short tail and light-coloured rump patch extending onto back above tail.

SIKA DEER (*Cervus nipon*) (*Plate* VI).

(Pictured on page 12.)

SHOULDER HEIGHT. To 38 in.

WEIGHT. To 180 lb.

COLOUR. Chestnut-red with white spots in summer ; uniform grey in winter. White rump patch throughout the year. The young are spotted white.

EARS. Round and bat-like.

TAIL. Long (10 in.), white on the underside.

ANTLERS. Usually eight-tined in the adult stag. The velvet is a golden colour with black patches.

HABITAT. Adaptable to a wide range of cover but prefers forest and dense scrub.

SIGHTING UNDER 50 *YARDS*. Often found in small groups but characteristics not known to the writers. The white tail patch is said to be only noticeable when the animal is alarmed when the hair is erected.

References.

KIDDIE (1962): 6, etc. and 33.
RINEY (1955): 13-14.

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RINEY, T. (1955). Identification of Big Game Animals in N.Z. *Dom. Mus. Handbook.* Wellington.

VAN BEMMEL, A. C. V. (1949). Revision of the Rusine Deer. *Treubia.* Vol. 20, Part 2 : 191-262.

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Accepted for publication, December, 1968.

Plate VI : SIKA DEER.—(Left) Sika stag. Note white spots and tail and position of white rump patch ; prominent glands on hind leg. (Below) Sika hind. Note white spots and tail, position of rump patch ; prominent light-coloured gland on hind leg.

(Photographs R. Prior, " Living with Deer ", Deutsch Lond., 1965.)

Appendix 1.

DEER SIGHTING REPORT.

Name..

Address..

....

....

For deer seen while hunting

Date..

Locality..

....

Number of deer not seen close enough to classify ☐

Number of STAGS ☐

Number of YEARLINGS ☐

Number of HINDS ☐

Number of CALVES ☐

Shape of antlers :—See *Figure* 1 and record whether type A, B, C, D, or E.

Appendix 2.

DEER SPECIMEN REPORT.

Name..

Address..

....

....

For each deer shot

Date..

Locality..

....

1. SEX.

Stag	.... Antlers present	Soft velvet	Hard polished	Number of tines	Testes enlarged	Antlers freshly cast
	☐	☐	☐	☐	☐	☐
Hind	.... Pregnant	Udder with milk	Udder without milk	Calf at foot	Foetus present	
	☐	☐	☐	☐	☐	

2. WEIGHT.

....lb. (Valuable if can be obtained.) Note: Dressed or whole weight.

3. SIZE.

The following measurements are useful if these can be obtained. See *Figure* 2.

Total length: tip of nose to end of last tail vertebrae. Lay the deer on its side and pass tape along curvature over face, head, neck, spine and part of tail. ☐

Height at shoulder: vertical distance from tip of the hoof of a foreleg to a point on the mid-line between the shoulders. ☐

Girth: the circumference of the chest cavity immediately behind the forelegs. ☐

4. JAWBONES.

Collect both lower jawbones, label with number..

5. FOOD.

Collect about ½ lb. food from rumen and preserve in ten per cent. formalin.

6. NOTE.—disease, parasites, malnutrition, etc.

Observations in Time of Maturity of Sweet Potato (Ipomoea Batatas *(LAM.)*)

G. I. JAMIESON.*

ABSTRACT.

To observe development of a sweet potato crop, a technique using successive row by row harvesting of plots was used. Comparisons were made of various crop characters on the one soil type with varied pre-crop histories. It was found that as the soil tended to exhaustion low yields were obtained, resulting from reduction in both number and size of tubers, and that maxima in crop yield, number of tubers and flowers occurred earlier than in less depleted soil. It was shown that maximum flowering is a useful indicator of time of achievement of maximum yield.

The range of tuber size and its influence on crop maturity is also discussed.

INTRODUCTION.

ALTHOUGH sweet potato *Ipomoea batatas* (Lam.) is the staple food of much of the indigenous population of the Territory of Papua and New Guinea, little work has been done on its agronomy in this country.

A sweet potato crop is described as mature when it is considered ready for harvesting. This stage is usually judged subjectively by loss of vigour of the topgrowth, death of the lower leaves, and general yellowness of the vines. These criteria are normally employed in early estimations of when to harvest a particular sweet potato variety, but once experience has been gained, time of harvesting is usually judged by the length of time the crop has been in the ground. Varieties are often described as four, five or six-month varieties.

Hassell (1955) stated that the crop is mature when the cut surface of a typical tuber dries clear, according to the normal colour of the flesh. If immature, it will dry a dark or greenish colour.

In parts of the highlands of the Territory of Papua and New Guinea, sweet potato crops are allowed to grow for up to two or three years, while individual tubers are harvested from the soil as they mature, without removal of the topgrowth. Maturity of the individual tubers is decided by size.

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In those parts of the world where frosts occur, the practice is to harvest sweet potato immediately after the first killing frosts of winter.

A casual observation was made during conduct of the Soil Exhaustion Trial (Newton and Jamieson 1968) that sweet potato crops were maturing earlier as the trial progressed.

Logically, a sweet potato crop is best harvested at the stage of maximum yield, consistent with acceptable eating qualities. The following project, consisting of three main trials, was an attempt to study the development of a sweet potato crop, to link some easily discernible crop character with the stage of maximum yield, and also to investigate the hypothesis that as the soil tends towards exhaustion, so a sweet potato crop matures earlier.

EXPERIMENTAL METHODS.

Three field trials were carried out on pumice-derived soils at the Lowlands Agricultural Experiment Station, Keravat, where the annual rainfall of 110 in. is well distributed. The soils have a high sand content and are very low in clay. They are therefore strongly susceptible to leaching. The plots used in the trials were 30 feet square, and the sweet potato was planted in hilled rows. The ridges were built with hand hoes to a height of about one foot.

The name of the variety of sweet potato used is unknown, but it is numbered K3 in the Keravat collection. The variety has red-skinned tubers with white flesh, and the leaves are palmate. It is reputed to mature in seven months.

The basic technique used in the trials was row by row harvesting. Consecutive rows were harvested with a determined time lapse between each row harvest. In this way, some indication of development of the crop with time was obtained. The first and last row records were ignored in Trials 1 and 2, and the last row records were ignored in Trial 3 because of possible edge effect. It was considered that there would not be any applicable edge effect on an inner row for the short period for which it was an edge row. Therefore, no arrangements were made to overcome this effect.

At each harvest, the following observations were made :—

1. Weight of tubers in each row ;
2. Number of tubers in each row ;
3. Number of rotted tubers in each row ;
4. Number of flowers in each row harvested ;
5. Vigour of the crop on each plot ;
6. The general colour of topgrowth on each plot ;
7. Colour of dried sap of the cut tuber ; and
8. Whether or not the sap formed beads or ran freely when the tuber was cut.

All fully formed tubers were harvested from each row. Tubers which weighed less than approximately one ounce were not considered, but were discarded from the harvest.

Score systems were used in the estimates of vigour and topgrowth colour :—

Vigor.	Score.	Topgrowth Colour.	Score.
Very good	4	all green	5
Good	3	¾ green	4
Fair	2	½ green	3
Poor	1	¼ green	2
Very poor	0	all yellow	1

There were slight variations in the observations made on each trial. These changes in procedure will be indicated where applicable.

TRIAL 1.

This trial was superimposed on part of a Three-Course Rotation Trial which is part of the project investigating farming systems (Newton and Jamieson 1968).

Basically, this trial compares four wide rotations involving an 18-month period of *Mimosa invisa* or *Pueraria phaseoloides* as cover crops and three rotations of virtually continuous food-cropping. Rotations in all treatments are on a three-year cycle.

Trial 1 was superimposed on Series A, Third Cycle, First Planting of the Three-Course Rotation Trial when all 21 plots of the series were planted to sweet potato.

The Rotation Trial had been in progress for over six years, and the wide rotations, particularly those involving a *Pueraria* cover crop, were yielding sweet potato significantly better than the narrow rotations. It was suspected that the yield differences were due to relative differences in the stage of soil deterioration. Thus it was hoped that by superimposing this trial on the sweet potato plots of the Rotation Trial, differences in behaviour between sweet potato on wide and narrow rotation plots could be observed.

There were ten rows of sweet potato on each plot. Harvesting commenced when the crop was six months old, and was continued at weekly intervals. At each harvest, observations were carried out as outlined above.

RESULTS.

The results are shown in *Table* 1. Those of the first and tenth harvests are excluded because of apparent edge effects.

In wide rotations, the sap exudate from cut tuber faces formed beads at and after the fourth harvest. This stage was not reached until the fifth harvest in the narrow rotations.

Statistical analysis indicated :—

1. No difference in time trend between the yield increases of wide and narrow rotations, and there was no significant difference between yields ;
2. Tuber size reached maximum during the period of the trial and wide rotations produced larger tubers than narrow rotations. There was no difference in the rate of increase in tuber size between wide and narrow rotations during the period of the trial ;
3. The slight increase in the number of tubers during the trial was not significant ; and

Table 1.—Trial 1 Means.

Harvest No.	Days After Planting.	Tuber Yields (lb./Row).		No. Tubers/Row.		Wt./Tuber (lb.).		No. Flowers/Row.	
		Wide Rotations.	Narrow Rotations.	Wide Rotations.	Narrow Rotations.	Wide Rotations.	Narrow Rotations.	Wide Rotations.	Narrow Rotations.
2	191	11.0	8.9	60	69	.18	.13	3	2
3	198	13.0	10.3	70	76	.19	.14	14	3
4	205	11.8	11.0	65	81	.19	.14	16	7
5	212	13.0	10.4	57	70	.24	.15	14	5
6	219	14.1	10.2	74	71	.19	.14	33	15
7	226	13.9	10.5	67	69	.21	.15	73	29
8	234	15.6	12.2	77	80	.21	.15	65	30
9	241	15.0	9.9	87	65	.18	.15	28	27
Mean Linear Coefficient		0.50 lb./week **		1.4/week		.002 lb./week *		——	
Mean Quadratic Coefficient						.003 lb./week *			

Mean Totals per Plot over the Eight Harvests.

	Wide Rotations.	Narrow Rotations	
Tuber Yield (lb.)	107.0	83.4	NS
No. Tubers	552	580	NS
Wt./Tuber (lb.)	.20	.14	LSD .04(P<.01)

4. Flowering came to a peak at about the time that yields reached a maximum, but there was no difference in flowering time trend between wide and narrow rotations.

DISCUSSION.

The results of Trial 1 indicate that achievement of maximum flowering and maximum tuber yield are linked, and that narrow rotations produced smaller tubers.

The results also indicate that, at least in the later stages of development, yield increases may be largely due to increase in tuber weight, rather than to production of more tubers.

It was unfortunate that observations on this trial did not commence earlier. Only the later stages of development of the crop were observed and by this stage most of the development had occurred. Further, crop yields in all rotations were extremely low, probably due to seasonal factors.

The results of this trial gave little support to the hypothesis that sweet potato crops mature earlier as the soil tends to exhaustion. However, since yield differences between wide and narrow rotations were not significant, the effect of season, or the soil fertility difference between wide and narrow rotation plots may not have been sufficient to show differential crop behaviour.

TRIAL 2.

As work progressed on the first trial, it became evident that knowledge of what comprises a mature sweet potato crop was lacking. To investigate development of the crop further, a nine-plot trial was laid down on virgin soil. Each plot was 30 feet square, and contained ten hilled rows of sweet potato.

Essentially the same techniques were used and the same observations made as in the first trial. However, in an attempt to establish a criterion of maturity, samples of the harvested tubers were boiled, and eating qualities were assessed by a panel of New Guinean station field workers. Broken and rotted tubers and tubers smaller than approximately 2 oz. were rejected from the random sample collected for each palatability test.

Harvesting commenced when the crop was three months old, and continued at fortnightly intervals for ten harvests until the crop was eight months old.

RESULTS.

The results of Trial 2 are shown in *Table* 2. Those of the first and tenth harvests have been omitted because of possible edge effects.

The estimations of trends in crop behaviour in this trial may have been upset by the fact that at least minor pilfering of tubers was found to have occurred towards the end of the trial.

The rate of increase in yield of tubers appeared to diminish in the later stages of the trial. Yields increased only three lb. per row from the fifth to the ninth harvest, in contrast to twelve lb. per row from the second and the fifth harvest. There is a suggestion of maximum yield having been reached between the eighth and ninth harvests.

There is an indication of a maximum having been achieved in the number of tubers at about the fifth or sixth harvest, but probably the increase in number of tubers after the third harvest is not significant.

Individual tuber weights increased linearly over the period of the trial.

The linear increase in individual tuber weights, coupled with the suggested maximum yield between the eighth and ninth harvests, seems illogical, unless tubers were lost. As rotting was not evident, it appears certain that significant regular pilfering occurred towards the end of the trial. Since trends would have been greatly influenced by this loss of tubers, statements of significance have been omitted from *Table* 2.

Flowering had not reached its peak by the end of the trial.

From the fourth harvest onwards, sap exudate from the cut tubers formed beads. Eating quality, judged by absence of fibre from boiled tubers, was acceptable from the fifth harvest onwards.

Vine colour had yellowed appreciably by the sixth harvest, and by the eighth harvest, vigour was declining noticeably.

DISCUSSION.

The value of this trial was considerably marred by the apparent loss of tubers towards the end of the trial.

The suggested maximum in yield between the eighth and ninth harvests is inconclusive, and may have been an artefact of the model fitted in the statistical analysis. Allowing for the evidence of pilfering, there is a strong possibility that a true yield maximum was not achieved during the trial period.

The recorded figures for tuber numbers indicated that the maximum number of tubers had probably been produced by the third harvest, or

Table 2.—Trial 2 Means.

Harvest No. / Days After Planting	2 / 111	3 / 125	4 / 139	5 / 153	6 / 167	7 / 181	8 / 196	9 / 209	* Linear Coefficient (per 2 weeks).	*Quadratic Coefficient (per 2 weeks).
Tuber Yields (lb./row)	12.6	16.2	19.5	24.2	26.8	27.8	25.6	29.7	2.31	0.71
No. Tubers/Row	128	150	163	195	182	162	145	154	1.97	†
Wt./Tuber (lb.)	.11	.12	.12	.14	.15	.18	.16	.21	.013	.002
No. Flowers/Row	0	0	0	0	1	4	12	11		
Vigour	4	4	4	4	4	4	3	3		
Leaf Colour	5	5	5	5	5	4	4	4		
No. Rotted Tubers	0	0	0	0	0	0	0	0		
Sap Bead or Run	Run	Sl B	B	B	B	B	B	B		
Appearance Boiled Tubers	Vitreous	Dry Floury	Dry Floury	Dry Floury	Dry Floury	Dry Floury	Dry Floury	Dry Floury		
Flavour Boiled Tubers	StSpSw	St	StSlSpTa	dry Ta	dry Ta	dry SlTa	dry SlTa	dry SlTa		
Dry Sap Colour	In all cases after ½ hour turned green-black and after a few hours turned red-brown									

* Unit varies with each line with the variable being considered

† Increase from 111 days to mean of 125 to 209 days = 34 tubers

Sl—Slightly
B—Beaded
St—Stringy (fibrous)
Sp—Spongy
Sw—Sweet
Ta—Tangy

at least by the fifth or sixth harvest. Pilfering, however, would have distorted this trend and its interpretation is of little value.

Other observations would not have been greatly affected by pilfering, and are worth discussing.

It is obvious that crop development had not run its full course by the conclusion of the trial, seven months after planting. Flowering was in its early stages, and tuber weights were still increasing linearly, although the variety used in the trial is reputed to mature in seven months. By the unrecorded tenth harvest (223 days after planting) flowering increased to 36 per row.

The late maturity of the crop in Trial 2 may have been due to seasonal factors. It is also possible that it may have been due to the fact that the crop was growing on a virgin soil. The decline of vigour and the tendency for leaves to yellow recorded towards the end of the trial would suggest that the crop was nearing maturity.

Palatability tests conducted on tubers at each harvest indicated that the tubers would be acceptable by the fifth harvest, when the crop was five months old. This was approximately the same time that the sap exudate from cut tubers formed beads, rather than running freely over the cut surface. Acceptable eating quality was attained somewhat earlier than maximum yield as determined by statistical analysis of the recorded yield trend. Palatability testing is discussed in more detail in the appendix.

The appearance of the boiled tubers did not show great promise as a determinant of tuber maturity.

TRIAL 3.

This trial can be considered as a repeat of Trials 1 and 2, as well as a comparison of sweet potato crop development in essentially the same soil at three stages of exhaustion.

The trial was carried out on two sites :—

The 21 plots of Series B, Third Planting Third Cycle of the Three Course Rotation Trial on which Trial 1 was superimposed ; and

Twelve plots, each 30 feet square, on a site adjacent to the Three Course Rotation Trial, which had been under a cover of the legume *Pueraria phaseoloides* for several years. It was anticipated that these plots would be higher yielding than those of the Three Course Rotation Trial. Of the twelve plots, the *Pueraria* topgrowth was removed from three prior to commencement of the trial, while it was dug into the plots on the remaining nine.

All plots contained eight hilled rows of sweet potato.

The first harvest was carried out 106 days after planting, and subsequent harvests were at three-week intervals, except that harvests 3 and 4 were each four weeks after the previous harvests. Essentially the same observations as in the two previous trials were made. It was hoped that differences in crop behaviour could be observed between sweet potato growing on wide and narrow rotation plots, and on plots which had supported *Pueraria phaseoloides* for a long period.

RESULTS.

Results of the trial are shown in *Table* 3. No distinction is drawn between the two treatments superimposed on the *Pueraria* plots, as there was no difference in crop behaviour. The results of palatability tests and beading of sap exudate are not included as they were variable and inconclusive.

These results were not analysed statistically, but it is clear that *Pueraria* plots out-yielded the wide rotation plots which, in turn, out-yielded the narrow rotation plots. Narrow rotation plots produced fewer and smaller tubers and fewer flowers, were less vigorous, and contained a higher proportion of yellow leaves than wide rotation and *Pueraria* plots.

Sampling variation within replicates precluded the posibility of defining maxima in the crop development. A comparative index was obtained by weighting the time of observation by the measure at this time and dividing the sum of these figures by the sum of the measure over the first seven harvests. A measure which increased sharply over the last harvests would give a high index. Results of the eighth harvest were excluded from the analyses because of suspected edge effects. Results of the analyses are shown in *Table* 4.

The clearest difference between treatments was in respect of flowering trends. The differences between the time indices may be due to prolonged flowering on the *Pueraria* plots, and an early brief peak on the narrow rotation plots.

Table 3.—Trial 3 Means.

Harvest	1	2	3	4	5	6	7	Means
Days after Planting	106	127	156	183	204	225	246	
Weight Tubers per Row (lb.)								
Wide Rotations	18.0	21.7	23.5	27.4	28.2	27.3	26.0	24.6
Narrow Rotations	5.7	8.1	10.7	8.6	9.2	7.2	5.8	7.9
Pueraria Plots	22.9	23.7	32.7	36.3	40.6	39.9	35.0	33.0
Number Tubers per Row								
Wide Rotations	121	120	109	117	134	124	142	124
Narrow Rotations	76	70	67	66	64	56	41	63
Pueraria Plots	126	99	106	146	143	153	164	134
Weight per Tuber (lb.)								
Wide Rotations	0.15	0.18	0.22	0.24	0.22	0.22	0.19	0.20
Narrow Rotations	0.07	0.10	0.14	0.12	0.13	0.11	0.12	0.11
Pueraria Plots	0.19	0.24	0.31	0.26	0.29	0.27	0.21	0.25
Number Rotted Tubers per Row								
Wide Rotations	0.1	0.1	0.1	2.4	1.7	2.0	5.2	1.7
Narrow Rotations	0.2	0.0	0.1	0.3	1.0	2.8	3.1	1.1
Pueraria Plots	0.1	0.2	0.1	1.2	1.2	1.7	4.2	1.2
Number Flowers per Row								
Wide Rotations	20.8	51.2	55.0	82.2	49.3	25.0	9.4	56.6
Narrow Rotations	17.8	33.1	31.4	16.3	17.4	4.9	4.0	41.8
Pueraria Plots	3.0	36.2	105.7	90.6	47.7	64.2	49.1	17.8
Vigour Rating								
Wide Rotations	2.6	2.5	2.2	1.9	2.2	2.9	1.8	2.3
Narrow Rotations	2.3	2.7	1.7	1.3	1.7	2.0	1.3	1.9
Pueraria Plots	4.0	4.0	4.0	4.0	3.8	3.9	2.6	3.8
Leaf Colour Rating								
Wide Rotations	4.6	4.4	4.0	3.9	3.7	3.6	2.6	3.8
Narrow Rotations	3.3	3.1	3.1	3.0	2.6	1.4	1.6	2.6
Pueraria Plots	5.0	4.9	5.0	5.0	4.7	3.8	3.3	4.5

Narrow rotation plots produced maximum yield and maximum number of tubers earlier than the *Pueraria* and wide rotation plots. From *Table* 3 it seems that for narrow rotations the number of tubers had reached maximum by the first harvest, while the weight per tuber reached maximum some time between the second and third harvests. This supports the suggestion from *Table* 3 that maximum yield was achieved between the second and third harvests. The flowering data for narrow rotations indicate a maximum between the second and third harvests, which coincides with maximum yield.

Table 3 data from *Pueraria* and wide rotation plots indicate maxima in yield, tuber number and tuber size by the fourth or fifth harvest, coinciding fairly closely with flowering maxima.

Table 4 shows that the leaf colour rating dropped earlier on the narrow rotation plots than on plots of the other treatments. Data from *Table* 3 suggest that this drop may have been by the sixth harvest on narrow rotation plots, and by the seventh harvest or later on plots of the other treatments.

DISCUSSION.

Trial 3 showed that, at least within a given soil, as crop producing capacity diminished, so various aspects of behaviour of the sweet potato crop tended to occur earlier. Thus, soil deterioration caused earlier development of the crop. Assuming the crop was mature at the stage of maximum yield, it can be stated that soil deterioration caused earlier crop maturity. Under the conditions of the trial the overcropped soil produced a sweet potato crop which matured at least one month earlier than the crop grown on fresh soil. However, the advantage of earlier maturity was offset by a considerably reduced yield.

The crop grown on the *Pueraria* plots was better than the wide rotation crop. However, the trend differences as the crops developed was not sufficiently wide to be distinguishable, except in the case of flowering. Flowering maxima for the two treatments were achieved at approximately the same time, but flower buildup and decline on the wide rotation plots was gradual, while on the *Pueraria* plots the buildup was sharp and the decline protracted. The protracted decline on the *Pueraria* plots was reflected in the time index (*Table* 4). Thus the difference between the flowering time indices between wide rotation and *Pueraria* plots probably does not refer to maxima.

Maximum flowering appeared to be related to the time of maximum yield. On the *Pueraria* plots maximum flowering appeared to pre-date maximum yield by as much as one month. Since these maxima were fairly ill-defined, the difference may have been less. On the wide and narrow rotation plots the two factors appeared to be virtually concurrent.

Appreciable changes in vigour and leaf colour ratings occurred two or three months after maximum yield.

CONCLUSIONS.

The results of Trial 3 substantiate the original hypothesis that as the soil tends towards exhaustion, sweet potato crops mature earlier. Crops grown on wide rotation and *Pueraria* plots were ready for harvest about six-and-a-half months after planting, while crops on narrow rotation plots were ready about five months after planting.

In this respect, however, Trial 3 results are not in agreement with Trial 1, where there was no significant difference between any trends in crop development on wide and narrow rotation plots. However, in Trial 1 there was little difference in yield between the two group treatments. As the different series of the Three Course Rotation Trial on which Trial 1 and part of Trial 3 were superimposed are replications in time, differences in crop behaviour between series should be purely due to seasonal effects. The fact that there were ten rows of sweet potato per plot in Trial 1, and eight in Trial 3 should have little bearing on the outcome of the two trials. Thus the failure of Trial 1 to differentiate between crop development on wide and narrow rotation plots was probably due to seasonal factors upsetting crop responses to treatment.

There is strong evidence from both Trials 1 and 3 that achievement of maximum flowering is closely linked to the stage of maximum yield. Considering evidence of pilfering of tubers, Trial 2 indications are not contrary. It is not possible to determine the time of maximum flowering until after the event, but there is scope for considerable flexibility in the time of harvesting sweet potato, as loss of crop through tuber rotting is minor until at least two months after achievement of maximum yield.

Vigour and leaf colour rating systems of determining crop maturity do not appear to be

Table 4.—Mean Time Index—Trial 3.

	Tuber Yield	No. of Tubers	Wt. per Tuber	No. of Flowers	Vigour	Leaf Colour	No. of Rotted Tubers
Wide Rotations	11.04	10.38	10.75	9.34	9.90	9.28	15.88
Narrow Rotations	9.99	9.14	10.21	6.89	8.83	8.40	16.06
Pueraria Plots	11.45	10.94	10.47	11.52	9.71	9.37	16.31
Variance Ratio for grouped treatments	7.66**	8.89***	0.65	17.05***	2.45	6.49**	0.12
L.S.D. between treatments							
Wide v Pueraria 5%	0.59	0.69		1.24		0.45	
1%	0.80	0.93		1.68		0.62	
Pueraria or wide v narrow 5%	0.64	0.74		1.34		0.49	
1%	0.86	1.01		1.82		0.67	

satisfactory, as their changes are not sharply defined. Further, appreciable changes usually occur well after maximum yield.

Assessment of the time of crop maturity based on tuber characteristics such as palatability and sap beading are not satisfactory, as there is a range of tuber maturity at any harvest. This aspect is discussed more fully in the Appendix.

ACKNOWLEDGEMENTS.

The author is grateful to Mr. G. A. McIntyre, of Division of Mathematical Statistics, C.S.I.R.O., for the the statistical analyses, and advice on the conduct of these trials. Mr. K. P. Haydock also of Division of Mathematical Statistics, C.S.I.R.O. kindly advised on interpretation of statistical analyses of Trials 1 and 2. Comments on the manuscript by Mr. A. E. Charles of the Department of Agriculture, Stock and Fisheries were much appreciated.

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APPENDIX.

Tuber Palatability.

After the tenth harvest of Trial 2, about 120 lb. of tubers from the trial were amassed and used to test tuber weight against palatability. Broken tubers were discarded, and the samples were sorted into weight categories. Sub-samples of each category were then diced so that their original sizes were not obvious, and boiled. Six New Guinean field workers then acted as a panel, and each independently judged the eating qualities of boiled tuber samples. The various components of palatability were ranked from 0 to 10 according to what was considered to be their position of importance in the palatability scale. The total score from this ranking for each weight classification is termed 'Palatability Index' (P.I.). Results of the trial are shown in *Table* 5.

Tubers under 2 oz. in weight were unpalatable (P.I. = 6), and made up 12 per cent. of the weight of tubers. Tubers weighing between 2 oz. and 8 oz. accounted for 38 per cent. of the weight of the tubers, and were of acceptable palatability (P.I. = 22). Ignoring the anomalous index of 22 recorded for the 18-20 oz. tubers, 50 per cent. of the weight of tubers were very palatable (P.I. = >32). These tubers were all in excess of 8 oz. weight.

Assuming that palatability and maturity of a tuber are equivalent, it can be said that there is a range of maturity in any sweet potato harvest, and smaller tubers are less mature than larger tubers. This accounts for the fact that smaller tubers are normally discarded from a harvest prior to cooking.

Palatability tests as applied in Trials 2 and 3 were not soundly based, as tubers for the tests were selected at random, regardless of size. This probably accounts for inconsistencies encountered during the conduct of these tests.

Table 5.—Tuber Size Palatability.

Weight Classification (oz.)	No. Tubers	Percentage.	Weight (oz.)	Percentage by Weight.	Palatability.				
					T	S	F	Ta	P.I.
0-2	166	43	242	12	0	2	1	3	6
2-4	89	23	270	14	4	6	5	7	22
4-6	46	12	247	13	4	6	5	7	22
6-8	29	7	218	11	4	6	5	7	22
8-10	14	4	132	7	9	6	10	7	32
10-12	12	3	140	7	9	6	10	7	32
12-14	2	1	33	2	9	6	10	7	32
14-16	8	2	130	7	9	6	10	7	32
16-18	2	1	35	2	9	6	10	7	32
18-20	3	1	50	3	4	6	5	7	22
20-22	2	1	41	2	9	8	10	7	34
22-24	5	1	110	6	9	8	10	7	34
24+	9	2	310	16	9	8	10	7	34
TOTAL	387	101	1949	102					

Score Key :—

Toughness (T).	
Tough	 0
Slightly tough	 4
Soft	 9

Fibre (F).	
Fibrous	 1
Slightly fibrous	 5
Not fibrous	 10

Sweetness (S).	
Not sweet	 2
Sweet	 6
Very sweet	 8

Tang (Ta).	
No tang	 3
Tangy	 7

Tuber Size Distribution.

As an adjunct to Trial 3, data were recorded on the range of tuber sizes taken at each harvest. A sub-sample of approximately 50 tubers was taken from the yield of each plot at each harvest, and the tubers were classified by weight in 2 oz. classes up to 32 oz.

In *Tables* 6A and 6B, these data have been summarized in categories 0 to 2 oz., 2 to 8 oz. and over 8 oz. to correspond to the results of the trial on tuber palatability. The numerical and weight distribution data were calculated using the plot data in *Table* 3. Results were not analysed statistically.

Data from *Table* 6A suggest that there was no change in size distribution of tuber numbers on wide rotation or *Pueraria* plots as the crops developed. *Table* 6B data suggest that yield increases on *Pueraria* and wide rotation plots were due to increased weight of larger tubers, while contribution to the yields by smaller tubers remained static as the crops developed.

Table 6A.—Size Distribution of Tuber Numbers.

Days after Planting	106	127	156	183	204	225	246	268	106	127	156	183	204	225	246	268
	Percentage Distribution.								Numerical Distribution.							
Harvest	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Weight Class (oz.)	Wide Rotations (1, 2, 6, 7)															
0-2	54	49	40	36	38	39	51	42	65	59	44	42	51	48	72	47
2-8	43	48	52	56	53	53	44	48	52	58	57	66	71	66	62	54
>8	4	5	8	9	10	8	6	11	5	6	9	11	13	10	9	12
Total	101	102	100	101	101	101	101	101	121	120	109	117	134	124	142	112
	Narrow Rotations (3, 4, 5)															
0-2	87	76	70	70	60	67	60	41	66	53	47	46	38	38	25	14
2-8	13	24	28	29	37	31	37	53	11	17	19	19	24	17	15	19
>8	0	1	3	1	3	2	3	6	0	1	2	1	2	1	1	2
Total	100	101	101	100	100	100	100	100	76	70	67	66	64	56	41	35
	Pueraria Plots															
0-2	38	36	33	45	34	30	52	40	48	36	35	66	49	46	85	68
2-8	49	48	45	38	48	50	39	44	62	48	48	55	69	77	64	74
>8	13	15	22	17	19	19	10	17	16	15	23	25	27	29	16	29
Total	100	99	100	100	101	99	101	101	126	99	106	146	143	153	164	169

Table 6B.—Size Distribution of Tuber Weights.

Days after Planting	106	127	156	183	204	225	246	268	106	127	156	183	204	225	246	268
	Percentage Distribution								Weight Distribution (lb.)							
Harvest ...	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Weight Class (oz.)	Wide Rotations (1, 2, 6, 7)															
0-2 ...	29	25	17	14	14	16	24	17	5.3	5.4	4.0	3.8	3.9	4.4	6.2	4.6
2-8	58	62	59	62	54	60	57	52	10.6	13.5	13.9	17.0	15.2	16.4	14.8	13.9
>8	13	14	24	25	32	25	19	32	2.3	3.0	5.6	6.9	9.0	6.8	4.9	8.6
Total	100	101	100	101	100	101	100	101	18.0	21.7	23.5	27.4	28.2	27.3	26.0	26.8
	Narrow Rotations (3, 4, 5)															
0-2	72	63	36	46	35	42	33	40	4.1	5.1	3.9	4.0	3.2	3.0	1.9	2.4
2-8	26	36	48	48	51	46	50	46	1.5	2.9	5.1	4.1	4.7	3.3	2.9	2.8
>8	2	1	16	6	13	13	16	14	0.1	0.1	1.7	0.5	1.2	0.9	0.9	0.9
Total	100	100	100	100	99	101	99	100	5.7	8.1	10.7	8.6	9.2	7.2	5.8	6.1
	Pueraria Plots															
0-2	13	12	9	14	10	8	21	12	3.9	2.8	2.9	5.1	4.1	3.2	7.4	4.9
2-8	52	47	37	34	39	40	45	34	11.9	11.1	12.1	12.3	15.8	16.0	15.8	14.0
>8	34	41	55	51	51	52	34	55	7.8	9.7	18.0	18.5	20.7	20.7	11.9	22.7
Total	99	100	101	99	100	100	100	101	22.9	23.7	32.7	36.3	40.6	39.9	35.0	41.2

By contrast, on narrow rotation plots (*Table* 6A), percentage and numerical distribution of small tuber numbers appeared to decline steadily as the crop developed, while the figures for large tubers rose steadily. *Table* 6B data indicate the percentage of the weight yield contributed by larger tubers increased until the third harvest, while the contribution by small tubers declined over the same period. There was a similar but weak indication from the tuber size distribution of yield. This supports the indication that maximum yield was achieved between the second and third harvests.

The indications are that the sweet potato crops in Trial 3 continued to initiate and develop tubers until production of new tubers was limited by the soil fertility level. Thus in low fertility soil tubers would tend to be more uniform in age, and maximum yield would be more sharply defined than in fertile soil. This appeared to be the case in comparison between narrow rotation crops and crops on *Pueraria* and wide rotation plots.

The trial commenced too late to study very early tuber development, and it is not clear whether the early rate of tuber initiation depended on soil fertility, or whether low fertility induced early decline in initiation rate.

A higher proportion of large tubers was produced in better soil than in less fertile soil in Trial 3. The rate of growth of tubers appeared to be higher in better soil, and the proportion of unpalatable tubers (under 2 oz.) was lower than in poorer soil. However, in poor soil the proportion of unpalatable tubers appeared to decline as the crop aged.

Accepted for publication July, 1968.

Cropping and Soil Fertility Studies at Keravat, New Britain. 1954-1962.

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ABSTRACT.

At the Lowlands Agricultural Experiment Station, Keravat, on the Island of New Britain, two long term farming systems trials have been in progress since 1954. *The trial sites are* 4 *degrees south of the equator, near sea level, and the climate is wet tropical. The trials are sited on deep pumice derived alluvial soils which, in the virgin state, supported rain forest.*

Soil Exhaustion Trial.

The rate at which sweet potato yields declined with constant cropping was studied. The soil was considered exhausted after a five-year period during which ten crops of sweet potato had been grown. A fertilizer trial was then superimposed on the trial plots. The only significant result was a negative response to nitrogen in the form of urea. This result may have been associated with omission of potassium and magnesium from the fertilizer trial treatments. Levels of total potassium in the soil are high. Work is continuing on the project.

Three-Course Rotation Trial.

This trial compares seven different rotations, four of which are wide and three are narrow. Each rotation cycle lasts three years; the narrow rotations consist of almost continuous foodcropping, while the wide rotations consist of one and a half years' food-cropping alternated with one and a half years' covercropping. After two rotation cycles it is evident that even in the wide rotations, foodcrop production cannot be maintained at original levels. It is apparent also that under such conditions of cropping, insect, disease and weed problems can be quite serious. Work on the trial is continuing.

INTRODUCTION.

In the Territory of Papua and New Guinea, subsistence foodcrops are traditionally produced by a method of farming which is generally referred to as 'shifting cultivation' or the 'bush fallow system'.

This system is dependent on the development of a natural bush fallow at the completion of the cropping period, after which land is cleared again and the cropping and fallow cycle repeated. In Papua and New Guinea, land is usually cleared and burned by men of the village. Large unburned logs and stumps often remain on the garden plot. Planting is mostly undertaken by the women of a village and many crop species are frequently planted together in the one plot, each species being harvested as it matures. Certain species such as cassava and bananas may be left to compete with the natural regrowth once the plot has been abandoned. Maintenance of gardens is normally quite good in the early stages of the cropping period but deteriorates in time. After the completion of cropping, the garden is allowed to revert through the various stages of the sere, toward the climax vegetation for the environment. Depending on the pressure of the population on the land, the sere may be interrupted at any stage, and the land replanted as a garden. This often results in conversion of bushland to grassland.

Although individual gardens are rather small, ranging up to the order of five or six acres, it is usual for a clan to maintain several gardens at the one time, each separated by a considerable distance of bushland. A village community garden is often planted as well, and is divided up into very small individually owned plots. This village garden is usually much bigger than the individual clan gardens. Once the gardens in a particular area have been harvested, land is usually opened up in another area, isolated from the first, and the process is repeated.

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Owing to the ruggedness of much of the Territory, flat land is scarce in many regions, and gardens are generally sited on steep hillsides.

Bush fallow rotations have been evolved by countless generations as a result of their efforts to develop a system of farming which was in harmony with their environment. The system serves to maintain crop yields at a satisfactory level by preventing the soil from becoming exhausted, and by avoiding a build-up of insect pests, disease organisms and weeds. Successive crops are planted in soil of reasonable to good fertility. Isolation between concurrently planted gardens and successive gardens helps to prevent the spread of pests and diseases.

However, it has been estimated that 14 million square miles of the tropics are farmed by shifting cultivation and that this area of land supports some 200 million inhabitants—an average of only 14 people per square mile. With the present growth in world population, this spectacular land wastage must be overcome, for with improved medical and social facilities and the expansion of commercial cropping, population pressures on land are increasing and will continue to increase. The bush fallow period is becoming shorter, land is being over-cropped, levels of fertility are falling and soil erosion increasing. Isolation between gardens and successive crops is being reduced, resulting in an increase in pest, disease and weed infestations.

In a few areas of the Territory of Papua and New Guinea, this stage is fast being reached. A more intensified system of farming is therefore required which is consistent with satisfactory yield and reasonable production costs. This would allow a more rational system of land utilization and land settlement and the development of unit farms and would therefore assist in the stabilization of agriculture. Long term land improvements would be possible while more land would be available for commercial development. In particular, a more intensive system of foodcrop farming would be of considerable value for the increasing number of settlers who are participating in land settlement schemes.

For these reasons, two trials were started at the lowlands Agricultural Experiment Station, Keravat, with the aim of studying soil fertility problems associated with intensified farming in the tropics. One was a *Three Course Rotation Trial*, aimed at studying the effects of rotational cropping both on crop yields and soil fertility, and also on the occurrence and control of pests, diseases and weeds. The other trial was a *Soil Exhaustion Trial*, in which the behaviour of the crop yields and soil fertility were studied under a system of continuous exploitative cultivation.

Location.

Keravat, where the two trials were carried out, lies 100 feet above sea level, near the north-eastern tip of the Island of New Britain, at longitude 152 degrees east and latitude 4 degrees 20 minutes south. Since 1950, rainfall has averaged 110 in. per annum, with a period of lower rainfall between June and August. However, rainfall is very variable both in annual total and distribution and has ranged from 85 to 132 in. per annum. Temperature is fairly constant, averaging about 80 degrees F. with a normal diurnal range of 70 degrees F. to 90 degrees F. Relative humidity is high.

Site.

The area used for the Trials had been under secondary regrowth for eight to nine years. Prior to that it had been used by the Japanese army for foodcropping during their wartime occupation. The land is flat, and of fairly uniform soil type. The soil is well over 20 ft. deep, and is derived from volcanic pumice and ash. It was probably deposited as a river flat during snap floods, which occur at times of volcanic eruption. The soil is a loamy sand, containing small amounts of clay and 70 to 80 per cent. coarse sand. It is dark brown in colour, and was originally high in organic matter. Organic matter decreases rapidly down the profile to 14 in. then increases slightly to 27 in., decreasing to nil at 33 in., indicating the presence of a buried profile. Most of the exchange capacity of the soil lies with the organic matter.

PART 1.—THE SOIL EXHAUSTION TRIAL.

Exhaustion of the Soil.

The Trial was designed to investigate the effect of continuous cropping with sweet potato on the level of soil fertility as measured by sweet potato yields, with the ultimate object of cropping the soil to exhaustion. It was planned to then investigate the fertilizer requirements for restoration of fertility and sweet potato yields to the original levels.

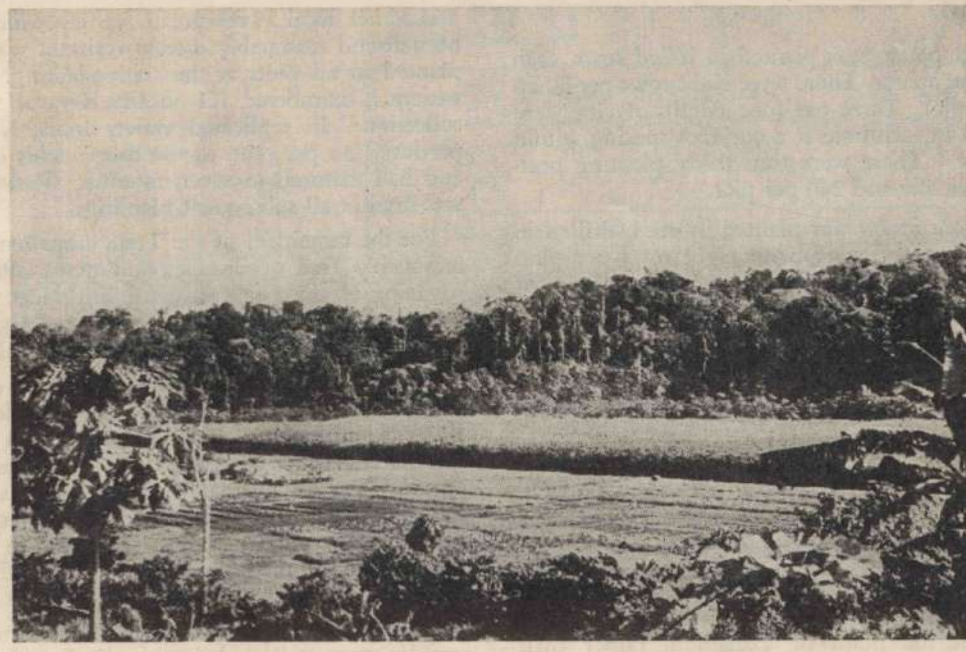


Plate I.—General view of the cropping and soil fertility trial plots in the programme.

Layout and Design.

Measurement of declining soil fertility through yields of successive crops is complicated by fluctuations in yield caused by seasonal conditions. The Trial was therefore designed so that declining fertility would be measured by study of crop behaviour on plots on which cropping had commenced at different times. The four treatments comprised four dates of planting to the first crop of sweet potato, treatment 2 being planted at the date of the second planting of treatment 1, treatment 3 at the date of the third planting of treatment 1 and treatment 4 at the date of the fourth planting of treatment 1 (*Table* 1). Each treatment was thus a replicate in time.

As it was impractical to retain the original secondary bush cover on later planted plots, all were cleared simultaneously. The short term leguminous cover crop *Phaseolus calcaratus* was sown on the plots of treatment 2 and the long term leguminous cover crop *Mimosa invisa* was sown on the plots of treatments 3 and 4. These cover crops were turned in before planting the first crops of sweet potato.

Details of the planting programme are shown in *Table* 1. The plots were set out in the form of a 4 × 4 latin square as shown in *Figure* 1.

Table 1.—Soil Exhaustion Trial—Keravat. Experimental Design.

Planting.	Treatment 1.	Treatment 2.	Treatment 3.	Treatment 4.
1	SP	P.c	M	M
2	SP	SP	M	M
3	SP	SP	SP	M
4	SP	SP	SP	SP
Thereafter	SP	SP	SP	SP

Treatments replicated four times in space.
SP = Sweet potato "Ipomoea batatas".
P.c = "Phaseolus calcaratus".
M = "Mimosa invisa".

Figure 1.—Soil Exhaustion Trial—Keravat. Layout of Treatments.

2	3	4	1
4	1	2	3
3	4	1	2
1	2	3	4

Plot Size—30 ft. square.
Plots separated by 4 ft. paths.

Procedure.

Sweet potato was planted in hilled rows, each four feet apart. There were eight rows per 30 ft. square plot. Three one-foot lengths of vine were planted in each hole at a one-foot spacing within the row. There were thus thirty planting positions per row and 240 per plot.

Mimosa invisa was planted by seed, drilled in rows four feet apart, with eight rows per plot. For ease of handling, the thornless strain of *Mimosa invisa* was used.

Phaseolus calcaratus was planted by seed in drills fifteen inches apart, the plants being subsequently thinned to a six-inch spacing within each row.

The first planting of the Trial was in May, 1954, with a local variety of sweet potato which is numbered K3 in the Keravat collection and which normally matures in about six months.

Maturity was judged to have been reached when the sap exudate from a cut tuber formed beads at the point of exudation, rather than spreading freely over the cut surface. When the crop matured, plots were harvested, and the total tuber yields of each plot were recorded. Sweet potato top growth was cut and carried away from the plots.

After each harvest an average of four weeks was required to prepare the plots for the following planting. For each consecutive planting, the direction of the hills was changed 90 degrees so that a fairly thorough mixing of the top 12 in. of soil in the plots was achieved as the Trial proceeded.

Sweet potato variety K3 was used in the first five plantings of the trial. However, in the third planting severe disease and insect damage practically destroyed the crop and symptoms of 'little leaf virus' were noted. Fresh vines from an outside source were introduced for the fourth planting, and the crop was sprayed regularly with B.H.C. miscible oil and white oil.

Severe damage to the crop by insects and disease occurred again during the fifth planting and all plots were planted to *Sorghum vulgare* for a period of six months in an attempt to clear the Trial site of diseases and to combat suspected infestations of soil nematodes and the crown rot fungus *Sclerotium rolfsii.*

Another local sweet potato variety which had been found reasonably disease resistant was then planted in all plots at the sixth planting. This variety is numbered K1 in the Keravat variety collection. In replicated variety trials, K1 had produced 53 per cent. of the tuber yields of K3, and had matured in seven months. Variety K1 was used in all subsequent plantings.

For the remainder of the Trial, crops remained reasonably free of diseases and pests, although rogueing of vines infected with 'little leaf virus' was necessary. The crops were dusted regularly with a mixture of B.H.C. and copper oxychloride.

By the tenth planting yields had fallen drastically with extremely poor vine growth evident on all plots and leaf size and internode length greatly reduced, although small isolated patches supported vigorous normal growth. It was considered that the soil had been exhausted and the study of exhaustion rate was terminated in order that a study of methods of rejuvenating the exhausted soil could be undertaken.

During the first ten plantings six series of soil samples were collected for chemical analysis at the intervals indicated below :—

1st sampling—prior to the first planting.
2nd sampling—After the first harvest.
3rd sampling—After the second harvest.
4th sampling—After the third harvest.
5th sampling—After the fourth harvest.
6th sampling—After the sixth harvest.

Ten soil samples were taken from each 30 ft. square plot at both the 0 to 6 in. and 6 to 12 in. levels.

In collecting these samples a two inch diameter pipe was hammered into the soil to a depth of six inches, withdrawn, and the 0 to 6 in. core removed. A similar pipe was inserted into the same hole, and hammered in another six inches, withdrawn and the 6 to 12 in. core removed. The ten samples from each plot at each depth were bulked, dried and one pound subsamples bagged and labelled for subsequent analysis.

Results.

A summary of yields from the first ten plantings of the Soil Exhaustion Trial is shown in *Tables* 2A and 2B.

Aphids caused distortion of leaves in most plantings and damage to the tubers by the weevil *Cyclas formicarius* and two species of hawkmoth,

Table 2A.—**Soil Exhaustion Trial Yield Data, First 10 Plantings.**
Mean Wt. Tubers/Plot (lb.).

	VARIETY K3.					*VARIETY K1.*									
	Planting.					Planting. Adjusted Yields *									
Treatment.	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10
1	502	402	215	307	Nil	266	213	114	163	—	335	181	208	134	56
2	P.c.	480	221	329	Nil	P.c.	254	117	175	—	355	193	232	132	71
3	M	M	205	366	Nil	M	M	109	194	—	379	207	228	158	67
4	M	M	M	449	Nil	M	M	M	238	—	416	212	226	124	76

Sorghum grown on plots for six months between 5th and 6th plantings.
* In a variety trial K1 yielded 53 per cent. of K3 yield.
M = Mimosa invisa.
P.c. = Phaseolus calcaratus.

Table 2B.—**Soil Exhaustion Trial Yield Data, First 10 Plantings.**
Mean Wt. Tubers/Plot (lb.).

	No. of Successive Crops (Variety K1).									
Treatment.	1	2	3	4	5	6	7	8	9	10
1	266†	213†	114†	163†	Nil	335	181	208	134	56
2	254†	117†	175†	Nil	355	193	232	132	71	....
3	109†	194†	Nil	379	207	228	158	67	....	....
4	238†	Nil	416	212	226	124	76	....	....	....
Mean	217†	175†	235*	251*	263	220	162	136	103	56

* Means derived from addition of K1 and adjusted K3 yields.
† Means adjusted from K3 yields.

Treatment.	No. of Successive Crops (Variety K3).				
	1	2	3	4	5
1	502	402	215	307	Nil
2	480	221	329	Nil	355†
3	205	366	Nil	379†	207†
4	449	Nil	416†	212†	226†
Mean	409	330	320*	299*	263†

* Means derived from addition of K1 and K3 yields.
† K1 yields.

Protoparce convolvulae and *Hippotion celerio*, occurred in varying degrees during the trial. A leaf scab similar to that caused by the fungus *Elsinoe batatas* was observed but was not positively identified. Giant African snails (*Achatina fulica*) caused minor damage to vines in the second planting, but were generally controlled with metaldehyde baits.

The variety K1 was able to resist the effects of 'little leaf virus' quite well, particularly if infected plants were rogued out. Varieties K1 and K3 were both subject to a certain degree to damage from the other pests and diseases noted.

The effect of length of cropping period on sweet potato yields was established by analysis of the yield data for each treatment at a particular harvest (*Table* 2A). This analysis showed that the general downward trend in yields was due to increased periods of cropping in each treatment. Statistical significance for this effect was attained in only the fourth and sixth harvests, but the trend was positive to the eighth harvest. It became negative in the ninth harvest and positive again in the tenth.

A further analysis was carried out, to investigate the relationship between seasonal factors, soil fertility levels and yields. To facilitate the analysis, all K3 yields were converted to the equivalent yield of K1, using data obtained from field variety trials carried out on land adjoining the Soil Exhaustion Trial. This analysis was based on the assumption that the soil fertility would decline asymptotically to some low level

Plate II.—Unthrifty sweet potato crop in the Soil Exhaustion Trial, 10th planting.

at which yields would remain constant, a typical experience with exhaustion trials. The model fitted was :—

$$Y = S\,[1 - a\,(1 - e^{-kt})]$$

where

Y = yield

S = seasonal factors including pests and diseases

t = the number of the crop in the series

a and k are constants determined by the trend between the crops in the same year, but for the different durations for which the plots had been under sweet potato.

Omitting the yields from the third planting, where severe insect and disease infestation caused a distortion of the relative yields, the values of a and k were calculated :—

$a = 0.472 \pm 0.059$

$k = 0.365 \pm 0.100$

The indication is that if the seasonal effects remain constant, the relative yield would be $1 - a\,(1 - e^{-kt})$ in succeeding crops. The decrease in relative yield is shown in the graph in *Figure* 2A.

FIGURE 2A

SOIL EXHAUSTION TRIAL

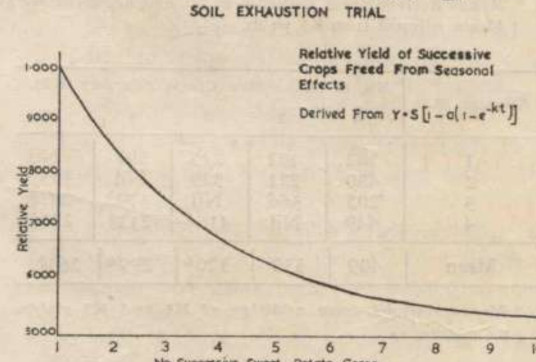
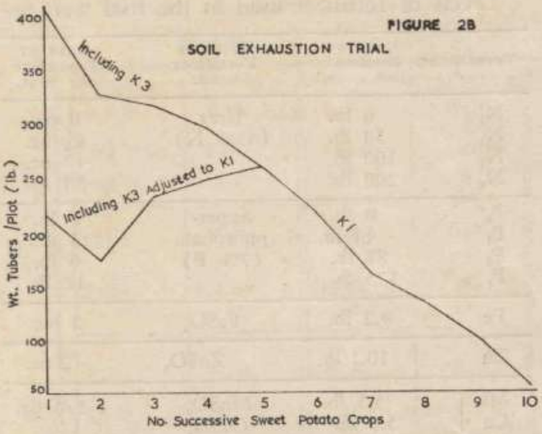


Figure 2B shows the actual yield curve recorded in the first ten plantings of the trial, and is derived from plot yields recorded after cumulative periods of successive sweet potato crops as set out in *Table* 2B.

Results of the analysis of soil samples collected at the first and fourth samplings are shown in *Table* 3. Unfortunately no other samples were analysed. Of more importance, no soil samples were collected after the 10th planting of the trial, when the soil was considered exhausted.



FERTILIZER STUDIES ON THE EXHAUSTED SOIL.

Having achieved exhaustion of the soil by continuous cropping with sweet potato, studies were undertaken to determine the fertilizer applications required to restore the soil to its original productive capacity.

Pot test.

As a preliminary study, a pot test was carried out in the laboratory with a composite sample of soil taken from all plots during the 10th planting of the Soil Exhaustion Trial. Sweet potato was the test plant and treatments were as follows :—

1. Control.
2. N.
3. NP.
4. NPK.
5. NPK + trace elements.
6. NPK + trace elements — Fe.
7. NPK + trace elements — Zn.

Trace elements were Fe, Mn, Zn, Cu, B, Mo, Co.

There were three replications of each treatment.

The only significant response of certainty was to the addition of P. It is possible that the absence of an N effect was due to mineralization of organic matter when the soil was disturbed during collection and potting.

Layout and Design of Field Trial.

After completion of the pot test and following the harvest of tubers from the tenth planting, a fertilizer trial was superimposed on the Soil Exhaustion Trial Plots. In this trial, fertilizers were applied to the eleventh and twelfth plantings of sweet potato.

To permit adequate replication of each of the fertilizer combinations tested, each of the sixteen plots of the Soil Exhaustion Trial was quartered as shown in *Figure* 3. Subdivision was thus into 64 plots, each 15 ft. by 14 ft. with an area of 1/207 acre.

The trial compared four levels of nitrogen and phosphorus in all combinations. Zinc and iron were also applied, singly, in combination and as nil treatments. An application of other minor elements, referred to as the Shotgun (Sh) mixture, was confounded with the blocks.

The sixteen combinations of nitrogen and phosphorus used in the trial resulted in application of these elements in the following ratios :—

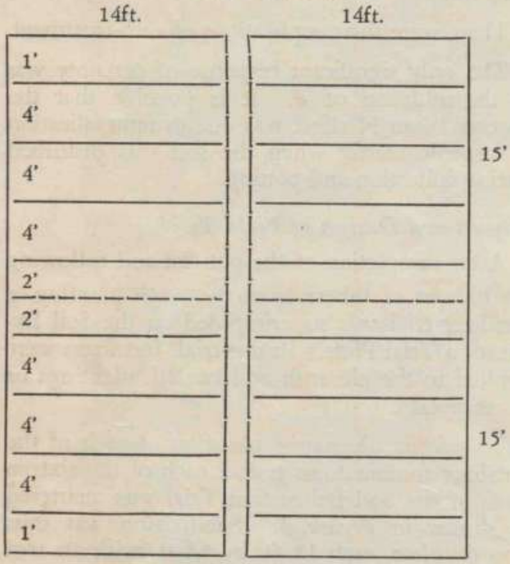
N_4P_1	1 level at 4 : 1.
N_4P_2 N_2P_1	2 levels at 2 : 1.
N_1P_1 N_2P_2 N_4P_4	3 levels at 1 : 1.
N_1P_2 N_2P_4	2 levels at 1 : 2.
N_1P_4	1 level at 1 : 4.

Table 3.—Soil Analysis.

Soil Analyses of first and fourth samplings—Means of four Plots.

	pH.	Specific Conductivity (Mhos⁶).	Available P (Olsen) p.p.m.	C% Walkley Black).	N%	C/N.	Exchangeable Cations (m.e,%). Ca.	Mg.	K.	K/N.	Exchange Capacity (m.e.%).
Sampling 1	6.8	83	8	2.6	0.465	10.6	17.5	1.8	1.15	2.5	19.9
Sampling 4	6.4	85	12	4.9	0.301	8.5	17.4	2.1	1.03	3.7	
	***		***	***	***	***				**	
Difference	0.433	—2.9	—4.0	2.34	0.164	2.12	0.17	—0.46	0.12	-1.19	

Figure 3.—Subdivision of 30 ft. x 30 ft. Plot into Four Sub-Plots.



A 1 : 2 ratio of nitrogen and phosphorus is commonly quoted for sweet potato cultivation in various parts of the world.

Other combinations of nitrogen and phosphorus which were applied in addition to the N_0P_1, N_0P_2, N_0P_4, and P_0N_1, above were N_0P_0, P_0N_2, and P_0N_4.

The layout of the plots and the treatment combinations used are shown in *Figure* 4.

Procedure.

As before, sweet potato runners were cut into one-foot lengths, three of which were planted in each hole. Each hole was at one foot spacing in the row and there were four hilled rows per plot, each fourteen feet long, and each supporting fourteen sweet potato plants.

Sweet potato variety K1, as used in the last five plantings of the exhaustion phase of the Soil Exhaustion Trial, was planted.

The fertilizers used in the minor element mixture were ground and mixed with approximately one pound of river sand before being added to the rest of the fertilizer to be applied to each plot. Where the total fertilizers to be added to a plot were too small for even distribution, sawdust was used as a spreader.

Levels of fertilizer used in the trial were :—

Treatment.	Rate of Element per acre.	Type of Fertilizer used.	Rate of Fertilizer per plot.
N_0	0 lb.	Urea	0 oz.
N_1	50 lb.	(45% N)	8¼ oz.
N_2	100 lb.		17 oz.
N_4	200 lb.		34 oz.
P_0	0 lb.	Super-	0 lb.
P_1	44 lb.	phosphate	3 lb.
P_2	87 lb.	(7% P)	6 lb.
P_4	175 lb.		12 lb.
Fe	9.2 lb.	$FeSO_4$	2 oz.
Zn	10.1 lb.	$ZnSO_4$	2 oz.
Mn } Sh	5.5 lb.	$MnSO_4$	1 1/5 oz.
Cu } Sh	5.0 lb.	$CuSO_4$	1 oz.
B } Sh	2.2 lb.	H_3BO_3	1 oz.
Co } Sh	4.8 lb.	$CoSO_4$	1 oz.
Mo } Sh	0.54 lb.	$(NH_4)_6Mo_7O_{24}4H_2O$	2 gm.

Sh = Mixture of Minor Elements.

In the eleventh planting, full fertilizer treatments were applied to each plot prior to planting. For application, sweet potato hills were first built up to a height of approximately four inches, the fertilizer mixture was spread along the tops of the partially completed hills and hilling was then completed.

In the twelfth planting, sweet potato was planted one month before any fertilizer application was made and fertilizer was applied in three equal split applications, which together were equivalent to the full fertilizer dressing of the eleventh planting. Applications were made when the crop was one month, three months and five-and-a-half months old, the crop being harvested when seven months old.

Leaf samples were collected from all plots periodically during both plantings. During the eleventh planting, four samplings were made for studies of leaf sampling techniques for sweet potato. During the twelfth planting, six leaf samplings were made, the first being twelve weeks after planting and the remainder at monthly intervals until the crop was harvested. The first, second and third mature leaves were collected from eight randomly selected vines per plot and all leaves from the four replicates of each N : P treatment were bulked.

Soil samples were collected at the completion of the twelfth harvest, the sampling procedure used being the same as that described earlier. The 0 to 6 in. and 6 to 12 in. samples were

FIGURE 4

P_0N_1 FeZnSh Plot No. 1	P_4N_1 Nil 2	P_1N_2 FeZnSh 3	P_2N_0 ZnSh 4	P_1N_4 FeZnSh 5	P_4N_1 FeZn 6	P_4N_2 Nil Sh 7	P_4N_4 Fe 8
2		3		4		1	
P_4N_2 FeSh 16	P_1N_4 Nil Sh 15	P_0N_0 Nil Sh 14	P_0N_4 Fe 13	P_4N_0 ZnSh 12	P_0N_2 Fe 11	P_1N_2 Zn 10	P_1N_1 FeSh 9
P_4N_4 ZnSh 17	P_2N_2 Nil 18	P_1N_1 Zn 19	P_1N_0 Fe 20	P_2N_0 FeSh 21	P_0N_1 ZnSh 22	P_2N_2 FeZnSh 23	P_2N_4 Zn 24
4		1		2		3	
P_4N_0 FeZn 32	P_0N_2 Zn 31	P_2N_1 FeSh 30	P_2N_4 FeZn 29	P_2N_1 Nil 28	P_1N_0 Nil 27	P_0N_4 Nil Sh 26	P_0N_0 FeZn 25
P_1N_0 FeZnSh 33	P_4N_4 Nil 34	P_2N_4 FeSh 35	P_2N_0 Nil 36	P_4N_1 FeSh 37	P_1N_2 Nil Sh 38	P_1N_4 Fe 39	P_2N_1 ZnSh 40
3		4		1		2	
P_4N_1 ZnSh 48	P_1N_2 Fe 47	P_2N_1 FeZn 46	P_0N_2 Nil Sh 45	P_2N_0 FeZn 44	P_0N_0 FeSh 43	P_1N_0 ZnSh 42	P_0N_4 Zn 41
P_4N_2 FeZn 49	P_1N_4 Zn 50	P_0N_4 FeZnSh 51	P_0N_0 Zn 52	P_4N_2 Zn 53	P_2N_4 NilSh 54	P_0N_2 FeZnSh 55	P_0N_1 Nil 56
1		2		3		4	
P_1N_1 Nil Sh 64	P_2N_2 ZnSh 63	P_0N_1 Fe 62	P_4N_0 FeSh 61	P_2N_2 Fe 60	P_4N_0 Nil 59	P_4N_4 FeZnSh 58	P_1N_1 FeZn 57

Figure 4.—Trial on Rejuvenation of Exhausted Soil Superimposed on the Soil Exhaustion Trial.

bulked for each of the sixty-four plots, thoroughly mixed, and a one quarter subsample prepared for analysis. This was labelled the 13th soil sampling.

Results.

11th Planting.

A summary of sweet potato tuber yields from all plots in the 11th planting is shown in *Table* 4. These figures do not indicate any significant response to the elements applied other than a negative response to nitrogen. It was thought that the lack of positive response may have been caused by leaching. The trial was therefore repeated using three equal split applications of fertilizer, each one equivalent to a third of the original application.

Table 4.—Mean Treatment Yields—11th Planting (lb./Plot).

—	Po.	P1.	P2.	P4.	Mean.
N_0	23	22	23	24	23
N_1	18	18	25	25	22
N_2	21	21	17	20	20
N_4	13	16	16	12	14
Mean	19	19	20	20	20

No responses from Fe, Zn or Sh treatments.

N_1+N_2 39 39 42 45

Results of analyses carried out on the first four lots of leaf samples collected are not considered because of variations in sampling technique.

12*th Planting*.

A summary of yields from the 12th planting is shown in *Table* 5. *Table* 6 shows the variation in levels of leaf nitrogen, phosphorus, potassium and calcium as the crop aged.

Table 5.—Mean Treatment Yields—12th Planting (lb./Plot).

—	Po.	P1.	P2.	P4.	Mean.
N_0	39	34	34	39	37
N_1	33	24	35	30	31
N_2	30	28	27	28	28
N_4	24	26	25	18	23
Mean	32	28	30	29	30

No responses from Fe,Xn or Sh treatments.

A summary of soil analyses for the 13th sampling is shown in *Table* 7.

During the 12th planting, visual appraisals were made on the vigour of sweet potato on all plots, when the crop was 10 weeks and 28 weeks old. Points were allotted to each plot according to the following scale :—

Good 2 points ;
Fair 1 point ; and
Poor 0 point.

Plot means of these points according to nitrogen and phosphorus treatments were as follows :—

Crop 10 weeks				Crop 28 weeks.			
N_0	0.1	P_0	1.1	N_0	0.1	P_0	1.1
N_1	0.9	P_1	1.1	N_1	0.9	P_1	1.1
N_2	1.3	P_2	1.1	N_2	1.4	P_2	1.0
N_4	2.0	P_4	1.0	N_4	1.9	P_4	1.2

Insect and disease attack during the 11th and 12th plantings was minor, and similar to that on sweet potato variety K1 during the 6th to 10th plantings of the trial.

Table 6.—Leaf Analyses from 12th Planting.
Percentage Oven Dry Basis.

Weeks After Planting.		N.	P.	K.	Ca.
4		1/3 Fertilizer Application			
7	P_0	4.86	0.51	2.78	0.42
	P_1	5.07	0.56	2.80	0.42
	P_2	4.96	0.55	2.90	0.45
	P_4	4.79	0.62	3.14	0.57
	N_0	4.06	0.54	3.11	0.47
	N_1	4.87	0.54	2.85	0.47
	N_2	5.28	0.57	2.90	0.44
	N_4	5.47	0.58	2.76	0.50
12	P_0	3.99	0.52	2.84	0.54
	P_1	4.04	0.55	2.55	0.56
	P_2	3.91	0.59	2.09	0.57
	P_4	3.92	0.62	2.82	0.57
	N_0	4.20	0.61	2.98	0.55
	N_1	3.94	0.57	2.69	0.58
	N_2	3.79	0.54	2.59	0.58
	N_4	3.92	0.55	2.54	0.53
14		1/3 Fertilizer Application			
16	P_0	4.53	0.48	2.56	0.54
	P_1	4.65	0.56	2.72	0.58
	P_2	4.66	0.56	2.54	0.62
	P_4	4.77	0.59	2.66	0.59
	N_0	4.06	0.55	2.64	0.47
	N_1	4.59	0.55	2.57	0.58
	N_2	4.82	0.54	2.63	0.63
	N_4	5.13	0.55	2.64	0.65
21	P_0	3.94	0.53	2.48	0.72
	P_1	3.87	0.54	2.40	0.91
	P_2	3.81	0.61	2.45	0.74
	P_4	3.80	0.61	2.55	0.63
	N_0	3.86	0.58	2.53	0.75
	N_1	3.59	0.58	2.42	0.80
	N_2	3.82	0.55	2.55	0.73
	N_4	4.15	0.56	2.38	0.71
23		1/3 Fertilizer Application			
25	P_0	4.46	0.56	3.01	0.82
	P_1	4.48	0.55	2.72	0.66
	P_2	4.51	0.56	2.55	0.50
	P_4	4.68	0.60	2.67	0.48
	N_0	4.01	0.57	2.76	0.61
	N_1	4.48	0.59	2.75	0.65
	N_2	4.70	0.55	2.69	0.60
	N_4	4.95	0.56	2.74	0.61
30	P_0	3.82	0.43	1.87	0.45
	P_1	3.68	0.45	2.02	0.45
	P_2	3.41	0.45	2.03	0.46
	P_4	3.64	0.50	2.02	0.46
	N_0	3.40	0.50	2.12	0.48
	N_1	3.54	0.46	2.08	0.43
	N_2	3.40	0.46	1.93	0.45
	N_4	3.96	0.42	1.82	0.46

Compared to table in Giles + Samuels (1957), N is higher, P is right, K is right (n. variable for Giles + Sam.), *Table* 7.—Means of Soil Analyses of 13th Sampling according to N and P Treatments.

Treatment.	pH.	Specific Conductivity (mhos x 10^6).	Available P Olsen (p.p.m.).	C% Walkley Black.	N%.	C/N.	Exchangeable Ca m.e.%.	Exchangeable Mg m.e.%.	Exchangeable K m.e.%.	K/N.	Exchange Capacity m.e.%.
P_0	6.4	116	4	4.6	.474	9.6	16.1	2.4	0.63	1.4	19.7
P_1	6.4	148	8	4.7	.481	9.7	17.3	2.4	0.62	1.3	20.9
P_2	6.3	173	10	4.4	.463	9.4	16.8	2.5	0.62	1.4	20.4
P_4	6.2	242	21	4.1	.440	9.4	17.2	1.8	0.62	1.5	19.9
N_0	6.4	160	11	4.3	.422	10.3	17.1	2.8	0.65	1.6	20.6
N_1	6.4	157	10	4.5	.472	9.4	17.6	2.7	0.63	1.4	21.2
N_2	6.2	178	11	4.4	.483	9.1	15.9	1.8	0.62	1.3	19.1
N_4	6.2	185	12	4.5	.482	9.4	16.7	1.9	0.59	1.2	20.0

A statistical analysis of the yields of the 11th and 12th plantings showed that the only significant response to the fertilizer treatments applied was a negative yield response to nitrogen.

DISCUSSION.

Plantings 1 *to* 10.

There was a trend for yield to decline rapidly as cropping with sweet potato continued (*Figure* 2B). The effects of adjusting K3 yields to 'equivalent' K1 yields have distorted the curve, so that it seems probable that the conversion factor of 53 per cent. is incorrect. Even if the factor were correct under the conditions of the variety trial, it apparently did not hold under the range of conditions experienced during the first five plantings of the Soil Exhaustion Trial.

The significant yield declines recorded between treatments at the fourth and sixth trial harvests indicate that at least part of the decline was attributable to length of cropping with sweet potato. The indication is also that the leguminous cover crops used during the first three plantings of the Trial had the effect of maintaining soil fertility better than did sweet potato cropping.

Factors which may have been responsible for the rapid decline in yields of all treatments are :—

1. *Change in climate.*—Apart from normal weather variations there was no evidence of consistent change for worse in climate at the site over the period of the trial.
2. *Weed Infestation.*—The trial plots were hand weeded constantly throughout the trial period. As sweet potato vigour declined, the effort required to keep weeds in control increased. In general the plots were kept weed-free fairly successfully. It may be that in spite of the rigorous control programme, weed infestation contributed to sweet potato yield decline.
3. *Disease.*—Sweet potato 'little leaf virus' infected many plants and for this reason a change in sweet potato variety was necessary after the fifth harvest. The disease problem was quite serious throughout the trial despite control measures and it is probable that sweet potato yield decline resulted at least in part from disease infestations.
4. *Insect Damage.*—Insect attacks in general were a great problem throughout the trial. Continuous cropping with sweet potato, as well as constant proximity of sweet potato in other trials would have provided infection reservoirs. It is possible that insect attacks were a predominant cause of sweet potato yield decline in the trial.
5. *Soil Deterioration.*—*Table* 3 shows that between the 1st and 4th soil samplings (taken at 1st planting and 3rd harvest respectively) there were significant declines in pH, per cent. C, per cent. N and C/N ratio, while there were rises in available P and K/N ratio. These data would suggest that soil fertility may have declined during the first three plantings of the trial. The apparent rise in available phosphorus may have resulted from the phosphorus fixation in the soil of the first sampling betwee its collection in 1956 and analysis in 1962.

cf Spence & Ahmad. all levels are high.

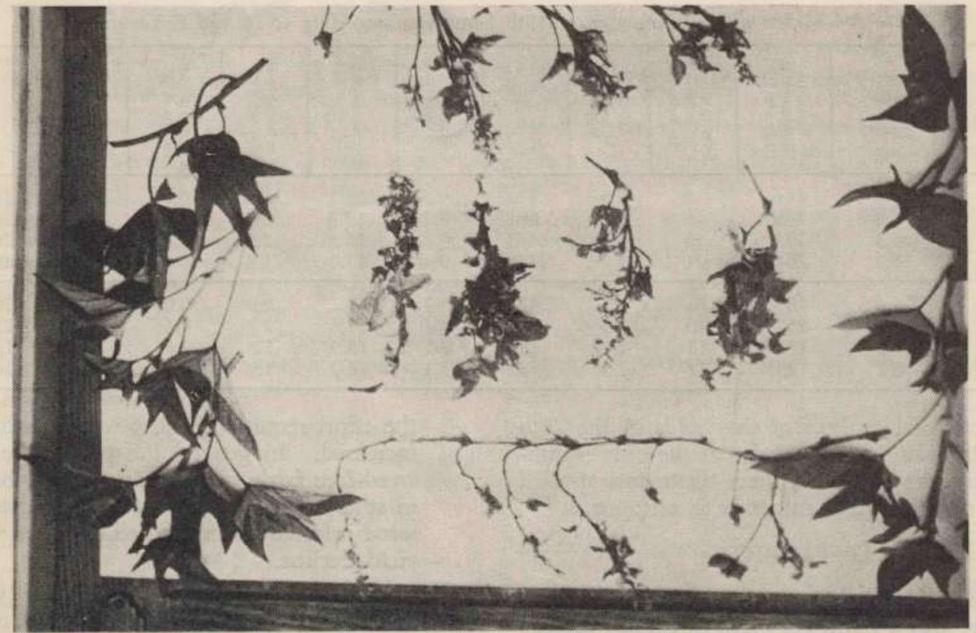


Plate III.—Sweet potato 'little leaf virus' and aphid leaf cure.

Statistical analysis of the soil chemical data indicated no difference between treatments, even though Treatment 4 had not yet been cropped with sweet potato. This would suggest that the leguminous cover crops used at the beginning of the trial had no chemical effect on the soil more beneficial than did sweet potato.

Removal of topgrowth after each crop of sweet potato would have added considerably to the nutrient drain on the soil. It would also have adversely affected the soil organic matter level. It has been shown that the soil at the trial site has a clay fraction of only about three per cent. It follows that the exchange capacity of the soil would be very dependent on its humus content. Thus removal of sweet potato topgrowth could have had a large effect on soil fertility.

It would be expected that leaching would account for heavy nutrient removal from such a light soil under the high rainfall conditions (110 in./annum).

Evidence of topsoil movement is dealt with under the discussion of Plantings 11 and 12.

Plantings 11 *and* 12.

Fertilizer trials were superimposed on the 11th and 12th plantings of the soil exhaustion trial to assess the hypothesis that sweet potato yield decline observed in the first ten plantings was due to nutrient stress.

The fertilizer trials failed to support the hypothesis in that the only significant treatment response was a depression in yield as nitrogen application increased. However, the results of the trials did not disprove the hypothesis, since potassium and magnesium treatments were not included. Potassium was omitted because of the high levels of total potassium previously recorded in the pumiceous soils at the site, and because of the lack of a potassium response in the pot trial. After the lack of response in the 11th Planting, it was thought that differential leaching may have affected the balance of nutrients applied. However, in spite of careful placement of split dressings in the 12th Planting, results were again similar to those of the 11th Planting.

Therefore no conclusions regarding the causes of sweet potato yield decline in the first ten plantings of the trial can be drawn as a result of the two fertilizer trials.

Results of chemical analyses of the soil sampled after the 12th Harvest (*Table* 7) show a marked increase in available P corresponding to phosphorus treatments. A similar trend occurred in specific conductivity. Soil exchangeable potassium levels are of the order of 0.6 m.e. per cent. It is considered that a level of available potassium of 0.4 m.e. per cent. is critical for sweet potato, with levels up to 0.8 m.e. per cent. being marginal. Thus it is uncertain from chemical analysis whether sweet potato would respond to potassium in this soil. It is possible that the negative yield response to nitrogen application was progressively enhanced by imbalance between available nitrogen and available potassium in the soil.

Statistical analysis of soil chemical data in *Table* 7 showed highly significant differences between results recorded from each of the four block quarters of the trial (*Table* 8).

The strongest trend is from quarter 1 to quarter 4, with quarters 2 and 3 generally taking intermediate values. The strong trend in carbon towards quarter 4 would reflect accumulation of organic matter by surface wash. The low magnesium and potassium values for this quarter could be a result of heavy leaching at the area of organic accumulation. This pattern of chemical behaviour in the soil may be a result of surface levelling.

Leaf chemical analysis data (*Table* 6) show increased nitrogen uptake corresponding to urea application, while leaf phosphorus levels have not been greatly affected by superphosphate application.

The low leaf levels of N, P and K recorded in the 10th sampling are normal for maturing plants.

Leaf potassium levels are generally low, and appear to have been affected adversely by urea application. Since the only sweet potato yield response in the trial was a negative response to urea application, and since leaf potassium uptake appears to have been depressed by the same fertilizer treatment, it could be postulated that the soil potassium status was sub-optimal and that it became critically limiting as the soil nitrogen status was raised.

Although these fertilizer trials failed to show the yield increase to be expected if nutrient stress were the cause of the yield decline observed over the first ten plantings, evidence of both soil and leaf chemical analysis left potassium as a suspected deficiency, particularly in relation to increased soil nitrogen levels. Factors other than nutritional deficiencies or imbalance, as listed in the discussion of the first ten plantings, may well have affected the sweet potato yield decline.

FURTHER INVESTIGATIONS.

The failure of fertilizers to restore yields of sweet potato in the 11th and 12th Plantings of the trial precluded the formulation of any conclusions concerning the cause of the yield decline. Despite this, a deterioration in soil fertility is the most likely factor responsible and future efforts will be directed at pot test studies of the soil as a forerunner to further fertilizer tests on the plots. The planning and design of these fertilizer tests will be guided by the indications from the pot tests and further soil analyses.

During the period in which pot tests will be carried out, the plots will be cropped continuously with sweet potato in an attempt to remove to the greatest degree possible the effects of previous fertilizer applications.

Should the next fertilizer trial fail to show any positive yield response to fertilizer applications, it should then be clear that some other factor has been responsible for the fall in yields, and a new approach to the problem may be necessary.

To provide a reserve of 'exhausted' soil for future studies a square 1.6 acre block has been planted to continuous sweet potato.

Table 8.—Means of Soil Analysis of 13th Sampling according to Trial Blocks.

Quarter.	pH	Spec. Cond.	Avail P. (Olsen)	C% (W.B.)	N%	C/N	Ca	Mg	K	K/N	Exch. Cap.
1	6.37	137	11.06	3.68	.427	8.59	16.31	3.18	0.68	1.62	20.40
2	6.28	172	9.88	4.31	.469	9.29	15.53	2.63	0.65	1.41	19.58
3	6.29	187	10.63	4.13	.446	9.34	15.76	1.44	0.58	1.32	17.98
4	6.37	184	11.69	5.61	.516	10.89	19.68	1.90	0.58	1.16	22.94
Difference		**		***	***	***	***	**	***	***	***
Average	6.33	170	10.82	4.43	.464	9.53	16.82	2.29	.62	1.38	20.22

PART II. THE THREE-COURSE ROTATION TRIAL.

DESIGN.

The trial was designed to compare seven different rotations, each with three replications in space. The basic block unit or 'series' therefore consisted of twenty-one plots and there were three of these series in the trial. Each series was a replication in time, so that seasonal effects on the results could be allowed for. The whole trial therefore comprised 7 rotations by 3 replications by 3 series = 63 plots.

A planting plan of the trial and the seven rotations tested are shown in *Table* 1.

From this it can be seen that Series A is two plantings (or phases) ahead of Series C in the rotation cycle, while Series C is two plantings ahead of Series B.

One cycle of the rotations takes approximately three years to complete.

For half of this three-year period, Rotations 1 and 2 have a cover-crop of *Mimosa invisa,* while Rotations 6 and 7 have a cover-crop of *Pueraria phaseoloides*. These four rotations are referred to as 'wide rotations'.

Rotation 3 has two separate three-month periods under *Phaseolus calcaratus*, while Rotations 4 and 5 have corresponding periods under peanuts, with either trash removed or trash returned respectively. For the remainder of the three-year cycle, plots in these rotations are under sweet potato and taro. These three rotations are referred to as narrow rotations.

Once in every three-year cycle all plots of a series have a sweet potato crop concurrently. Because of this and because the rotations in each series are at different stages (two crops apart), one of the series has sweet potato on all plots at every second planting of the whole trial. This allows comparisons between rotations at frequent intervals.

To summarize: within each series the seven rotations are replicated three times in a balanced incomplete block design. The three series were laid down contiguously in the field (*Table* 2).

LAYOUT AND PROCEDURE.

General.

After clearing, the site was ploughed twice with a sundercut plough and all debris removed. Each plot was thirty ft. square and strips five ft. wide were left between plots.

SWEET POTATO (*Ipomoea batatas*) was planted on ridges spaced four feet apart and there were eight ridges or rows per plot. The planting material consisted of runners cut into lengths of approximately eighteen inches.

Three cuttings each were planted in holes one foot apart within rows. The sweet potato variety used, numbered K 1 in the Keravat collection, matures in about seven months. When plots were harvested, weights of tuber yield per plot were recorded and tubers and vine growth were removed from the plots.

TARO (*Colocasia antiquorum*) was planted at a three feet square spacing which gave one hundred positions per plot. As is customary in the planting of taro, offshoots of parent plants were used. The variety numbered K 12 in the Keravat collection was planted. At harvest, the number of plants and the weight of tubers per plot were recorded. Following harvest, tubers and top growth were removed from the plots. K 12 matures in approximately eight months.

PEANUTS (*Arachis hypogaea*) were planted in rows two ft. apart, with a nine-inch spacing within the rows. This gave 600 positions per plot. The variety Red Spanish was used for the first cycle of the trial, but was replaced by Schwarz 21 in the second cycle, because of susceptibility of Red Spanish to the fungus *Sclerotium rolfsii*. Also, in the second cycle, the practice of returning peanut crop trash to the plots in Rotations 1, 2, 5, 6, and 7 was discontinued in an effort to reduce the build-up of this crown rot fungus. Thus, all P+ treatments in the first cycle became P— treatments in the second cycle. At each peanut harvest, the number of plants per plot, and the yield per plot of peanuts in the shell were recorded. For both varieties, maturity was reached in about three months.

SORGHUM (*Sorghum vulgare*) was planted in drills eighteen inches apart. When the crop reached about six in. in height, plants were thinned to a six-in. spacing within the row. The variety known locally as Red Sorghum was used throughout the trial. During the first cycle when sorghum was grown, one crop only was planted, and the trash was left to lie on the plots until the corresponding taro crop in the same planting had been harvested. In the second cycle sorghum plots were retained under crop

Table 1.—Three-Course Rotation Trial Planting Plan—Keravat.

	Series A.						
Rotation No.	1	2	3	4	5	6	7
Planting No. 1	SP	SP	SP	SP	SP	SP	SP
Planting No. 2	To	So	To	To	To	To	So
Planting No. 3	P+	P+	Ph	P—	P+	P+	P+
Planting No. 4	M	M	SP	SP	SP	Pu	Pu
Planting No. 5	M	M	To	To	To	Pu	Pu
Planting No. 6	M	M	Ph	P—	P+	Pu	Pu

	Series B.						
Rotation No.	1	2	3	4	5	6	7
Planting No. 1	M	M	To	To	To	Pu	Pu
Planting No. 2	M	M	Ph	P—	P+	Pu	Pu
Planting No. 3	SP	SP	SP	SP	SP	SP	SP
Planting No. 4	To	So	To	To	To	To	So
Planting No. 5	P+	P+	Ph	P—	P+	P+	P+
Planting No. 6	M	M	SP	SP	SP	Pu	Pu

	Series C.						
Rotation No.	1	2	3	4	5	6	7
Planting No. 1	P+	P+	Ph	P—	P+	P+	P+
Planting No. 2	M	M	SP	SP	SP	Pu	Pu
Planting No. 3	M	M	To	To	To	Pu	Pu
Planting No. 4	M	M	Ph	P—	P+	Pu	Pu
Planting No. 5	SP	SP	SP	SP	SP	SP	SP
Planting No. 6	To	So	To	To	To	To	So

M = *Mimosa invisa* SP = Sweet potato (*Ipomoea batatas*) P+ = Peanuts (*Arachis hypogaea*)—trash returned

Ph = *Phaseolus calcaratus* To = Taro (*Colocasia esculenta*)

Pu = *Pueraria phaseoloides* So = Sorghum (*Sorghum vulgare*) P— = Peanuts—trash removed.

Table 2.—Layout Three-Course Rotation Trial.

Rotation.	Rotation.	Rotation.	Rotation.	Rotation.	Rotation.	Rotation.	
7	5	6	3	6	4	2	Series B
1	7	1	7	4	3	1	
3	6	2	5	4	2	5	
6	1	2	3	1	5	6	Series A
2	3	4	3	7	4	1	
7	5	2	6	4	5	7	
1	7	1	6	4	2	5	Series C
3	3	6	5	3	1	7	
4	6	2	7	5	2	4	

for the full period of the corresponding taro crop. Yields of all crops were recorded, and in the second cycle, crop residues were removed from the plots. Crops matured in about ten weeks.

MIMOSA INVISA AND PUERARIA PHASEOLOIDES seed were drilled in rows four feet apart and, as with the sweet potato, there were eight rows per plot. Both cover crops were continued over the three plantings indicated in *Table* 1 and were thus retained on the plots for about eighteen months. At the end of this period, when crops in the other rotations had been harvested, *Mimosa and Pueraria* were slashed, allowed to dry on the plots, and then turned under.

PHASEOLUS CALCARATUS was planted by seed in drills fifteen inches apart, and the plants were later thinned to a six-in. spacing. At the conclusion of the corresponding peanut crop, *P. calcaratus* was slashed, allowed to dry on the plots, and then turned under.

Soil Samples.

Soil samples were collected at various stages through the trial for chemical analysis. In all, eight samplings were made as follows :—

1st Sampling. Prior to the first planting, first cycle.

2nd Sampling. After the first harvest, first cycle.

3rd Sampling. After the second harvest, first cycle.

4th Sampling. After the third harvest, first cycle.

5th Sampling. After the fourth harvest, first cycle.

6th Sampling. After the fifth harvest, first cycle.

7th Sampling. After the sixth harvest, first cycle.

8th Sampling. After the first harvest, third cycle.

Unfortunately, no sampling was made at the end of the second cycle, but the eighth sampling, made after the first planting, third cycle, was quite useful for comparative purposes.

In the first seven samplings, soil samples were taken from depths of 0 in.-6 in. and 6 in.-12 in., ten samples at each depth being taken from each plot. A two-inch diameter pipe was hammered into the soil to a depth of six inches, withdrawn, and the 0 in.-6 in. core removed. A similar pipe was inserted into the same hole, hammered in another six inches, withdrawn and the 6 in.-12 in. core removed. The ten samples from each depth from each plot were bulked, dried, and one pound subsamples prepared. These were bagged and labelled for subsequent analysis. In the 8th sampling, ten one-inch auger samples were collected 0 in.-12 in. from each plot. These samples were then bulked for each rotation within a series, and the composites used for chemical analysis.

RESULTS.

Summaries of the yields of the various crops are shown in *Tables* 3 to 6, while yield trends are shown graphically in *Figures* 1 to 4.

Table 7 shows the summary of results of chemical analyses of the 1st and 8th soil samplings. In the 1st soil sampling, samples were collected separately from each plot from depths of 0 in.-6 in. and 6 in.-12 in., and bagged separately. However, because of the mixing of the surface 12 in. of soil by cultivation during the seven year period over which the first two cycles extended, it was decided by the time the 8th sampling was taken that a 0 in.-12 in. sample would give more accurate results. It was necessary therefore to mix equal volumes of the 0 in.-6 in. and 6 in.-12 in. plot samples of the first sampling to form composite plot samples for analysis and direct comparison with results from the 8th sampling. One other difference between comparative sets of figures in *Table* 7 should also be noted. Results for a particular rotation at the first sampling have been derived by calculating the arithmetic mean of results from the individual plots of that rotation, whereas results for the 8th sampling are from samples bulked from all crops in a rotation.

Assays could not be performed on the first sampling of Rotations 6 and 7 of Series B. These samples were inadvertently lost.

DISCUSSION.

Yield Trends.

An examination of the yield responses of the different crops to the various rotations suggests that yield trends over a period of time are different between crops. Possible causes for these differences are :—

1. Differences between species in reaction to nutrient stress ;
2. Differences between species in reaction to diseases, insect pests or weather ; and
3. Different soil conditions at different phases of the rotations.

It was considered unprofitable at this relatively early stage of the trial, to analyse yield trends statistically. However, the graphs of yields versus planting number (*Figures* 1, 2, 3 and 4) show that the general trend for sweet potato and taro yields is definitely downwards, while peanut and sorghum yields appear to be holding.

For the present, however, the main effects to be considered are the reactions of individual crops to the different rotations in which they are grown.

For convenience in *Tables* 3 to 6, crops are distinguished by number according to their sequence of planting as in Series A, viz. :—

First Crop	...... sweet potato.
Second Crop	...... taro or sorghum.
Third Crop	...... peanuts.
Fourth Crop	...... sweet potato.
Fifth Crop	...... taro.
Sixth Crop	...... peanuts.

Sweet Potato.

From *Table* 1 it can be seen that all rotations of a series come into a crop of sweet potato at the same time and these simultaneous sweet potato plantings therefore serve as the main basis for comparison of rotation effects. From *Figure* 1 it can be seen that there was very little difference between the yields of sweet potato in the various rotations until the third and fifth plantings of the second cycle when the superiority of the wide rotations became apparent. At this stage the mean yield for all four wide rotations was superior to the mean yield for the three narrow rotations. Further, within the wide rotations, the mean of rotations 6 and 7 (*Pueraria*) was superior to the mean of Rotations 1 and 2 (*Mimosa*). This result may be due to the fact that *Mimosa* is a coarser plant than *Pueraria,* taking longer to rot and release its nutrients. It also appears to have much less leaf litter than *Pueraria.* Rotting *Mimosa* may even lock up nitrogen from the soil more than the rotting *Pueraria.*

The superiority of the wide rotations was not so marked at the beginning of the third cycle and if mean yields for the wide and narrow rotations continue to approach each other it would suggest that other effects, e.g. soil nutrient deficiencies, are negating any advantageous effects of the legume cover.

Table 3.—Sweet Potato Yields (lb. per acre).

		First Cycle.						Second Cycle.						Third Cycle.
	Planting	1	2	3	4	5	6	1	2	3	4	5	6	1
Rotation	First Crop : Series :	A		B		C		A		B		C		A
	Fourth Crop : Series :		C		A		B		C		A		B	
1		17956		24926		17969		12745		16569		11293		8244
2		19408		24119		16424		13520		15101		14423		7139
Mean		18682		24523		16897		13133		15835		12858		7692
6		18360		27104		14810		15617		20054		17440		6042
7		18650		31202		14746		15085		20054		17295		6703
Mean		18505		29153		14778		15351		20054		17367		6373
3		18490	5308	25764	3275	15795	11003	14520	12552	13568	5001	14585	6760	4550
4		23022	6469	24861	3759	13713	15601	15278	13665	9712	7260	7567	6276	5066
5		19731	7631	21570	2952	16537	14068	14213	14617	9906	6502	10995	4533	6816
Mean		20414	6469	24065	3329	15348	13557	14670	13611	11062	6254	11049	5856	5477
Variance Ratios	Grouped Rotations	1.16		3.65		0.32		6.17*		16.85**		17.81***		2.24
	Ungrouped Rotations	1.21	0.53	1.87	0.25	0.21	16.16***	2.47	0.82	6.21**	2.31	9.31***	1.95	1.21
L.S.D. Between Rotations	5%						2013			5211		3708		
	1%						3310			7222		5139		
L.S.D. Between 1, 2, & 6, 7	5%							1400		3685		2622		
	1%							1941		5107		3634		
L.S.D. Between 1, 2 or 6, 7 & 3, 4, 5	5%							1278		3364		2394		
	1%							1771		4662		3317		

Table 4.—Taro Yields (lb. per acre).

		First Cycle.						Second Cycle.						Third Cycle.
	Planting	1	2	3	4	5	6	1	2	3	4	5	6	1
Rotations	Second Crop : Series :		A		B		C		A		B		C	
	Fifth Crop : Series :	B		C		A		B		C		A		B
1			5017		6211				4130		5227		1823	
6			4227		7099				3227		4130		1468	
3		3372	4082		5953	5517		3275	2049	2581	3516	2097	1323	1791
4		4178	3888		6550	6018		4001	2726	3646	2694	2759	1613	1033
5		4130	4517		5227	5227		4356	2839	3533	2274	3275	1823	984
Mean		3893	4162		5910	5587		3877	2538	3253	2828	2710	1586	1269
Variance Ratios	Grouped Rotations		1.05		1.96				11.78**		7.06*		0.44	
	Ungrouped Rotations	2.82	0.72		1.79	1.77		1.25	6.98**	10.45*	4.13*	3.76	0.64	17.61*
L.S.D. Between Rotations	5%								911	626	1821			373
	1%								1295	949	2588			565
L.S.D. Between 1 or 6 & 3, 4, 5	5%								744		1487			
	1%								1057		2113			

Table 5.—Sorghum Yields (lb. per acre).

		First Cycle.			Second Cycle.		
	Planting	2	4	6	2	4	6
Rotation	Second Crop : Series	A	B	C	A	B	C
2		1468	2323	1000	1234	1129	2081
7		1613	2823	1186	984	1226	1758
Variance Ration		0.37	1.82	0.98	1.61	0.36	2.37

Table 6.—**Peanut Yields (lb. per acre).**

	Planting	First Cycle. 1	2*	3*	4	5	6	Second Cycle. 1	2	3	4	5	6	Third Cycle. 1
Rotation	Third Crop : Series :	C		A		B		C		A		B		C
	Sixth Crop : Series :		B		C		A		B		C		A	
1		2517				1678		2823		2678		2404		1710
2		2743				1888		2888		3620		2210		1800
Mean		2630				1783		2855		3154		2307		1605
6		2952				1581		2791		2839		2710		1533
7		2662				1662		2501		2727		3211		1517
Mean		2807				1621		2646		2783		2960		1525
4		2952			1129	1726	855	2517	2469	2678	1823	2388	2113	1517
5		2807			1033	1549	823	2549	2404	2888	1855	2517	1839	1517
Mean		2880			1081	1637	839	2533	2436	2783	1839	2452	1976	1517
Variance Ratios	Grouped Rotations	1.05				1.53		6.28*		0.83		3.16		0.79
	Ungrouped Rotations	0.94			0.91	1.41	0.25	3.56	0.43	1.21	0.03	1.68	2.17	0.68
L.S.D. Between Grouped Rotations	5%							202						
	1%							282						

* Crop destroyed by "**Sclerotium rolfsii**"

Table 7.—**Summary of Chemical Analyses of Soils.**

	pH	EC mhos x 10^6	Olsen P ppm	C % (Walk'ey Black)	N %	Exchangeable Cations (m.e. %) Ca	Mg	K	Exch. Cap. (m.e. %)	K/N	C/N
					Rotations 1 and 2						
1st Sampling Means	6.6	122	4	6.0	0.635	18.3	2.4	1.24	24.8	2.2	10.6
8th Sampling Means	6.2	135	8	6.0	0.551	16.1	1.9	0.75	23.4	1.5	11.2
					Rotations 6 and 7						
1st Sampling Means	6.6	128	5	5.9	0.591	21.3	2.8	1.41	27.0	2.4	9.9
8th Sampling Means	6.2	133	7	5.6	0.519	15.4	2.0	0.75	24.3	1.5	10.9
					Rotations 3, 4 and 5						
1st Sampling Means	6.3	109	3	6.2	0.579	15.4	2.5	1.19	24.3	2.0	10.6
8th Sampling Means	6.2	123	7	5.3	0.486	15.3	1.9	0.61	21.5	1.3	11.1

FIGURE I

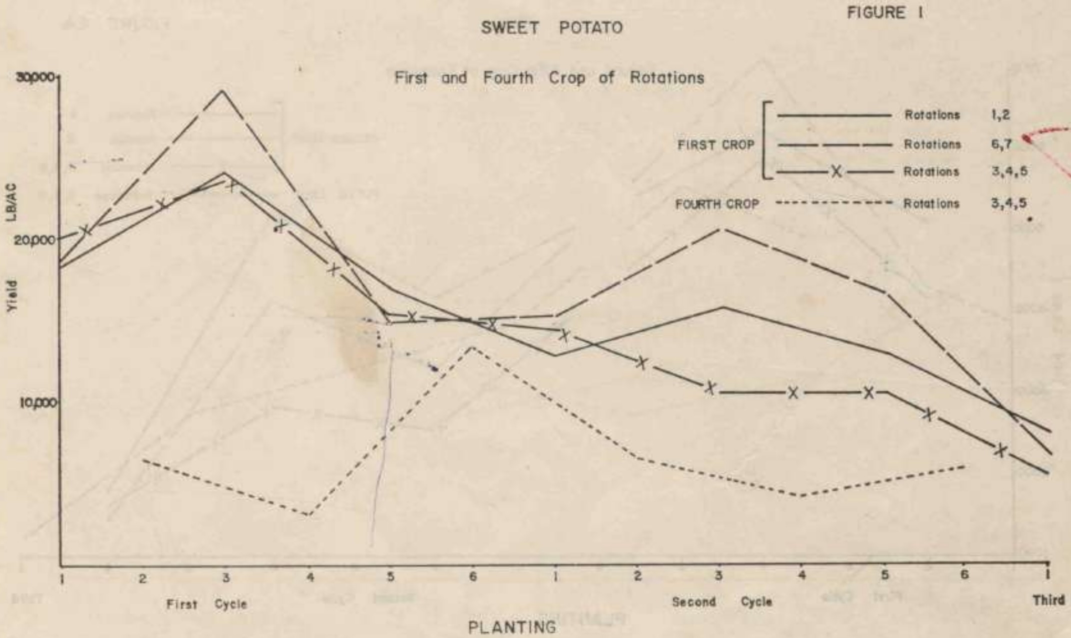
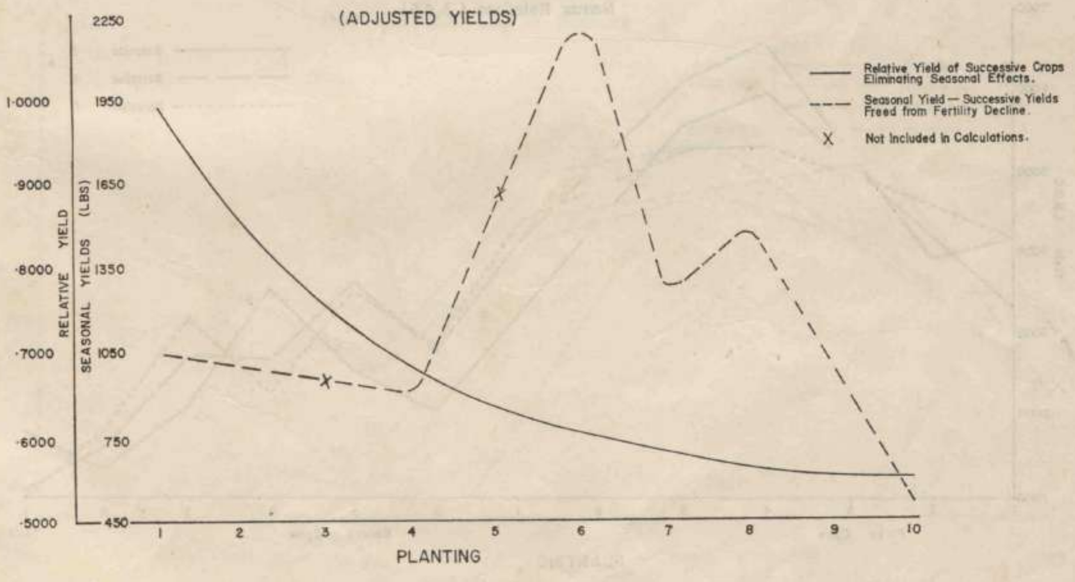
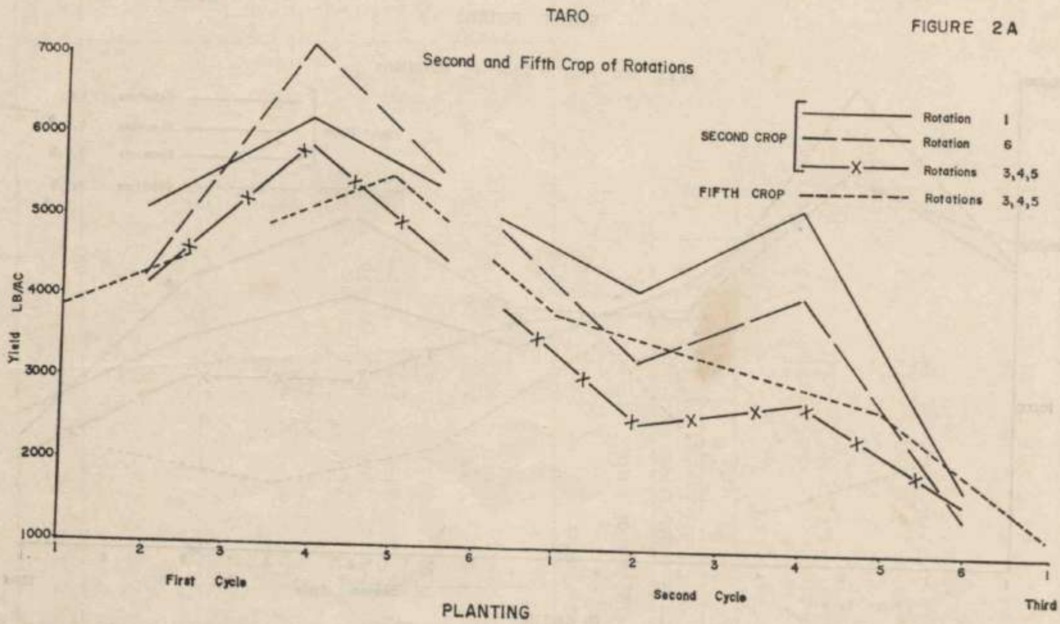
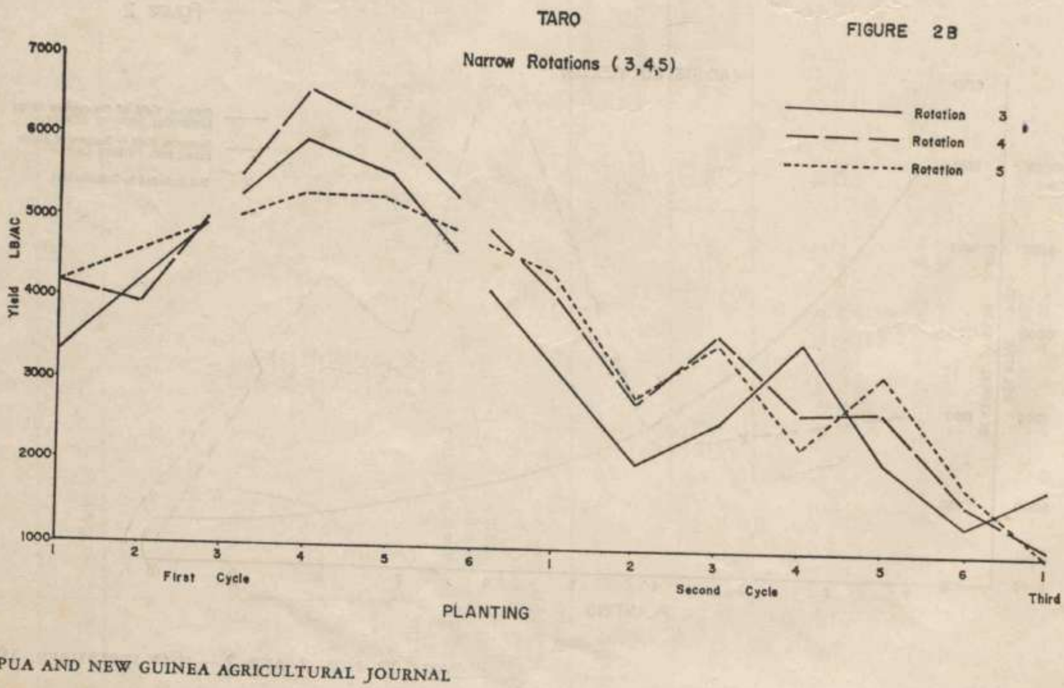


Figure 2




TARO
FIGURE 2 A
Second and Fifth Crop of Rotations
SECOND CROP
Rotation 1
Rotation 6
Rotations 3,4,5
FIFTH CROP
Rotations 3,4,5
Yield LB/AC
7000
6000
5000
4000
3000
2000
1000
1
2
3
4
5
6
First Cycle
Second Cycle
Third
PLANTING


TARO
FIGURE 2B
Narrow Rotations (3,4,5)
Rotation 3
Rotation 4
Rotation 5
Yield LB/AC
7000
6000
5000
4000
3000
2000
1000
1
2
3
4
5
6
First Cycle
Second Cycle
Third
PLANTING

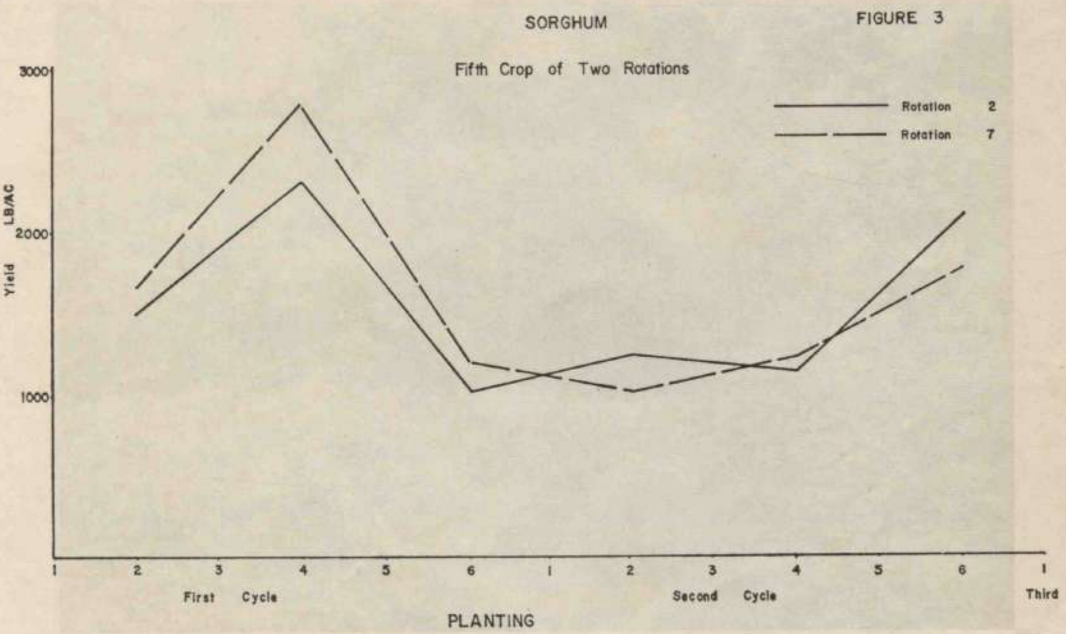


FIGURE 3

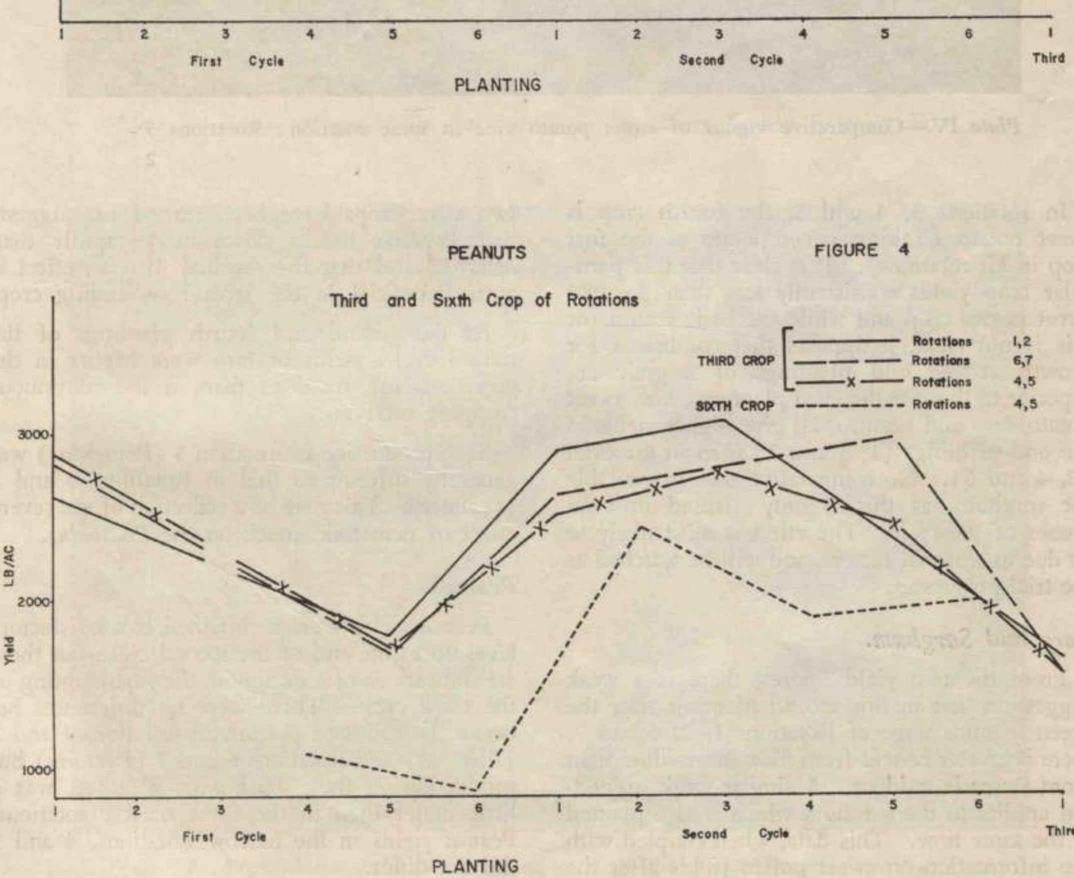


FIGURE 4

Plate IV.—Comparative vigour of sweet potato vine in some rotation : Rotations 5 7
2 1.

In rotations 3, 4 and 5, the fourth crop is sweet potato (Taking sweet potato as the first crop in all rotations). It is clear that this particular crop yields consistently less than the first sweet potato crop and while the basic reason for this is not clear, it appears that conditions for growth at the odd plantings of a cycle are superior to those at the even plantings, viz., sweet potato, taro and peanuts, all give higher yields in the odd plantings (1, 3 and 5) than in the even (2, 4 and 6). No comparative data is available for sorghum, as this is only planted in even phases of the cycle. The effect is most likely to be due to seasonal factors, and will be watched as the trial progresses.

Taro and Sorghum.

From the taro yield figures, there is a weak suggestion that in this second planting after the green manure stage of Rotations 1, 2, 6 and 7, there is greater benefit from *Mimosa* residues than from *Pueraria* residues. A similar weak suggestion applies to the sorghum which is also planted at the same time. This data, when coupled with the information on sweet potato yields after the two cover-crops have been turned in, suggests that *Pueraria* breaks down more rapidly than *Mimosa,* and that the residual *Mimosa* effect is more beneficial in the second succeeding crop.

At the second and fourth plantings of the second cycle, yields of taro were higher in the green manure rotations than in the continuous cropping rotations.

Taro production in Rotation 3 (*Phaseolus*) was generally inferior to that in Rotations 4 and 5 (peanuts). This may be a reflection of the severe effect of nematode attack on the *Phaseolus.*

Peanuts.

Peanut yields were maintained at a satisfactory level up to the end of the second cycle, but there are indications of a decline in the first planting of the third cycle. There were no differences between the yeilds of peanuts in Rotations 1 and 2 (*Mimosa*) and Rotations 6 and 7 (*Pueraria*) but production in these four wide rotations was a little better than in the three narrow rotations. Peanut yields in the narrow Rotations, 4 and 5 did not differ.

Plate V.—Sweet potato 'little leaf virus' in the Three Course Rotation Trial.

Plate VI.—*Phytophtora colocasia* infecting taro in the Three Course Rotation Trial.

Diseases and Pests.

Plant diseases affected crop yields, particularly in the first cycle when effective control measures had not been developed.

Sweet potato suffered periodic infection with 'little leaf' virus which causes a reduction in tuber size on diseased plants, but attacks were not widespread enough to have a serious influence on crop production. The disease was kept in check by roguing out infected vines.

Taro leaves were attacked throughout the first two cycles of the trial by the fungus, *Phytophthora colocasiae*. The intensity of attack varied, and on occasions reduced effective leaf area to below 50 per cent. All taro crops were damaged to some degree. Partial control of the diseases was obtained by spraying with copper oxychloride or Bordeaux mixture. Investigation of a suspected virus disease of taro showed that the symptoms of leaf crinkling were due to physiological causes.

In the first cycle of the trial, peanuts were severely attacked by the crown rot fungus, *Sclerotium rolfsii*, two crops of Red Spanish being completely destroyed. Changes in cultural practice (hilling was discontinued) and in variety (to Schwarz 21) were therefore instituted in an effort to reduce losses.

Sclerotium rolfsii is a facultative saprophyte and the return of infected crop residues to the plots after harvest facilitated the carry-over of the disease from one crop to the next. The five treatments in the trial in which peanut trash was returned to the plots were therefore amended after the completion of the first cycle, and all peanut crop residues were removed from the plots. In the second cycle the fungus ceased to be a problem, although occasional infected plants were found.

Minor infections of Schwarz 21 peanuts with Marginal Chlorosis virus were reported.

The legumes, *Mimosa invisa* and *Phaseolus calcaratus*, were attacked by root knot nematodes, *Meloidogyne* spp. *M. invisa* was able to withstand the attacks sufficiently to maintain a cover on the plots for the eighteen months required. However, *Phaseolus calcaratus* was sometimes killed by nematodes well before maturity. Nematode infestation appeared to increase as the Trial proceeded. Commencing late in the first cycle of the trial, attempts were made to control nema-

Plate VIII.—*Phaseolus calcaratus* showing effects of nematode damage.

todes by injection of ethylene dibromide into the soil, prior to planting susceptible species. E.D.B. was injected at six inches depth, at the rate of 3 to 5 cc. per injection, on a 12 to 18-in. grid. This provided a measure of control sufficient to allow crop survival, but failed to eliminate the nematode population.

Insect damage to crops was noted throughout the trial. Aphid attacks on sweet potato leaves led to distortion of the leaves. Control by a mixture of benzine hexachloride miscible oil and white oil proved effective. Two species of Hawk-moth, *Protoparce convolvulae* and *Hippotion celerio* and the weevil, *Cyclas formicarius*, were also responsible for damage to the crops.

Taro tubers were attacked by two species of scarab beetle of the genus *Papuana*. Leaves were attacked by the cutworm *Prodenia litura*.

Throughout the Trial special effort was required to control insect and disease infestations. Cultural and chemical means were necessary, as well as a change of variety in the case of peanuts. In the second cycle, as a result of precautions taken, insect and disease damage were only moderate.

Soil Chemical Analysis.

Results were not analysed statistically. It is evident that potassium levels dropped markedly from a satisfactory level at the 1st sampling to a marginal level at the 8th sampling. However this is not reflected in the differences in crop behaviour between the grouped rotations.

Phosphorus levels rose between the 1st and the 8th samplings. Both sets of samples were analysed in 1963, and the apparent rise may be due to fixation of phosphorus during storage of the samples taken at the first sampling.

Generally, other nutrient levels fell in all rotations but there appears to be little difference between levels for the wide and narrow rotations. Thus, the analyses have not reflected the agronomic differences between rotations shown in the trial.

CONTINUATION OF THE TRIAL.

The trial is at an interesting stage of development, with sweet potato and taro yields tending to decline, while peanut and sorghum yields were being maintained. It will be continued for the purpose of determining how these relative yield differentials will respond in time and at what stage the decline in yields will level off. It is clear that none of the rotations has maintained the productive capacity of the soil at a satisfactory level, but at this stage there is no direct evidence, other than the marked decline in potassium levels, to indicate whether the drop in yields is in fact due to soil deterioration.

NOTE ON ANALYSIS.

In the statistical analysis of the trial, evidence on block effects was sought from the analysis of the first phase sweet potato yields, in the three series, over the two cycles. For no series at any harvest was the block effect, freed from effects of the rotations, significant. Taken over the three series and two cycles, the average value of the mean squares for blocks and the residual variation within blocks were 4,538 and 3,959. A locality effect would be expected and evidence was not to the contrary, but the effects were so small that virtually nothing was lost in precision by ignoring it. Consequently all phases of the rotations at each planting were analysed as if the plots were completely randomized.

ACKNOWLEDGEMENTS.

The work of Mr. J. M. Richardson who established the trials and conducted the early investigations while an agronomist in this Department is gratefully acknowledged.

To Mr. G. A. McIntyre, of the C.S.I.R.O., who carried out all the statistical analyses and assisted in the planning of the trials, our thanks are extended.

Further thanks are due to Mr. D. W. P. Murty, Principal Chemist for his soil chemical analyses, and to Mr. P. J. Southern, Senior Chemist, for the foliar analyses.

(Accepted for publication May, 1967)

*Note on the Production of Cardamoms.**

BY E. BROWN.

THE cardamon of commerce consists of the dried ripe fruit of *Elettaria cardamomum* Maton (fam. Zingiberaceae). The name cardamom has also been applied to the fruit of other plants of the Zingiberaceae family, especially to those of the genus *Amomum* that are cultivated in Indonesia. These latter are little known outside the Far East. It is of particular importance to note that only the fruit of *E. cardamomum* is official in the British and United States Pharmacopoeias.

The cardamom plant requires elevation, moisture and shade. In Southern India and Ceylon, it grows at altitudes between 2,500 ft. and 5,000 ft. in districts with an average temperature of 72 degrees F. and average yearly rainfall of 120 in. The shade provided by moist mountain jungles is also highly important.

The soil should be rich, with a high humus content ; even swampy ground is suitable. Loamy soil, as used for pepper, is quite satisfactory, and cardamom is often planted as a secondary crop alongside pepper. In some areas it is grown with coffee.

In parts of India, plantings are started in February or March. A part of the forest is cut down, rows of trees 20 to 30 yards wide being left standing between the plantings, to act as shade trees. The first harvest can be gathered in the fifth year ; † production may continue for eight years after which the planting has to be renewed.

Improved methods of planting are in use in Ceylon and along the Malabar coast. The plants are propagated either by division of the rhizomes ('bulbs') or by seed grown in beds and nurseries, though the seeds germinate very slowly. If rhizomes are used, the soil is thoroughly cleaned, and holes are dug 12 to 15 in. deep, 1½ to 2 ft. wide and 7 ft. apart in both directions. In Ceylon, cardamom is now propagated mainly by means of seedlings after they have been in a nursery bed for about a year.

Harvesting takes place principally in February/March and August/September ; but smaller quantities can be obtained throughout the year, at two-monthly intervals. The capsules are gathered from the stems just before complete maturity, when still somewhat green but beginning to turn yellow. If left on the stem to ripen, the capsules split and eject the seeds. It is now the practice to cut off each fruit carefully with scissors, a portion of the pedicel being left attached to each capsule. It was formerly the custom to pull off whole racemes of fruit, but this was wasteful because not all fruits ripen together. The yield is from 150 lb. to 300 lb. of cardamoms per acre.

The capsules are prepared for the market by drying or curing, which can be done in two ways. In the oldest but cheapest, and still widely used, method, the fruits are dried slowly on mats by exposure to the sun ; care is necessary, as too rapid, or excessive, drying may cause the capsules to swell and burst, leading to loss of seed. Sun-drying also bleaches the capsules to some extent.

Artificial drying, in kilns, is often preferred. Kiln-dried cardamoms retain their green colour well, are less liable to split and fetch a higher price than the sun-dried spice ; but they must be thoroughly dried, otherwise they may become mouldy in the course of shipment. Fresh cardamoms lose about 75 per cent. of their weight on drying, but the precise amount varies, as some types are moister than others. In India, completion of drying is judged by weight loss, the standard loss for any particular locality having been determined by practical trials. Commercial cardamoms contain about ten or eleven per cent. of moisture.

Details of some cardamom kilns are given in the following publications :—

Note on the Departmental Cultivation, Collecting and curing of Cardamoms in the Evergreen Forests of Madras Presidency, by A. H. Khan (*Indian Forester* 1944, April 70 : 106-114).

* Reprinted from *Tropical Products Institute Report No.* G.26, June, 1966, Tropical Products Institute, 56-62 Gray's Inn Road, London, W.C.1.

† Maturity in the Territory of Papua and New Guinea has been much more rapid as experienced in experimental plantings of the crop to date.

Cardamoms," by W. Molegode, (*Tropical Agric.* (*Ceylon*) 1938, December, 91 : 325-332).

Both articles describe wood-fired, flue-heated buildings, constructed of materials easily obtainable locally. In the Indian kiln, the cardamoms are dried on bamboo floors, whilst in the Ceylon kiln the drying trays are timber framed with wire-mesh or hessian bottoms.

The main objective in drying cardamoms is to prevent the capsules from splitting, and thus exposing the seeds to the atmosphere. The seeds contain the bulk of the volatile oil in the spice, averaging about 6 per cent., but the pericarp contains very little ; *decorticated seeds lose their volatile oil fairly rapidly, as much as* 30 *per cent. in eight months, whereas the loss from the whole, unsplit fruits is very slight in the same period.*

Apart from this, the trade attaches great importance to the external appearance of the capsules themselves, which may be either green or bleached. Green cardamoms are most suited for distillation and should be firm to the touch and tightly closed. Bleached cardamoms are a fancy grade used mainly in mixing spices for pickling and other culinary purposes. Bleaching is sometimes carried out by exposing the fruits to the fumes of burning sulphur in sealed rooms ; or it may be done by stirring the fruits in an extract of the soap-berry tree, and then exposing to the sun, occasionally sprinkling with water.

When the capsules are sufficiently dried, the pieces of attached stalk are clipped or rubbed off, and removed by hand—or machine-winnowing. The final product may need a further air drying before shipment. Sunlight spoils the colour of the dried fruits and they should be stored in a dark room, in rat-proof metal or wooden boxes. For export, the capsules should be packed in venesta cases, lined with tin foil, polythene or sisal-kraft, or in new jute bags with waterproof linings. Cardamom seeds should be packed in clean, dry tin-plate containers or in waterproof lined wooden cases.

Notes on the Vegetative Propagation of Greenwood Cuttings with Reference to Tea.

ANTON J. H. VAN HAAREN.*

ABSTRACT.

Vegetative propagation by means of leafy softwood cuttings in general and techniques used in the propagation of tea nodal cuttings in particular, are discussed.

Principles of mist propagation are briefly described and a report on mist-propagated, pre-callused tea cuttings is given.

INTRODUCTION.

Before describing the propagation of tea cuttings, it is thought that an outline of the principal techniques and factors connected with the vegetative propagation of greenwood cuttings generally, will be helpful to introduce the techniques used in the propagation of tea cuttings.

These notes on the vegetative propagation of greenwood cuttings, with particular reference to tea cuttings, are based on more than twenty years of practical experience as an experimentalist and a nurseryman in the field of vegetative propagation, supplemented by information gained from experiments conducted by other research workers.

The notes are intended as a guide to the plant breeder-experimentalist, as well as the tea planter in Papua and New Guinea.

PROPAGATION OF GREENWOOD CUTTINGS IN GENERAL.

Of the various types of cuttings used in the vegetative propagation of plants, e.g., hardwood, softwood, leaf and root cuttings, each of which requires the use of a different technique, this paper will discuss only softwood cuttings, because this is the type of cutting used in the vegetative propagation of tea.

The propagation of leafy softwood cuttings has become increasingly important in the past decade. It is now a practical, safe and quick method in the vegetative multiplication of many plant species. This is mainly due to the results of plant research work, particularly the investigations into environmental conditions influencing success in striking cuttings and the development of advanced techniques, which has enabled vegetative propagation to take great steps forward. Modern mist propagation, for instance, has revolutionized nursery management by making large scale multiplication of leafy softwood cuttings a practical and economical method in vegetative propagation.

There are a number of internal as well as external factors which influence success in the striking of cuttings. Among the internal factors are the condition and age of the mother plants as well as the physiological condition of the cutting itself.

Of the external factors, the more important ones are light, humidity and temperature, while the rooting medium used can greatly influence results in the propagation of cuttings.

INTERNAL FACTORS.

Condition and Age of the Mother Plant.

It goes without saying that the parent material from which the cutting is taken must be in a healthy and vigorous condition. The practical nurseryman usually selects his original parent material on general appearance and on desirable characteristics. He often sets aside a special area for these mother plants where they receive special attention with regard to watering, positioning, pruning, etc., to enable him to obtain the maximum amount of healthy, vigorous cutting material.

As far as the condition of the mother plant in relation to position is concerned, it is of interest to note that Harris (1953) experienced considerable trouble in rooting cacao softwood cuttings when taken from plants in an exposed position. He found that a much better root strike was obtained if the cuttings were taken from plants

* Horticulturist, experimentalist, D.A.S.F., Bisianumu, Port Moresby.

which had received 40-50 per cent. of the full light intensity. Garner (1944), quoting Feilden and Garner on the other hand, stated that in coffee softwood cuttings the best results were obtained if the cuttings were taken from plants grown in full light.

Garner (1944) also said that Starring found that a high carbohydrate content of softwood cuttings with low soluble nitrogen, favoured rooting.

As far as the age of the mother plant is concerned, it is common knowledge among nurserymen that cuttings taken from young plants produce quicker and better roots than cuttings from old plants. Eden (1965) reported that :

"New light on the kind of shoot that provides the most vigorous cuttings comes from work at the East Malling Research Station on the propagation of apple root stocks. Rooting capacity is inversely related to maturity. This applies not only to the individual shoots on a mother plant but to the mother plant itself. Applied practically, this means that shoots used for cuttings should be those arising from a hard pruning, which stimulates rapid growth. Moreover, it is better to use relatively young bushes as a source of material."

With regard to *the physiological condition of the cutting itself*, it is known to most nurserymen that a dormant shoot often produces better and quicker roots than an actively growing shoot. This is probably caused by the amount of carbohydrates available. It may be expected that dormant shoots have a higher carbohydrate content than the actively growing shoot.

It is also a recognised fact that the presence of flowers or flower buds on the cutting has a depressing effect on root formation. Garner (1944) reported that the experiments by O'Rourke with blueberry hardwood cuttings indicated that it is not the presence of flower buds that depresses rooting but rather the conditions that lead to the formation of flower buds.

The time of year that cuttings are taken seems to have an influence on rooting and growth, but this is probably more related to climatic conditions and the resulting condition of the parent plant than to the actual time of the calendar year.

Summarizing the *internal factors* influencing root formation in cuttings it could be stated that :—

(1) parent plants must be healthy and vigorous ;

(2) food reserves (carbohydrates) in the cutting are an important factor in root formation ;

(3) cuttings from young plants produce better and quicker roots than cuttings from older plants ; and

(4) taking cuttings from dormant shoots without flower buds promotes root formation.

EXTERNAL FACTORS.

Light.

The amount of light a leafy softwood cutting receives is of vital importance in root formation, growth and general health of the cutting. Van Haaren (1955) working with coffee cuttings reported 12 per cent. rooted cuttings and 54 per cent. dead under a light intensity of 30 to 40 per cent. of daylight against 59 per cent. rooted cuttings and 8 per cent. dead when grown under 80 to 85 per cent. of daylight.

Most softwood cuttings when made have low reserves of carbohydrates and these may be depleted within a week unless the photosynthesis process can continue to produce food for root formation and growth. Without sunlight and the chlorophyll tissues of the leaf, the photosynthesis process cannot continue and the cutting will die. Thus, the bigger the leaf area and the more sunlight available, the greater are the chances of success.

Temperature.

Temperature is often the limiting factor in the possible amount of light and leaf area, particularly under tropical conditions where greater amounts of sunlight increase the temperature of the air. This results in excess transpiration through the leaf and subsequent wilting of the cutting and finally death. To control transpiration, the shading and reduction of the leaf area were common practices in the propagation of softwood cuttings before the advent of mist propagation techniques.

Humidity.

A humid atmosphere surrounding the leaf area is necessary for the leaf to keep its turgor, to stay alive and to function to produce the required substances for root formation.

Light, temperature and humidity are closely inter-related factors ; indeed, one influences the other.

The maximum possible amount of sunlight and high humidity coupled with a warm atmosphere are the external conditions required to keep the leafy softwood cutting alive and healthy. Root formation and growth will subsequently follow.

Mist propagation has provided the tool to create and control optimum external conditions to a much greater extent than ever before.

Rooting Medium.

The various types of cuttings, as well as cuttings from different species, require a different rooting medium. Softwood cuttings need a better aerated rooting medium than hardwood and root cuttings. To achieve this, coarse sand is usually incorporated in the top four to six inches of the medium. Various mixtures of coarse sand and peat moss, or coarse sand and soil of little clay content are the more popular rooting media. Fine sands are not suitable as they tend to pack quickly and become waterlogged resulting in rotting and death of the cutting. Although coarse sands are usually essential in a good rooting medium, even the best of sands has its drawbacks. Sand not only contains very little in plant nutrients, but also, because of the greater aeration, there is the danger of excessive callus growth, resulting in slow root formation.

Mixtures of coarse sand and soil and peat moss are preferred by most nurserymen.

Well-leached sawdust is another rooting medium. Excellent rooting results are obtained with softwood cuttings of cacao in a 100 per cent. sawdust medium under mist propagation at the Keravat Lowlands Experiment Station, New Britain. However, the author experienced very disappointing results with coffee cuttings in a sawdust medium at the Aiyura Highlands Experiment Station, New Guinea, when, for instance, only 37 per cent. of the cuttings in sawdust rooted (5 per cent. dead) against 80 per cent. rooted cuttings (nil dead) in a coarse sand medium (van Haaren 1955).

A disadvantage of either a 100 per cent. sawdust or a 100 per cent. sand medium is the difficulty usually experienced in transplanting the initially rooted cuttings to normal soil or potting mixtures. The changed conditions often cause setbacks and heavy losses.

The use of peat moss in a rooting medium has in recent years become more popular. One of the main features of peat is its excellent moisture retaining capacity combined with an efficient aeration ; its acid reaction is a desired characteristic in the propagation of *Azalea* and *Rhododendron* cuttings.

Sterilization (by heat treatment) of the rooting medium is usually beneficial to root growth. The *temperature of the rooting medium* is probably of more importance in the colder regions than in the tropics. Generally speaking, the temperature of the soil should be the same as, or slightly warmer than, the temperature of the air surrounding the cuttings. Garner (1944) stated that the temperature at the basal end of the cutting should be somewhat higher than at the apex, hence the beneficial effect of bottom heat.

Hormone Treatment.

There are numerous hormone preparations on the market. Applications and results of these root-promoting substances vary according to the plant species treated. The subject is, however, too complex to deal with in the context of this paper. It suffices to state that hormone treatment has its practical applications in the propagation of cuttings and that it can be a great help in root promotion of the more difficult and slow-rooting species of cuttings. The indolyl-butyric acid-based hormones appear to be the most effective of these synthetic growth-promoting substances for stimulation and root development in softwood cuttings.

Summarizing the *external factors* in influencing successful propagation of cuttings, it is stated that :—

(1) light, humidity and temperature are the most important correlated factors ; maximum amount of sunlight, a high humidity, a warm atmosphere and the greatest possible leaf area are the keys to success in the striking of softwood cuttings ;

(2) a good aerated but moisture-holding rooting medium is essential ; and

(3) sterilization of the rooting medium, the use of bottom heat and hormone treatment of the cuttings may give added success in the propagation of softwood cuttings.

After the above general discussion on factors influencing vegetative propagation by softwood cuttings, and before dealing with tea cuttings in particular, a few words have to be said about the present day most popular and successful method of striking softwood cuttings, i.e., mist propagation.

MIST PROPAGATION.

In mist propagation, the cuttings are grown in a humid atmosphere obtained by spraying a fine mist of water over the cuttings at regular intervals. Thus, the relative humidity is kept high, transpiration through the leaf is greatly reduced and the cuttings may be exposed to the benefits of sunlight without harmful effects. Only a very light shade is used and even the propagation of softwood cuttings in full sunlight has become possible.

In the early days of mist propagation, some 20 to 25 years ago, the cuttings were grown under a continuous spray of water. It soon became apparent, however, that too much water caused excessive nutrient leaching of the leaves and kept the rooting medium rather cold. Experiments indicated that a mist spray turned on at intervals, so-called intermittent mist, was sufficient to keep the leaves moist and in a turgid condition. An intermittent mist application in full daylight enables the photosynthesis process to continue. Thus, food reserves are accumulated and this results in a higher survival rate and earlier rooting of the cuttings than was ever before possible with the conventional methods of cutting propagation.

Intermittent mist, often combined with electrically-supplied bottom heat to keep the rooting medium around the optimum temperature of about 75 degrees F., is producing excellent results and has become the standard method of propagation of many plant species in present day nurseries. For a detailed description of mist propagation techniques, it is highly recommended to study the booklet *Mist Propagation of Cuttings* by Patricia Rowe-Dutton, published by Commonwealth Agricultural Bureaux, Farnham Royal, Bucks, England.

TEA CUTTINGS.

History.

The earliest work on vegetative propagation of tea has been recorded in Formosa and Japan where layering and marcotting was practised as early as 1887. In Java, the vegetative propagation of tea began to be studied seriously in 1912, by Dr. J. P. Cohen Stuart. Wellensiek, who continued this work described a propagation method of tea cuttings in 1931. Budding and grafting of tea was practised in West Java in the years before World War II but the technique never gained much popularity. The work of van Emden (1950), just before the second World War, and in the years immediately after, laid the basis for tea propagation by cuttings in Java. In Ceylon, Kehl, Visser and Eden, and in Kenya, Green, have given detailed accounts of their experimental work in tea cuttings (Eden 1965).

Van Emden (1950) in Java, used a continuous mist propagation method for tea cuttings as early as 1949.

During the last decade the propagation of tea by single internode cuttings either under mist or without use of mist, has by far become the more popular method in any breeding and selection programme of tea. The technique is a dependable and an economical method for the rapid multiplication of selected clonal planting material.

In the propagation of tea cuttings the same general principles and factors apply as described in the earlier chapter. Further discussion will therefore deal with those techniques and factors which relate to the striking of tea cuttings in particular.

Mother Plants.

Mother plants are bushes selected because of high yield and good quality and which preferably have a wide plucking table. Mother bushes are allowed to grow unpruned for about four to six months, producing in that period many shoots. Hundreds of single internode cuttings can be taken twice a year from one mother plant.

Mother bushes are specially cared for in order to keep them healthy and vigorous. A nitrogenous fertilizer is usually applied twice a year at three months before taking the cuttings,

As described earlier, the age of the mother plants influences rooting ability. This principle applies also to tea. In this regard, van Emden (1950) reported that cuttings taken from one-year-old seedlings showed 80 per cent. rooting in four weeks' time, whereas in the control series taken from ten-year-old plants, not a single cutting had rooted. The impression was also gained that cuttings taken from a budded plant do not root as readily as do those taken from a seedling of the same age. Van Emden (1950) furthermore stated that there is no difference in rooting performance between cuttings taken from shoots with flowers and cuttings from shoots without flowers. He added however that if cuttings produced flowers while in the propagation beds, root as well as shoot growth stagnated.

Generally speaking, the making of cuttings from shoots that are in flower should be avoided as these cuttings often produce flowers and little or no growth.

Kehl (1950) reports that it is no disadvantage if the cuttings are made from shoots with growing buds, but if much growth has been produced, the shoot is cut back to the so-called 'fish-leaf'.

Green (1964) on the other hand stated that the axillary buds should be dormant.

It is the author's opinion that cuttings with active axillary buds up to a length of say one-half of an inch are quite acceptable, but that cuttings with one inch and over in axillary bud growth may present difficulties because of excess transpiration (not under mist, of course) while they also appear to be slow in rooting.

Making the Cuttings.

The shoots are cut from the mother bush at about one inch above the old pruning cut, are placed in a bucket of water and are carried to the propagation bed.

Making of cuttings is always done under shade and many nurserymen prefer the cuttings to drop into a bucket or a dish of water to prevent drying out. The author prefers the late afternoon and evening hours to the early morning hours in making the tea cuttings, and also immediately planting out without dropping them in water first; the cool hours of the night seem to "settle them in" better.

Time of the year in making the cuttings appeared to be rather immaterial in West Java, but Harler (1966) states that in north-east India, the best time of the year to take cuttings is between mid-April and early May and from mid-September to early October. The cut is made just above the leaf with a sharp knife or a good pair of secateurs, taking care not to damage the axillary bud and the leaf. The cut is often made at a 45 degree angle, sloping away from the bud. It is the author's opinion that it does not matter whether the cut is made on an angle or straight across the stem, and he has mostly used the secateurs instead of a knife in making tea cuttings. The indications were that making the cut with secateurs and thus slightly bruising tissues had a stimulating effect on root formation. Using secateurs and cutting straight through the stem just above the leaf is a simple and a quick method which became the author's standard technique in making tea cuttings.

Length of the cutting is governed by the length of the internodes and although short as well as long internode cuttings can be successfully used, the ideal length of a tea cutting is $1\frac{1}{4}$ to $1\frac{3}{4}$ in. Long internodes (over 2 in.) may of course, be shortened to about $1\frac{1}{2}$ in., but cuttings shorter than $\frac{3}{4}$ in. are usually discarded unless it is very valuable material and in short supply. Shoots with rather short internodes may be used in making two internode (or more) cuttings by removing the lower leaf or leaves.

The full length of the shoot can be made into cuttings although cuttings made from the lower, woody part take longer to root and in practice are mostly discarded if sufficient material is available. Without mist propagation, the two to three top internodes cannot be used, as stem tissues are too soft causing the cutting to wilt and die. Their rooting potential however, is as good as or even better than in cuttings made from the greenwood middle section of the shoot.

Planting the Cuttings.

Planting during the late morning hours, midday and early afternoon must be avoided for obvious reasons. Planting is best carried out in the late afternoon and evening hours. Spacing of the cuttings depends on leaf size. The author has always planted tea cuttings as closely together as possible without leaves touching or overlapping others. The planting technique consists merely of taking the upper part of the stem between thumb and index finger, leaf pointing outwards, and pushing the cutting vertically into the earlier prepared soil or special rooting medium, so that the base of the leaf is just touching soil level; the leaf itself is then usually off the ground and pointing slightly upwards. A planting stick, or dibbler, was never used because of the danger of leaving an air pocket under the base of the cutting. The soil in the propagation bed is firmed just before planting. Naturally, planted cuttings are immediately 'watered-in'. The ordinary knapsack-sprayer was found to be satisfactory for this purpose. Light spraying is done after each batch of approximately one hundred cuttings is planted; cuttings are kept moist as planting progresses. Needless to say, that planting is done under shade or at least away from direct sunlight.

Rooting Medium for Tea Cuttings.

It is generally recognized that tea cuttings planted in humus-rich soils show poor rooting performance. Whether this is related to the fact that the tea plant, in most countries, grows best in a soil with a pH value of around 5.0—an acid-type soil which is often poorly textured—is unknown. However, it seems generally agreed that the tea cutting roots best in a soil of a low organic matter content with a pH ranging from 4.5 to 5.5 (Green 1964). The author believes that the pH has little or no influence upon root formation, but may well have an influence after the initial root development when the young rootlets begin to function. Not enough is known about the factors influencing rooting in cuttings; it is quite possible that a combination of factors in the rooting medium, such as aeration, water-holding capacity, nutrient status as well as pH, govern the rooting process.

The repeated poor rooting ability of some tea clones is, of course, a genetic factor and a clonal characteristic which should not be confused with results influenced by environmental conditions.

The main requirement of a rooting medium for tea cuttings (and greenwood cuttings in general), is that it drains well and is adequately aerated, particularly in the top three to four inches of the medium. Coarse sands meet these requirements. However, sands usually have a high pH value. If it is desired to bring the pH value down, the sand could be mixed with soils of low pH, or could be treated with sulphur powder (or ammonium sulphate) as an acidifying agent. Any soil not too rich in organic matter and with little or no clay content and an open texture will be suitable in itself or in mixtures with coarse sands as a rooting medium for tea cuttings, provided that drainage and aeration are adequately taken care of. Sterilizing the medium is usually beneficial to rooting. If the cuttings are to be left in the medium for some time after initial rooting, it is a good practice to fertilize the subsoil before planting the cuttings. In most instances, however, cuttings are left in the rooting medium for six to twelve weeks—depending on root development—and are transplanted to nursery beds as soon as possible.

A more recent method is to propagate the cuttings in polythene bags under the same conditions as in the propagation beds. The cuttings are left in the bags to root and grow, and after a hardening-off period, are normally ready for transplanting to the field in about six months' time; they could be left in the polythene bags for up to 12 months if necessary. In the polythene bag technique, using bags of ten inches in length, the bottom six to seven inches are filled with a suitable subsoil, which is often mixed with fertilizer. The top three to four inches consist of the desired rooting medium.

Light, Humidity and Temperature.

The same principles apply for tea cuttings as described in the propagation of greenwood cuttings, these being as much daylight as possible, combined with a high relative humidity and an air and soil temperature of around 75 degrees F.

REMARKS ON PROPAGATION OF TEA CUTTINGS IN PAPUA AND NEW GUINEA.

Although the author believes that modern mist propagation techniques are the answer to large-scale and rapid propagation of tea cuttings, it is realized that under Papua and New Guinea conditions, this technique is often impracticable. Provided that the general principles for striking greenwood cuttings are adhered to, a relatively simple and economical method of propagating tea cuttings is feasible.

The imaginative planter-propagationist will be able to adapt the above-outlined principles and techniques to suit local conditions. The method as described by van Haaren (1955) for coffee cuttings in the New Guinea Highlands could easily be modernized and adapted to the propagation of tea cuttings. The author will be interested to learn of locally developed techniques in tea cutting propagation and will be pleased to advise in such developments.

As a general guide to root and shoot growth, it can be stated that tea cuttings under suitable conditions produce the first callus growth in two to six weeks after planting, root growth follows in four to eight weeks after planting, and growth of the axillary bud commences after five to twelve weeks. Using mist propagation, rooting and shoot growth are accelerated.

It must be emphasized, however, that rooting and growth are greatly influenced by environmental conditions and that rooting ability of the cuttings is a clonal characteristic, which can vary greatly within clones.

In 'shy rooting' clones, the use of root-promoting hormones is often beneficial.

REPORT ON CALLUSED TEA CUTTINGS.

In conclusion, the propagation of pre-callused tea cuttings is discussed.

It is sometimes necessary to send tea cuttings over long distances to other areas for propagation and planting. Freshly-made cuttings dry out very quickly and cannot be transported over long distances. However, when callus has formed at the base of the cuttings. they stand travelling much better. The technique developed in East Africa is to callus the cuttings first in the propagation bed. This takes about three to four weeks. Cuttings are then lifted, washed in water, inspected for callus formation, packed in polythene bags (200-gauge), and then loosely packed into cardboard boxes for transportation. On arrival at their destination, these pre-callused cuttings are immediately planted into their propagation beds in the same way and under the same conditions as freshly-made cuttings.

Although this method seems to work satisfactorily, the author does not favour it and believes that there must be better ways of striking cuttings at long distances away from their source. It is evident that lifting the callused cuttings after some two to four weeks in the rooting medium, at a time when these cuttings are at the most critical period of the rooting process is a disturbing and severe operation, which it is thought, must be detrimental to the cuttings. As every nurseryman knows, one of the principle rules for the successful propagation of cuttings is not to touch them during the first eight weeks when initial root development takes places. This lifting operation of two to four week old tea cuttings, followed by transportation and replanting, into what is often a changed environmental condition, must give the cuttings a severe physiological shock which cannot be anything else but detrimental to final success.

As an alternative method of striking cuttings at some distance away from their source, it is suggested that the complete shoot, less the two top internodes, as taken from the mother plant, is moisture-sprayed and packed in polythene. Some four to six, or more, shoots may be packed together, in rather the same way as bunches of flowers are packed and dispatched all over the world. Upon arrival at their destination, the shoots should then immediately be made into single internode cuttings and propagated in the usual manner.

In view of the above, it is perhaps interesting to examine the planting and treatment of pre-callused tea cuttings grown at the Plant Quarantine Laboratory, Yarralumla Nurseries, Canberra, A.C.T.

In October, 1966, a consignment of pre-callused tea cuttings for a Territory trading and planting firm were sent from Kenya (East Africa) to Canberra (Australia), where these cuttings had to undergo intermediate quarantine in accordance with plant quarantine regulations, before they could be forwarded to New Guinea.

The author, assisted by Officers of the Plant Quarantine Section, Department of Health Canberra, took delivery of these cuttings and attended to planting and further treatment.

The cuttings arrived at Canberra after some 40 hours of travel and perhaps as long as three days after lifting from the propagation nurseries in Kenya. The cuttings were well packed in polythene sleeves and generally appeared to be in remarkably good condition, except for a number of cuttings from one or two clones which showed a copper-brownish discolouration of leaves and stems, reminiscent of fermented tea leaf. Three clones—K5/179, K1/4/12 and 12/90 in this order—showed excessive callus development, while it was also noticed that clone 12/90 had produced rather lengthy shoots from the axillary bud.

Before planting, all cuttings were dipped in a malathion 0.2 per cent. solution to comply with Australian plant quarantine regulations, after which the basal ends (callus tissues in this case) were dipped in 'Seradix' B, No. 2 powder, an indolyl-butyric acid-based hormone preparation. It may be noted that *Camellia* cuttings in particular have responded well to treatment with 'Seradix' when removed from the rooting medium and not having produced roots as yet.

A total of 322 cuttings from 13 different clones were planted in four rooting media as follows * :—

(A) sand + peat 1 : 1, pH 5.0, 112 cuttings in 20 pots ;

(B) sand + peat 2 : 1, pH 5.5, 78 cuttings in 15 pots ;

(C) sand + peat 1 : 2, pH 5.0, 78 cuttings in 15 pots ; and

(D) perlite 100 per cent., pH 7.5, 54 cuttings in 10 pots.

* *Plates* I and II.

Plate I.—Tea cuttings one day after planting perlite (rooting medium D) in foreground.

Plate II.—Tea cuttings one day after planting perlite (rooting medium D) in background.

The cuttings were planted in plastic pots of about ten inches deep and some eight inches wide at the top. The bottom six inches of every pot was filled with a sterilized mixture of river sand and peat 1 : 1 (pH 5.0) which included superphosphate at the rate of 2 oz. per 4½ cubic yards of this subsoil mixture. The top three to four inches consisted of the various rooting media (sterilized) as described above in A, B, C, and D.

Because of the rather high pH value (7.5) of it was decided to mix this sand with imported of the local (Canberra) type of coarse river sand, German peatmoss (pH 4.0) in a ratio of one to one and to make this mixture the main rooting medium (A). Media B and C were added to test drainage and moisture-holding capacities of the medium. Perlite was added as a rooting medium to check rooting in relation to pH value. Perlite is a coarse granular mineral used as a plaster aggregate in the building industry ; it has excellent drainage and aeration qualities and is well known to nurserymen as a good rooting medium for softwood cuttings. The perlite in this case had a pH value of 7.5.

The pots with the cuttings were placed in the brick-constructed propagator in the centre of the glasshouse under an intermittent mist spray of 15 seconds misting in every two minutes, aiming at a relative humidity of 70 per cent. The air temperature in the glasshouse was controlled by an automatic hot water heater, set at 70 degrees F., which would blow warm air into the glasshouse when the temperature dropped below 70 degrees F.

Results obtained as reported to the author by the Officer-in-Charge of the project, Mr. Lance Smee, Plant Quarantine Officer, Department of Health, Canberra, A.C.T., were briefly as follows :—

At seven weeks after planting, 14 per cent. of the cuttings had produced good shoots of four inches and over in length ; 43 per cent. of the cuttings had shoots of two to one inch in length, and 41 per cent. had shoots under one inch in length (*Plate* III). Only four cuttings had died by that time. On appearance, the medium had no significant influence upon growth of the cuttings. The best clone in vigour appeared to be 1097, while clones K4/45, K3/23 and 12/90 were far behind in vigour. At this stage, i.e., seven weeks after planting, nearly all of the shoots were rather pale in colour ; indicative it is thought, of nutrient leaching through excessive watering ;

Plate III.—Tea cuttings six weeks after planting. Note growth of axillary bud.

Hardening-off commenced at this time by reducing the mist frequency and gradually removing the pots with the more advanced cuttings to the humidity chamber in the screen-house where they were watered twice daily. The last, and least developed, lot of cuttings were removed from the mist 12 weeks after planting. During the hardening-off period, some losses occurred.

In late February, 1967, twenty weeks after planting, the majority of cuttings were ready for dispatch to New Guinea (*Plate* IV), but for various reasons, they were not air-transported to Port Moresby until early April, 1967, 25 weeks after planting.

At the time of dispatch to Port Moresby, all the cuttings, except in clone K4/45 and 12/90, had formed good quality roots of three to six inches in length with the best rooting clones K5/206 up to ten inches root length and K2/45 with roots up to eight inches in length.

There were no marked rooting differences in the cuttings from the sand + peat mixtures, media A, B and C, but the cuttings in medium D, perlite, had produced a stiffer and branched type of root. They were about one inch shorter than the average in the sand — peat mixtures, but were also of good quality.

It may be concluded that—

(1) the high pH value in the perlite had no influence upon initial root development;

(2) drainage and aeration are of greater importance in a rooting medium than the pH; and

(3) a sand — peat mixture 1 : 1 is the more practical rooting medium and would make an ideal medium for tea cuttings in polythene bags under intermittent mist propagation.

Cuttings in such a medium could stay in the polythene bags for uninterrupted growth until transplanting to the field.

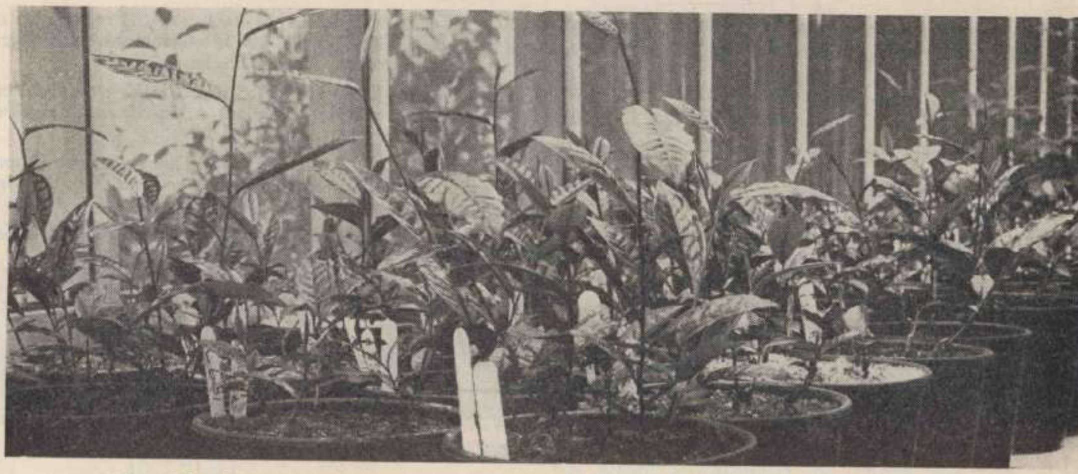


Plate IV.—Tea cuttings 22 weeks after planting, just before dispatch to New Guinea.

The best all-round clone, for rooting as well as for vigour, of this consignment as Canberra, was undoubtedly K5/206.

It is interesting to note that—

(1) the best rooted clones, i.e., K5/206, 1097 and K2/454, showed a very light to light type of callus development and a medium to small axillary bud growth on arrival at Canberra ; and

(2) the poorest rooter, clone 12/90, had a relatively long axillary shoot and a medium to heavy callus development on arrival.

This bears out the author's opinion, as well as literature sighted, that excessive callusing and early shoot development are contrary to root formation.

Finally, it must be added that the striking of cuttings, including tea cuttings, requires the constant supervision of the propagationist. Without daily attention to environmental conditions and a keen eye for the general behaviour and health of the plants, any cuttings propagation programme will result in failure. It is usually the experienced nurseryman who will achieve best success.

ACKNOWLEDGEMENTS.

The author is indebted to the following persons :—

Mr. A. W. Charles, Assistant Director, Research and Surveys, Department of Agriculture, Stock and Fisheries, Territory of Papua and New Guinea, for critically reading the paper ;

Dr. J. R. Morschel, Assistant Director-General, Plant Quarantine, Department of Health, Canberra, A.C.T., for the co-operation and assistance in making available quarantine facilities at Canberra and for the detailed notes and observations made on the rooting of tea cuttings in intermediate quarantine at Canberra ;

Mr. W. L. Conroy, Director, Department of Agriculture, Stock and Fisheries, Territory of Papua and New Guinea, for assistance and advice in the Canberra tea cuttings assignment ; and

Mr. Lance Smee, Plant Quarantine Officer, Department of Health, Canberra, A.C.T., for assistance in planting, care and attention to the tea cuttings in Canberra, as well as for notes and observations on growth of these cuttings—and for *Plates* III and IV.

The author is particularly grateful to his former Director, of the Botanical Division, C.P.V. Research Station, Buitenzorg (Bogor), West Java, Ir. J. H. van Emden, whose advice and encouragement directed him in the field of vegetative propagation.

Their assistance, interest and efforts are gratefully acknowledged.

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Accepted for publication December, 1968.

Traumatic Vertical Lysigenous Canals in Cacao in Papua and New Guinea.

BY DOROTHY E. SHAW.*

ABSTRACT.

The occurrence of tangential series of traumatic vertical lysigenous canals or pseudo growth rings is recorded in some cacao wood specimens from three areas in Papua and New Guinea. The traumatic canals replace xylem and fibres and constitute a zone of weakness in the wood when it is cut from the tree. Normal and traumatic lysigenous cavities of cacao are clearly distinguished with excitation with ultra violet light after treatment with acridine orange, the mucilage appearing brilliant red. The cause of the traumatic canals is not known but was probably injury to the cambium.

INTRODUCTION.

During the examination of sections through the stem and branches of many specimens of cacao (*Theobroma cacao* L.) at the Port Moresby laboratories several cases have been noted where lysigenous canals have occurred in tissue other than the pith and cortex, viz., in the wood. In cacao the normal location of lysigenous cavities filled with mucilage is in the pith and cortex (Metcalfe and Chalk 1950, Brooks and Guard 1952).

Record (1925) described traumatic vertical lysigenous intercellular canals in various plant families including Sterculiaceae. Later he listed *Theobroma* as one of the genera of the Sterculiaceae in which the intercellular canals occur, without, however, further elaboration (Record, 1934).

A description of the condition found in the Papua and New Guinea specimens is given below.

MACROSCOPIC EXAMINATION.

In stems and branches split longitudinally or cut transversely the abnormal elements were slightly yellower than the rest of the wood.

They were much easier to see after the wood had been split for some time, at which stage they appeared speckled brown to the naked eye. In transverse section they formed tangential series or pseudo growth rings (*Plate* I, A) and in longitudinal section they formed lines running parallel to the long axis (*Plate* I, B and C). The lines were unbranched, each varying very little in width throughout its length although some were wider than others. Where side branches occurred, the lines could be traced into the branches in positions similar to those in the main axis (*Plate* II, A).

To date no more than three rings or partial rings have been noted in any stem; in some stems only two occurred and in others only one. The distance of the rings from the centre of the stem and from one another varied between specimens.

In freshly split specimens the mucilage was viscous but became brown and hard in wood which had been split for some time, at which stage it formed thin incrustations in the canals; the canals themselves could usually be distinguished with a 10 x hand lens as minute holes in the wood. The speckled appearance was due to fine strands of normal tissue interrupting the longitudinal lines of canals (*Plate* I, C).

In some of the affected branches which had been split for a week it was found that the ring of abnormal tissue formed a zone of weakness so that very little pressure was necessary to cause fracture of the wood in that area. *Plate* II, A shows where such a zone of weakness occurred, and *Plate* II, B shows the cleavage after a little pressure had been applied and the two parts had separated with little difficulty. The faces of the cleavage planes slightly resembled honeycomb with very tenuous cross walls, as shown in *Plate* II, B.

MICROSCOPIC EXAMINATION.

Sections through tissue of affected stems revealed that the pseudo growth rings consisted

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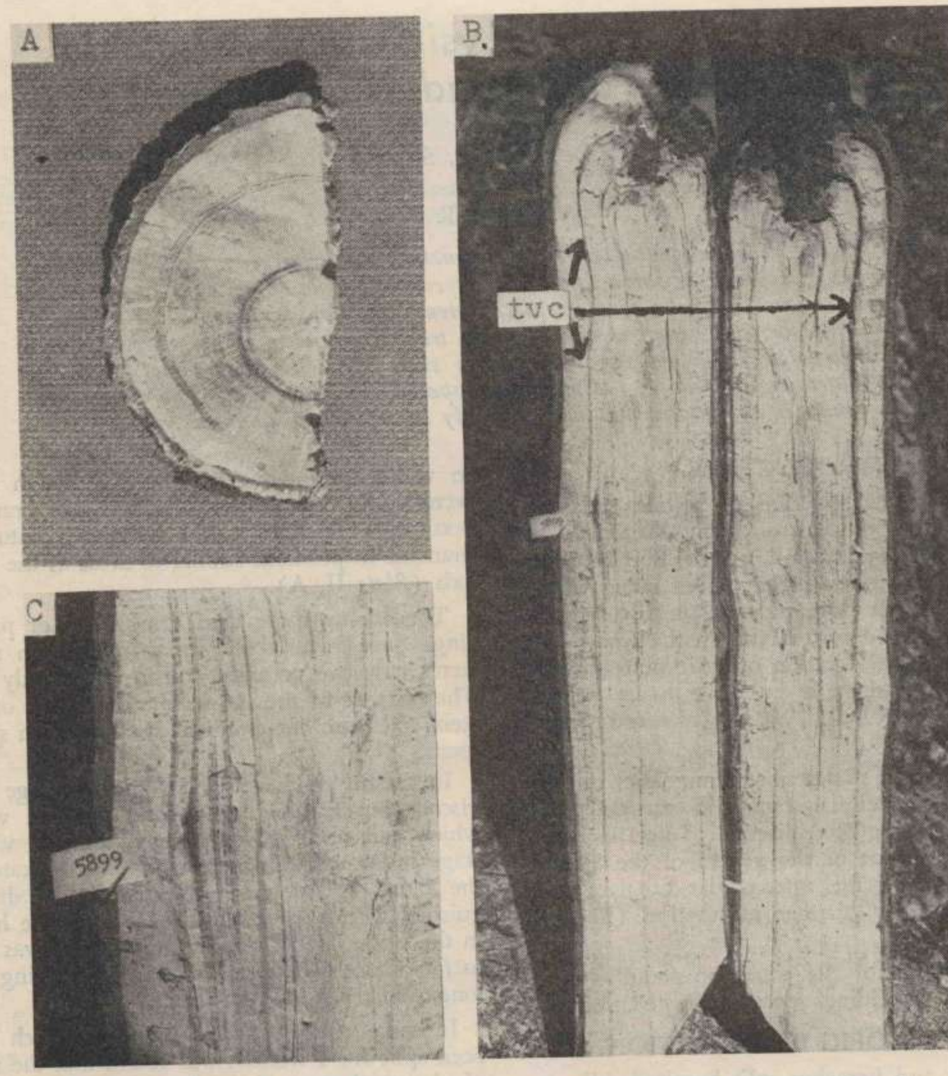

Plate I.—(A) Transverse section showing two pseudo growth rings each consisting of several rings of traumatic certical lysigenous canals. (B) A branch split longitudinally showing line of traumatic vertical canals (tvc). (C) Enlargement of portion of (B) showing speckled appearance of the lines of canals due to cross strands of tissue.

of tangential series of lysigenous cavities (or canals, as the length was greater than the width) formed in the wood. The lysigenous cavities of the pith and cortex occurred as usual.

A portion of a transverse section is shown in *Plate* III. The canals occur between the rays, replacing the xylem vessels and fibres. The rays are slightly compressed where they pass between two canals. One or more vessels or groups of vessels occur between the rows of canals. In this specimen three rows of canals occurred in the zone shown in the Plate.

The canals are mostly very regularly oval in outline in transverse section. In *Plate* III they are approximately five times longer and four times wider than the vessels, the average lengths and breadths of twenty cavities and vessels taken at random in one section being 345 x 230u for the canals compared with 66 x 64u for the vessels.

In longitudinal section the lacuna of each canal is seen to be interrupted at intervals of up to 1.3 mm by thin cross strands of parenchyma.

The narrow strands of ray parenchyma between the canals and the relative absence of fibres in the ring of tissue in which the cavities were situated constituted the zone of weakness which was evident when a little pressure was applied to the wood, resulting in the cleavage as shown in *Plate* II, B.

Plate II.—(A) Lines of traumatic vertical canals (tvc) passing into two side branches. Zone of weakness (zw) due to lines of canals already partially split. (B) Same section as (A) with cleavage in zone of weakness; faces of the cleavage zone with slight minute honey comb appearance.

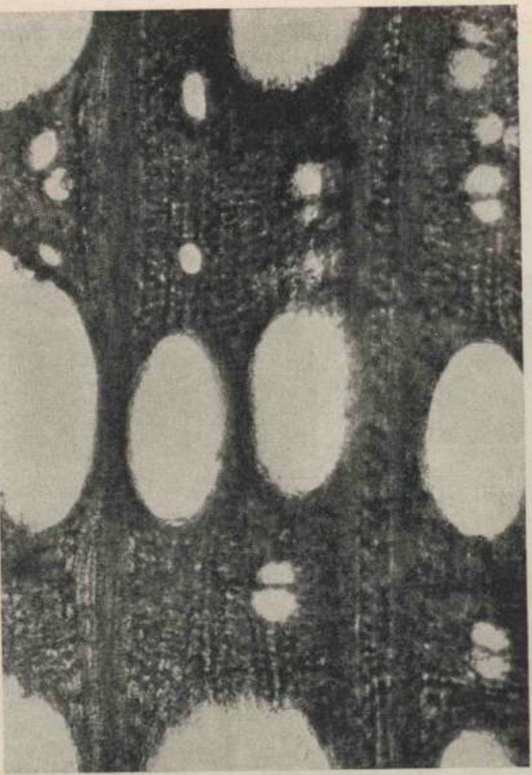

Plate III.—Transverse section through stem showing three rings of traumatic canals in the wood replacing xylem and fibres. x60

EXCITATION WITH ULTRA VIOLET LIGHT.

When sections of normal cacao wood direct from the tree are treated with acridine orange and ultra violet light is used as the excitant, the xylem, fibres and parenchyma of the wood and the fibres of the cortex capping the phloem groups appear yellowish green. The non-living mucilage, however, appears brilliant red, whether it occurs in the mucilage cells of the cortex or in the lysigenous cavities of the cortex and pith. Much of the mucilage seeps out of the cavities and cells in thin sections taken from young shoots of normal cacao so that the cells of the pith and the cells of the cortex other than the fibres also have a red cast. The mucilage which seeps into the mountant is also brilliant red (*Plate* IV).

The traumatic lysigenous canals which occurred in some branches as described in this paper also appeared brilliant red in acridine orange with ultra violet excitation, and were spectacularly distinguished from the xylem, fibre and parenchyma tissues of the wood.

OCCURRENCE.

The rings of traumatic lysigenous canals have been found to date in cacao wood from the Popondetta area in Papua, and from the Gazelle Peninsula in New Britain and from New Ireland, both in New Guinea. It is quite possible that they occur in cacao in other areas.

DISCUSSION.

The cause of the condition is at present unknown.

The wood samples which were found to contain the traumatic lysigenous canals were forwarded to the writer as sample lengths from six inches to three feet in length and were stripped of leaves before dispatch. The trees from which the samples were derived were unmarked so that it was not possible for the collectors or the writer to go back to the trees and examine them in order to determine whether any abnormal growth habit or damage was evident.

Brooks and Guard (1952) stated that in the stem tips of normal cacao the position of the lysigenous cavities is indicated by groups of cells in which cytoplasm is more granular and has a greater affinity for stain. Each of the groups rapidly develops into a large lysigenous cavity filled with mucilage.

Record (1925) considered that traumatic (as distinct from normal) vertical intercellular canals presumably arise as a consequence of injury to the cambium.

Whether the factor initiating the traumatic vertical canals under discussion was mechanical or insect damage, or a physiological disturbance to the tree, is not known. Whatever the initiating factor, it seems (from the lengths of wood studied to date) that once the canals form they persist for several feet at least. It is not known whether the growing point can revert to normal wood production without the traumatic canals once they have been formed in the stem ; tracing throughout the whole tree will be necessary to determine this point.

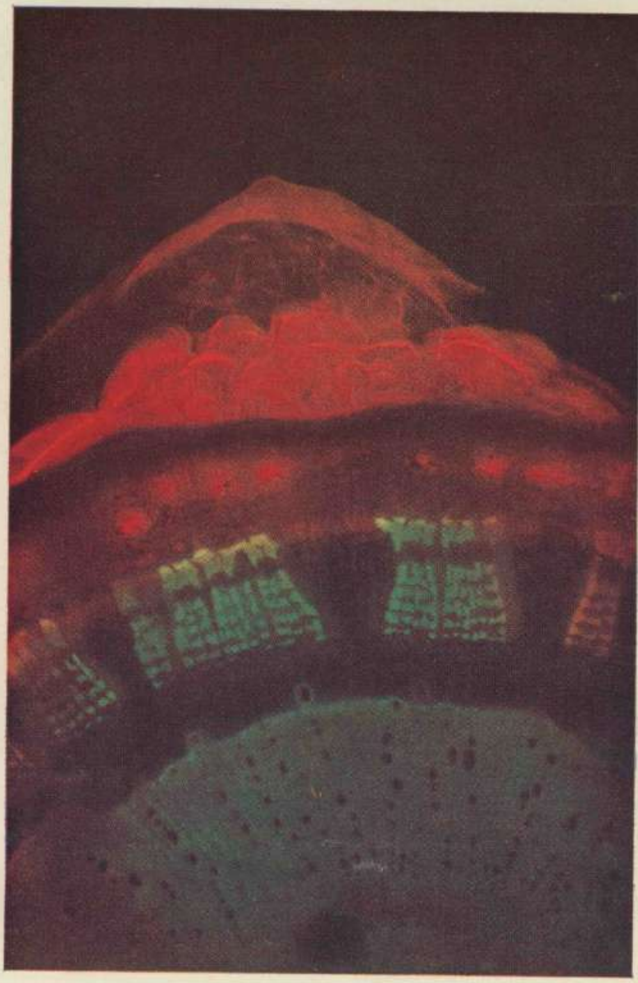

Plate IV.—Transverse section through stem of healthy Cacao stained with Acridine Orange and with U.V. excipation. Mucilage in cells of cortex and seeping into mountant brilliant red. x15.

While the canals constitute a zone of weakness in the wood when the tree is cut, it is not known whether their presence constitutes a zone of weakness in the live tree, that is, as distinct from the presumed injury which initiated their occurrence.

ACKNOWLEDGEMENTS.

One group of specimens mentioned in this paper was forwarded by a planter in the Gazelle Peninsula of New Britain and this is duly acknowledged

I would also like to acknowledge the very helpful discussions with Dr. C. R. Metcalfe, Keeper of the Jodrell Laboratory, Royal Botanic Gardens, Kew, England, on intercellular canals.

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(Accepted for publication October, 1968)

Book Review.

THE FARMING OF FISH C. F. HICKLING (Pergamon).

This small book (85 pp. and index) is one of a Biology in Action series of Pergamon's Commonwealth and International Library. It serves as an authoritative introduction to the subject, as there is none in the world with a wider experience in the field than Dr. Hickling. It it 'essential reading' for an understanding of fish-farming, which in its broadest sense includes not only freshwater but also brackish and marine pisciculture, and which will one day be of considerable importance in Papua and New Guinea.

The format is logical, as one would expect, and includes, besides an introduction which stresses the problems of international co-operation in marine fisheries, an aside on the history and present intensity of pond-culture. Dr. Hickling, whose estimates are as well-informed as anybody's, considers that annual production from ponds is about 600,000 tons, or about 4 per cent. of the total production of edible fish, allowing for the considerable manufacture of fishmeals and other non-edible products.

The major part of the book is devoted to the principles and practices of fish-farming ;—the physico-chemical basis of the methods, the biological requirements, the importance of thorough preparation and considered appreciation of techniques. Increased productivity through culture of mixed species is discussed, tantalizingly, since at this stage these species are unavailable in the Territory, due to quarantine restrictions. The vast potential of farming the sea is touched upon, and is of special interest to this country, with its relatively extensive coast-lines, much of them agriculturally useless or at best uneconomic.

Dr. Hickling's question ; "Why Not More Fish-Farming ?" is very appropriate to us here, when it is appreciated that "poor tropical soils" can produce 2500 lb. of fish per acre per annum —at least *ten* times what can be expected from say, cattle. However, it is cautioned that "though fish-farming is neither more difficult nor more laborious than other kinds of farming, it fails unless the people have some tradition of intensive livestock husbandry" (as, of course do other forms of intensive stock-farming) ; it is therefore recommended for small-scale work in mixed holdings.

Finally a short list of Further Reading is appended for those interested in more detailed information in some of the technical aspects. Not the least of these recommendations are two other books on fish-farming by Dr. Hickling, which this reviewer has used extensively in his own work.

L. W. C. Filewood

Port Moresby: V. P. Bloink, Government Printer.—A7375/5.69.