THE RHIZOBIUM SUPPLY SERVICE IN PAPUA NEW GUINEA

DOROTHY E. SHAW,[1] M. J. TRINICK,[2] W. A. LAYTON[3] AND E. GWENDA CARTLEDGE[3]

ABSTRACT

This report of the Rhizobium Supply Service in Papua New Guinea since its inception in 1956 *includes an account of the history of the service, the strains used and their origins. Up till June,* 1971 *nearly* 18,000 *bottles of inoculum were supplied to local growers and to some overseas countries, mainly for legumes of economic importance. The results of field sowings of inoculated and uninoculated seed are given; these showed, among other things, that in* 36.9 *per cent of the cases recorded uninoculated plants had nodulation as effective as occurred on the inoculated plants and that in* 36.8 *per cent of the cases plants derived from inoculated seed performed better than the uninoculated controls. The details of performances in field sowings are also given for some selected legumes.*

INTRODUCTION

FIXATION of atmospheric nitrogen (N) has been recorded as occurring in non-leguminous plants (members in nine families including the Casuarinaceae with root nodules and six families with leaf-glands) including lichens. Nitrogen is also fixed by free-living bacteria (*Azotobacter, Beijerinckia, Clostridium* and others) and by some algae (the blue-greens), but claims for fixation by fungi are at present mainly unconfirmed (Henzell and Norris 1962; Norris 1962).

However, according to Henzell and Norris (1962), the cultivation of leguminous plants is probably the most important method of adding N to the soil/plant system.

Only a small percentage of the described species in the Leguminosae have yet been examined for nodulation by Rhizobium bacteria. In 1956 only 1200 or about 10 per cent of the then described 11,000 species had been checked in varying degrees[4] (Norris 1956), and of these 133 (9 per cent) apparently never bear nodules at all, the figures for the three subfamilies being 64 without nodules of the 97 species examined in the Caesalpinioideae, 12 without nodules of the 134 examined in the Mimosoideae, and 57 without nodules of the 969 examined in the Papilionoideae.

Absence of nodules at one particular time, however, is no guarantee that the species is a non-nodulating type, as the occurrence of nodules may be cyclic at least in perennial shrub and tree legumes (Hannon 1949, cited by Norris 1956) or absent because of drought or other reasons (Beadle 1964).

The presence and number of nodules is no guide to their effectiveness; if they are ineffective the bacteria may be parasitic on the host for nitrogen and the legumes must obtain their nitrogen from the soil, in which case they deplete the nitrogen reserves quicker than cereals and grasses. Effective nodules contain red leghaemaglobin which can be seen on cutting them across. Ineffective nodules are usually small, hard, spherical and a greenish colour inside. Norris (1956) has stated that in species that can nodulate, the absence or ineffectiveness of nodulation results in a much lower protein content.

The Rhizobium bacteria are not obligate symbionts; they spend much of their existence as free-living saprophytic soil inhabitants. As

1. Chief Plant Pathologist, Department of Agriculture, Stock and Fisheries, Port Moresby.

2. Former Pathologist, Department of Agriculture, Stock and Fisheries, Port Moresby. Present address: CSIRO, Western Australia.

3. Pathologists, Department of Agriculture, Stock and Fisheries, Port Moresby.

4. Grobbelaar *et al.* (1964) stated that no more than about 15 per cent of the family had been investigated for the capacity to form root nodules.

such they possess the ability to survive and multiply in the soil for long periods between chance sojourns within legume root nodules (Norris 1956).

Norris (1965) considers that there are two great groups of Rhizobium nodule bacteria associated with legumes, viz., the ancestral, alkali- ~~alcohol~~-producing "cowpea" type, largely tropical, tolerant of acid soils and promiscuous on a wide range of hosts; and the recent, largely temperate, fast-growing, acid-producing type, intolerant of acid soils with very specific host ranges, such as those on species of *Trifolium* (clovers) and *Medicago* (medics).

Investigations into the nodulation of legumes in Papua New Guinea started, as far as is known, in 1954 and proceeded in conjunction with the development of the free Inoculum Supply Service inaugurated in 1956 by the Department of Agriculture, Stock and Fisheries.

HISTORY OF THE INOCULUM SUPPLY SERVICE

As far as can be traced, at least one importation of a Rhizobium culture was made into Papua New Guinea about 1955, that is, just prior to the establishment of the Papua New Guinea Rhizobium Service. Details are given later in the section on Rhizobium strains.

The initial work with Rhizobium in Papua New Guinea was done by Mr L. B. Thrower in the period 1954-57. This work consisted mainly of the isolation of Rhizobium from *Leucaena leucocephala* and the initiation of some field trials. Further isolations were undertaken by Shaw, who began work in 1955. The regular supply to growers of cultures of Leucaena Rhizobium isolated in this country commenced in August, 1956.

In 1956 importation from Australia of isolates of proved efficiency for other hosts was begun. The first two cultures were for *Medicago sativa* (lucerne) and *Trifolium pratense* (red clover), both from the Queensland Department of Primary Industries, followed by cultures for peanut and soybean.

Since that date various officers have been involved with the maintenance of the service but any comments or opinions in this paper are the responsibility of the senior author.

ORIGIN OF STRAINS

Leucaena leucocephala

The culture of Rhizobium introduced about 1955, prior to the establishment of the Rhizobium Service, was culture CB81 for *Leucaena leucocephala*, originally isolated by Norris from nodules on a specimen plant in the Botanic Gardens, Brisbane, in June, 1954. In July, 1955 Norris isolated culture CB415 from nodules from well-nodulated introduced *L. leucocephala* growing at Keravat in New Britain. It is not known where in Papua New Guinea if at all CB81 was used, or whether any Rhizobium was accidentally introduced with the early Leucaena[5] seed introductions.[6] In 1956 Norris reported to Shaw (in correspondence) that in tests at the Cunningham Laboratory CB415 performed nearly as well as CB262 and just a little better than CB430 and four other isolations, all from sources outside Papua New Guinea.

The first isolations from Leucaena made in Papua New Guinea were those of Thrower from nodules found on plants growing at Keravat and in the Lower Markham Valley and designated K1, K2, K3, etc., and M1, M2, M3, etc., and by Shaw from plants growing in areas around Port Moresby.

Up to January, 1961, the cultures for Leucaena regularly supplied in the service were of the K and M series, particularly K3, K5, K6 and M1. From January, 1961 the main culture supplied was RM1 this being a reisolate by Trinick from M1; in October 1961 RM1 was renamed NGR8 and since then has retained this designation. In 1963-64 NGR8 replaced CB81 as the Rhizobium strain recommended in Australia for Leucaena by U-DALS (the University-Department of Agriculture Laboratory Service), Department of Microbiology, University of Sydney, and has continued to be supplied both in Papua New Guinea and in

5. The common name for *Leucaena leucocephala* in Papua New Guinea is "Leucaena" and throughout this paper Leucaena refers to *L. leucocephala* (Lam.) de Wit, syn. *L. glauca* (L.) Benth., in the subfamily Mimosoideae.

6. Norris (1956) pointed out that the Leguminosae failed to evolve a system for ensuring that the appropriate bacterium was automatically transferred with the seed, except in such genera as *Arachis* and *Trifolium* which bury their seed pods.

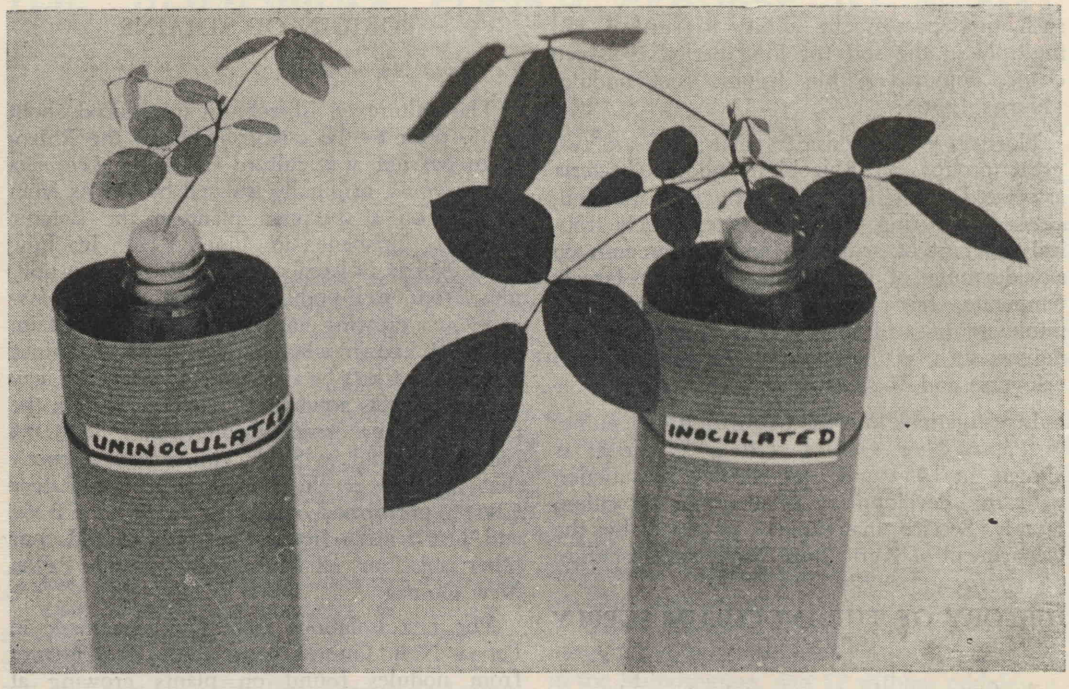

Photo D Shaw

Plate I.—Laboratory check on effectiveness of nodulation. Young inoculated and uninoculated plants of *Pueraria phaseoloides* growing in agar culture. The uninoculated are yellowish with fewer leaves than the inoculated and these differences will become more pronounced as the plants age

Australia as the recommended strain. The culture has also been forwarded to some overseas countries as described in a later section. However, widespread nodulation failures of Leucaena on acid soils in Queensland have now been traced to inability of NGR8 to multiply under acid conditions, and a return is to be made to strain CB81 which is adapted to acid soils (Norris, personal communication). Both strains are now being used in Papua New Guinea.

Other Hosts

As mentioned previously, Rhizobium cultures for other hosts were imported from Australia by Shaw, later by Trinick and after 1966 again by Shaw, as new recommendations became available. Centres supplying cultures were the Cunningham Laboratory (CSIRO), Queensland; the Department of Primary Industries, Brisbane; the Department of Agriculture, Sydney; U-DALS, University of Sydney;[7] and the University of Western Australia, Perth. Cultures originating elsewhere were usually obtained through the above centres.

The cultures used for the main groups of economically important legumes are shown in *Table* 1.

Some growers in Papua New Guinea have occasionally imported peat cultures from Australia.

CULTURES

Since the service was initiated in 1956, cultures on agar medium have been sent to most areas in Papua New Guinea and to some overseas consignees. An agar medium suitable for the growth of Rhizobium was used initially on the advice of the Acting Chief Biologist of the Department of Agriculture in N.S.W., and continued in use for the following reasons:

(1) It was easier to handle with the laboratory facilities available than the preparation of peat cultures.

7. Replaced in July, 1970 by the Australian Inoculants Research and Control Service (AIRCS), housed since February, 1971 at the Biological and Chemical Research Institute, Rydalmere, N.S.W.

Table 1.—Strains[1] of Rhizobium and number of bottles distributed for the economically important legumes during 1956-1971

Host	Standard Strain Distributed[2]	No. of Other Strains Occasionally Distributed (All Purposes)[3]	No. of Bottles Supplied
Arachis hypogaea (Peanut)	CB756	2	94
Cajanus cajan (Pigeon pea)	CB756		14
Calopogonium caeruleum	CB756		26
Calopogonium mucunoides (*Calopo*)	CB756		28
Calopogonium sp.	CB756		18
Centrosema pubescens (Centro)	*NGR*118[2], *NGR*26, CB1103	10	1,023
Crotalaria spp.	CB756	1	45
Desmodium intortum	CB627	1	90
Desmodium uncinatum	CB627		102
Desmodium spp.	CB627	3	74
Dolichos axillaris	CB756		46
Dolichos lablab	CB159	5	114
Dolichos spp.	CB756	3	26
Glycine max (Soybean)	*NGR*27R, *NGR*38, *NGR*47, *NGR*147, CB1809	6	175
Glycine wightii (*javanica*)	*QA*922, *CB*450, CB756	4	198
Leucaena leucocephala	*K*1, *K*2, *K*5, *K*6, *M*1, *M*2, *M*3, *M*5, *RM*1 (reisolate of M1), NGR8 (redesignate of RM1)		13,684
Lotononis bainesii	*CB*360, CB376		37
Lupinus spp.	W72	2	10
Medicago spp.	*SU*277, U45, SU47	2	44
Phaseolus atropurpureus (Siratro)	CB756		207
Phaseolus vulgaris (Bean)	CC511		5
Phaseolus spp.	CB756		47
Pueraria phaseoloides	CB756	6	981
Stizolobium deeringianum	CB756		18
Stylosanthes guianensis (*Stylo*)	CB756		157
Stylosanthes spp.	CB756		41
Trifolium pratense (Red Clover)	*UNZ*29, TA1	3	76
Trifolium repens (White Clover)	*UNZ*29, TA1	1	77
Trifolium spp. (Clovers)	*CB*772, *UNZ*29, TA1	4	94
Vigna sinensis (Cowpea)	CB756	3	93
Vigna spp.	CB756		53
Other legumes	Various		44
		Total	17,741

1. Imported cultures distributed from June, 1965 to March, 1968 had been redesignated by Trinick NGR (e.g., CB756 designated NGR241, CB627 as NGR224, etc.). However, after March 1968 and herein, cultures are designated by their original numbers.

2. Strain numbers shown in italics not now distributed; all strains being distributed at present are those recommended by U-DALS (now AIRCS).

3. Including cultures isolated from the host specified and other hosts and used in sowings to check ability or inability to nodulate and efficiency in the field. As much of this work was part of Trinick's research studies, it is not given here in detail.

(2) It was more striking to indigenous growers than peat cultures.

(3) No peat cultures were or are yet produced commercially in Papua New Guinea, and indigenous growers are unlikely to carry out importation involving correspondence and money with an overseas country such as Australia.

Close touch has been kept with Rhizobium workers in Australia, particularly with Professor J. M. Vincent and the U-DALS (now AIRCS) organization in Sydney, and with Dr D. O. Norris at CSIRO, Cunningham Laboratory, Brisbane, who with the Department of Primary Industries in Brisbane, has supplied many of the cultures. The officers in charge of

the Papua New Guinea Rhizobium Service have attended Australian Rhizobium Conferences. The recommendations of the AIRCS organization are closely studied to ascertain the strains of Rhizobium shown to be the most efficient nodulators of crops common to both Australia and Papua New Guinea. When necessary new cultures are imported to maintain the Papua New Guinea Rhizobium Supply Service at maximum efficiency; some cultures were isolated from local nodules.

Cultures are supplied in bottles of three sizes, depending firstly on the quantity of seed to be inoculated, and secondly, on the size of the seed (either large, medium, or small); sheets on inoculation technique are supplied with each consignment. With most consignments Record Sheets were also forwarded, requesting that some uninoculated seed be sown as well as the main sowing of inoculated seed, so that the grower could see the difference himself, and so that the officers in charge of the service could determine the necessity for inoculation in that area, or perhaps detect abnormalities in results for further investigation.

Cultures are maintained on nutrient agar, under oil and with freeze drying.

NODULATION OF ECONOMICALLY IMPORTANT LEGUMES

Leucaena (Hawaii strain) is the most important legume used as shade for plantation crops in Papua New Guinea. In some areas, for example, parts of the Gazelle Peninsula around Keravat and in the lower Markham Valley around Lae, introduced Leucaena was found by Thrower (1954-57) and by Shaw from 1955 to be well nodulated without, as far as is known, artifical inoculation.

Because of the proved suitability of Leucaena in those areas where it grew well with good nodulation, and the undoubted difficulty of establishment in many areas where no suitable strain of Rhizobium was present in the soil, cultures were established of Rhizobium isolated from Leucaena nodules in those areas

Photo: D. Shaw

Plate II.—Inoculated Leucaena leucocephala as shade for Robusta coffee at Popondetta, an area where it had been practically impossible to establish uninoculated Leucaena

where they occurred abundantly and with apparent efficiency. The supply of these cultures, made available free of charge to any planter or grower who required them, initiated the Rhizobium Supply Service.

Almost 14,000 bottles of Leucaena inoculum were sent out by the Department from August, 1956 to June, 1971, as shown in *Table* 1. Nearly 75 per cent of the cultures were used on the Papuan lowlands, mainly in the Popondetta area.

Because of the importance of Leucaena, one officer undertook research on the Leucaena-Rhizobium complex as his main problem. Published work arising from these studies (Trinick 1965) showed that Leucaena failed to nodulate with slow-growing root nodule bacteria isolated from 41 different tropical legumes, but successful nodulation was obtained with Rhizobia from tropical legumes which were fast-growing and had cultural characteristics similar to those of the Leucaena root-nodule bacteria. Three cultures isolated from Leucaena were successful in nodulating a wide range of tropical legumes including *Vigna sinensis*, *Phaseolus lathyroides*, *P. atropurpureus*, *Centrosema plumieri* and *Calopogonium mucunoides*; two of the three cultures nodulated *Medicago sativa*.

Later Trinick (1968) showed that Leucaena failed to nodulate with 94 of the 99 strains of Rhizobium tested, representing the seven recognized cross-inoculation groups. A group of legumes including *L. leucocephala*, *Mimosa invisa*, *M. pudica*, *Acacia farnesiana* and *Sesbania* spp. showed the properties of a cross-inoculation group of plants. Rhizobia isolated from these legumes were all fast-growers and nodulated Leucaena, often effectively, and also many other tropical legumes, including *Vigna sinensis*, which are usually nodulated effectively with slow-growing root nodule bacteria.

The results of field sowings of Leucaena with inoculated and uninoculated seed are given in a later section.

Other leguminous species used mainly for temporary shade include *Crotalaria anagyroides* which has been used mainly as the initial and temporary cover for Arabica coffee in the Highlands, and to a much less extent, *Tephrosia candida*. Both species nodulate without artificial inoculation in those areas where checks have been made, but Rhizobium cultures are available for those growers who wish to test the performance of plants from inoculated seed against uninoculated.

Albizia fulva, an indigenous species, was used initially on some Arabica coffee plantations as the permanent shade tree, but as it is very susceptible to the twig-deforming rust caused by *Uromycladium tepperianum* (Shaw 1963) it has been replaced by the introduced species, *A. stipulata*, which appears to be immune. *A. stipulata* has been noted as nodulated naturally in the field, and both species grow well without artificial inoculation.

The most important ground covers are *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium mucunoides*, although the latter is not now recommended. *P. phaseoloides* has also been used as a ground cover in the New Britain oil palm plantings, now over ten thousand acres in extent, all with inoculated seed. Usually all these legumes are nodulated in the field, but cultures are available for those growers who wish to inoculate. The total quantity of inoculum for *C. pubescens* and *P. phaseoloides* for all purposes (i.e., for ground cover and pasture) during 1956-71 was over 2000 bottles, as given in *Table* 1. The results of field sowings with inoculated and uninoculated seeds of these ground covers are given in a later section.

A variety of legumes has been under trial for use in pastures in both the lowlands and the highlands, and some species have been in use in commercial pastures for some time (Hill 1970b). Many of these species nodulate naturally in the field, but inoculum is available for growers who wish to inoculate, and it is recommended for those species which are new to any area. The amount of inoculum supplied for these species is shown in *Table* 1, and includes figures for *Centrosema pubescens* (1023 bottles), *Pueraria phaseoloides* (981 bottles, all purposes, i.e., ground covers and pastures) and

Photos: N. Mendham

Plate III.—Inoculated Pueraria phasedoides as ground cover in oil palm plantation, West New Britain. *A.* Young Pueraria growing from inoculated seed sown directly after burn with young transplanted oil palms in background. *B.* Established Pueraria cover over 2ft 6in high (about 80cm) between oil palms

other species just becoming popular, viz., *Desmodium* spp. (266 bottles), *Trifolium* spp. (247), *Phaseolus atropurpureus*[8] (207), *Glycine wightii*[9] (198), *Stylosanthes* spp.[10] (198) and *Dolichos* spp. (186). The results of inoculated and uninoculated field sowings are given in a later section.

From trials carried out mainly in the Markham Valley (unpublished reports and Hill 1970a) and by spot checks on the nodulation in village plantings, it has been found that inoculation is usually not necessary with peanuts, although cultures are available if required. It is recommended that soybeans be inoculated, especially in new areas.

The average indigenous food garden contains a wide variety of leguminous vegetables, such as *Psophocarpus tetragonolobus, Phaseolus lunatus; Dolichos lablab*[11] *and Vigna sesquipedalis*[12] although species such as *Phaseolus mungo, Phaseolus calcaratus, Vigna sinensis,*[12] *Canavalia ensiformis* and *Cajanus cajan* have not as yet been widely accepted into gardening practices and diet. All these village sowings have so far been made without inoculation, although inoculum is available if required.

Although as far as is known to the senior author, little or no use is made medically of species of *Cassia* such as *C. alata* and *C. fistula* or of *Tamarindus indicus* but those plants which are grown do so without artificial inoculation.

Some species of *Derris* are indigenous while others have been introduced, and to date none has been artificially inoculated. Trinick (1968) isolated from a nodule on *D. elliptica* and found the culture effective on *Vigna sinensis* and *Phaseolus lathyroides* but no nodulation occurred on Leucaena.

Many foreign legumes, especially introduced horticultural species and weeds, as well as long-established and indigenous species, grow well in Papua New Guinea without artificial inoculation. These include *Acacia farnesiana*, and species of *Aeschynomene, Alysicarpus, Bauhinia, Calopogonium, Cassia, Caesalpinia, Centrosema, Clitoria, Crotalaria, Delonix* (*D. regia*, Poinciana), *Desmodium, Erythrina, Mimosa* (especially *M. invisa* and *M. pudica*), *Peltophorum* (especially *P. pterocarpum*, syn. *P. ferrugineum*), *Prosopsis, Pueraria triloba* (syn *P. lobata* and *P. thunbergiana*), *Samanea saman* (rain tree), *Sesbania aculeata* and *Uraria lagopodioides*, as well as the indigenous leguminous forest components in the genera *Adenanthera, Albizia, Cathormion, Erythrina, Inga, Inocarpus, Cassia, Kingiodendron, Maniltoa, Pahudia* (=*Afzelia*), *Pericopsis, Piptadenia, Pithecellobium* (*sensu lato*) and *Pongamia*. The roots of the above, and of other indigenous legumes are being checked for presence or absence of nodules, and effectiveness if present, whenever possible.

SUPPLY OF CULTURES TO OVERSEAS COUNTRIES

During the 15 years since the inception of the Rhizobium Supply Service cultures have been supplied for several overseas countries.

The countries receiving cultures have been Australia, the British Solomon Islands Protectorate, Cocos Island, Costa Rica (Central America), French Polynesia, Gilbert Islands, Indonesia, Malaysia, South Africa, Trinidad, U.S.A., West Irian (Indonesia), Western Samoa. The cultures forwarded have been for the following hosts: *Centrosema pubescens, Flemingia congesta, Glycine max, G. wightii, Leucaena leucocephala, Phaseolus atropurpureus, Pisum-Vicia* group, *Stylosanthes guianensis, Trifolium* spp., *Vigna sinensis*. Cultures for *L. leucocephala* were particularly in demand.

8. The Director, Royal Botanic Gardens, Kew, has recently stated (letter H0005/71) that one of their specialists thinks that there is a good case for maintaining *Macroptilium* separate from *Phaseolus* —thus this species would be *Macroptilium atropurpureum* (DC.) Urb.

9. Syn. *G. javanica.*

10. Including *Stylosanthes guianensis*, which is sometimes designated *S. guyanensis* or *S. gracilis*. The Director, Royal Botanic Gardens, Kew, has recently (letter H4481/70) advised the senior author that "*Stylosanthes gracilis* Kunth is a synonym of *S. guianensis* (Aubl.) Sw. according to the latest revision of Mohlenbrock in *Ann. Missouri Bot. Gard.* 44 (1957). We prefer the spelling '*guianensis*' to '*guyanensis*', because Aublet used this rendering for the original description, though the plate was labelled '*guyanensis*' ".

11. Given by some authors as *Lablab niger* Medik.

12. Usually given now as *Vigna unguiculata* subsp. *sesquipedalis* and *Vigna unguiculata* subsp. *unguiculata* respectively.

Figure.—Copy of record sheet sent to growers for inoculated legume sowings

DEPARTMENT OF AGRICULTURE, STOCK AND FISHERIES

LEGUME RHIZOBIUM TRIAL

Sheet 1

Host _____

Culture No _____

Owner _____

Address _____

Locality _____

Date despatched _____

Date sown _____

Acreage or amount sown _____

_____

2 months after sowing:

INOCULATED			UNINOCULATED		
Height or spread*	Colour*	Nodules*	Height or spread*	Colour*	Nodules*

Other observations

Signed.....

*Height or spread: Give average in inches and feet; mark H or S.

*Colour: State whether green, yellow-green, etc., or state whether inoculated plants are greener than (or the same as) the uninoculated plants.

*Nodules: Nodules on the roots are very easily detached. Carefully remove or rinse soil from the roots of about six plants and state whether nodules are present or not, abundant or sparse. Cut a few big ones in half and state whether the inside is pink-red-brown or white-grey-green.

RESULTS OF FIELD SOWINGS BY GROWERS

General

Since 1956 Record Sheets have been forwarded with most batches of cultures to both private growers and agricultural officers, the latter being responsible for distribution to indigenous growers and for trial plantings in new areas. The present sheet for readings two months after sowing is reproduced in the *Fig*; a similar sheet is also sent for recordings

at four months after sowing. Previously, readings were sometimes obtained for two, four and six months and even for longer periods, with a maximum of six readings.

With each sheet went a request that the grower sow a little uninoculated seed when the main inoculated sowings were made, so that he could see for himself the result of inoculation. In the 15-year period from 1956 to 1971, 731 Record Sheets were returned, while some other growers sent qualitative comments. The readings were studied and the grower advised whether he should or should not continue to artifically inoculate seed of that plant species in his area.

In the case of no response to inoculation, the grower was advised to check his technique of inoculation and sowing and to note carefully the results of his next sowing with new cultures. On occasion lack of response to nodulation was perhaps due to time taken by cultures to reach their destination.

In *Table* 2 the results are summarized as to the various degrees of effective nodulation, or ineffective nodulation, or no nodulation, of both inoculated and uninoculated seed for 615 Record Sheets returned for inoculations with the main strains of Rhizobium in the Supply Service.

It will be noted that:—

(1) In 36.9 per cent of the Records uninoculated plants showed nodulation as effective as occurred on the inoculated plants indicating either

(*a*) the presence of a naturally occurring effective strain in the soil of that area, or

(*b*) build-up of an introduced effective strain previously artificially inoculated on seed sown in the area.

(2) In 21.8 per cent of the Records, uninoculated plants were either sparsely nodulated, nodulated with a strain not as effective as the supplied strain, or nodulated ineffectively, the latter as determined in some cases by inspection of the interior of the nodules by the agricultural officer or grower. Some of these results are given in detail in a later section.

(3) In 15.0 per cent of the Records no nodulation occurred on the uninoculated controls at all. Some of these results are given in a later section.

Inoculation of the seed can be seen to have been well worthwhile in cases (2) and (3).

(4) In 5.7 per cent of the Records, inoculation produced plants which were not well nodulated, not a good green colour or which had some or many ineffective nodules, while the controls were ineffectively nodulated. In 1.3 per cent of the cases nodulation was effective at the next reading.

(5) In 4.7 per cent of the records inoculated plants were as in (4) above while the controls were without nodules. At a later reading 0.5 per cent of the inoculated plants were effectively nodulated.

(6) In 0.7 per cent of the Records, no nodulation was obtained with inoculation and controls showed sparse or ineffective nodulation.

(7) In 12.4 per cent of the cases no nodulation was obtained in either inoculated or control sowings. In some cases a further reading was taken later and then 2.8 per cent had effective and 0.3 per cent ineffective nodulation of inoculated plants.

In the cases of (4), (5), (6) and (7) above, strains were checked for purity in the laboratory, and growers were advised to watch age of cultures in the future, to check techniques of inoculation and sowing, or to take extra care in lifting plants from the soil for checks on the presence or absence of nodules in the future; soil nutritional aspects were also considered and in some cases further sowings with selected fertilizing treatments were carried out. Some experiments are also under way with pelletting in order to determine whether this is desirable for some species on certain soils.

(8) In 2.9 per cent of the Returns, records were incomplete in some way, either because of death of controls or no controls were sown, or the area was flooded or waterlogged.

Table 2.—Analysis of nodulation reports for field sowings for standard strains[1] of Rhizobium on various hosts for 1956-1971

Host	Sites	Plantings	Record Sheets Returned	Record Sheets for Standard Strains	Nodulation of Inoculated v. Uninoculated plants in the following classes: Effective v. Effective	Effective v. Ineffect.[2]	Effective v. No nods.	Ineffect. v. Ineffect.	Ineffect. v. No nods.	No nods. v. Ineffect.	No nods. v. No nods.	Information Incomplete
Arachis hypogaea	3	5	7	7	7							
Cajanus cajan	3	3	5	2	2							
Calopogonium caeruleum	2	2	3	3	2				1			
C. mucunoides	4	5	7	4	4							
Centrosema pubescens	21	27	59	33	16	5	1	4	5		1	1
Crotalaria laburnifolia	1	1	1	1	1							
C. striata	1	1	1	1	1							
Crotalaria sp.	1	1	5	0								
Desmodium intortum	15	16	26	22	8	8	3				2	1
D. uncinatum	12	14	19	18	5	3	6	1	1		1	1
Desmodium sp.	2	3	5	5	1		4					
Dolichos axillaris	7	8	13	13	7		2	2	1		1	
D. biflorus	3	4	6	6	6							
D. lablab	11	13	18	17	6	3	2	2	2		1	1
Flemingia congesta	6	7	8	5	4						1	
Glycine max	31	46	70	70	25	13	10	5	6		8	3
G. wightii	21	39	75	68	39	10	2	6	3		6	2
Leucaena leucocephala	41	76	192	191	35	71	43	4	2	2	33	1
Lotononis bainesii	2	2	3	2							1	1
Lupinus angustifolia	1	1	3	3							2	1
L. digitatus	1	1	3	3				1		1		1
L. luteus	1	1	3	3							3	
Lupinus sp.	2	2	4	4	2	1		1				
Medicago sativa	3	3	4	4		1		1			2	
Mimosa sp.	1	1	1	0								
Mundulea sericea	1	1	1	1	1							
Ornithopus compressus	1	1	3	3					2		1	
Phaseolus atropurpureus	24	29	55	34	22	2	2	3	1		2	2
P. calcaratus	1	1	1	1	1							
P. lathyroides	4	4	6	3	3							
P. vulgaris	3	7	8	0								
Phaseolus sp.	2	2	4	4	1				2		1	
Pisum sativum	2	2	4	0								
Psophocarpus palustris	1	1	1	1	1							
Psophocarpus tetragonobolus	1	1	1	1		1						
Pueraria phaseoloides	6	6	9	8	2	5						1
Stizolobium deeringianum	2	2	3	3	2						1	
Stylosanthes guianensis	10	13	18	11	5	2	1	1	1		1	
S. humilis	3	4	5	2								2
Stylosanthes sp.	1	1	3	0								
Tephrosia noctiflora	1	1	1	1	1							
T. vogelii	1	1	1	0								
Trifolium pratense	10	15	21	20	4	2	6	2	1		5	
T. repens	8	14	20	16	1	3	6	2	1	1	2	
T. subterraneum	1	1	2	2	1	1						
Trifolium sp.	2	2	3	3			2				1	
Vicia atropurpurea	1	1	1	0								
Vicia sativa	1	1	1	0								
Vigna luteola	6	6	9	7	4	1	2					
Vigna sesquipedalis	1	1	1	1	1							
Vigna sinensis	5	6	8	8	6	2						
Totals	295	406	731	615	227	134	92	35	29	4	76	18
					% 36.9	21.8	15.0	5.7*	4.7*	0.7	12.4*	2.9

1 Standard strains as designated in Table 1
2 "Ineffective" in this case includes ineffective, sparse effective and not as effective
* In some cases later readings showed improved nodulation in inoculated plants

Even so, some of these Returns were of interest. For example, a report on the performance of *Lotononis bainesii* at Mendi stated that inoculated plants were 4½ inches high with abundant nodules, with the further remark, "it has taken a good hold and has come away well. Uninoculated seed showed but was weak and spindly and after the very cold night of 16th June, petered away to nothing."

Details of some sowings

In this section details are given of the results of some of the sowings where nodulation of inoculated plants was effective and where nodulation of the controls was either:—

(1) effective but sparse, or not as effective as the inoculated, or ineffective, or

(2) lacking.

In many cases the records were substantiated by qualitative statements as to appearance and vigour of the inoculated and uninoculated controls, amount of leafage and onset of flowering, and occasionally yield where applicable. The information given in the Tables is, therefore, a selected summary of only the main points.

A reading given in the Tables may be only one of a series taken for one particular sowing, the others being omitted. Some of the readings are for different periods after sowing, so that the only figures which can be compared directly in the Tables are the uninoculated with its own inoculated. Also, the sowings are at different altitudes and rainfalls, and for some species especially (for example, as shown in *Table* 3 for Leucaena), altitude affects the height of the plants.

Details of some of the results for sowings with effective nodulation of inoculated plants, and with effective but sparse, or less effective or ineffective nodulation of uninoculated controls are given in *Table* 4, and the results of sowing with effectively nodulated inoculated plants but with uninoculated controls lacking nodulation altogether are given in *Table* 5.

It will be seen that inoculation in these cases was well worthwhile.

ACKNOWLEDGEMENTS

Grateful thanks are extended to all growers and agricultural officers for taking readings on inoculated and uninoculated field sowings and for returning Record Sheets with their observations; their co-operation has been very much appreciated.

Thanks are also extended to Mr J. S. Womersley, Chief, Division of Botany, Department of Forests, and his staff for identifications of some leguminous specimens and for advice on aspects of nomenclature and origin; to Mr K. White, Assistant Director (Silviculture), of the same Department for discussion on forest species; to Mr G. P. Keleny, formerly of the Department of Agriculture, Stock and Fisheries, for information on the early importation of a Rhizobium culture; to Mr R. M. Burnett and Mr A. Williams for laboratory assistance; to other officers

Table 3.—Height of inoculated *Leucaena leucocephala* at sites differing in rainfall and altitude at 6 months after sowing[1]

Site	Region	Average Annual Rainfall (in)[2]	Altitude (ft)[3]	Height (ft)[3]
Madang	....NGL	139	25	12
Popondetta	....PL	95	400	10-12
Pakia Village nr Kieta	....B	119+[4]	500[5]	10
Erap	....NGL	49	856	8- 9
Dumpu	....NGL		870	6
Goroka	....EH	76	5200	3.5
Mt Hagen	....WH	103	5500	3
Aiyura	....EH	85	6000	2

1 Sowings made at different times and read by different observers

2 1 inch = 100 points = 25.4 mm

3 1 foot = 0.305 m

4 Rainfall estimated to be higher than 119 inches, the average recorded for Kieta, the nearest recording centre

5 Altitude estimated only

Table 4.—Comparison of size, colour and nodulation of some inoculated hosts at different sites with poorer performance of controls[1]

Host	Site	Region[2]	Inoculated			Uninoculated		
			Height (or spread) (in)	Colour of Plant[3]	Nodules	Height (or spread) (in)	Colour of Plant	Nodules
Centrosema pubescens	Popondetta	PL	5-20	G	med.-large, av. 5.7 per plant	14	G	very small, white, av. 6.8 per plant
C. pubescens	Leron Plains Markham V.	NGL	av. 72	YG	present	48-60	YG	present
Desmodium intortum	Kagua	SH	12	G	fair	6-9	LG	few
D. intortum	Mendi	SH	6-18	BG	abundant	2-6	lighter	sparse
D. intortum	Bundi	FT	30	G	abundant	20	G	less than inoculated
Desmodium uncinatum	Mendi	SH	6-18	PG	abundant	2-6	PG	sparse
Dolichos lablab	Popondetta	PL	24-41	G	large, red inside, 9.7 per plant	20-32	G	large, green-brown, 8 per plant
Glycine wightii	Passam, Sepik	NGL	15-28½	G	very abundant	12-18	PG	sparse
G. wightii	Mendi	SH	7	PG	abundant	4½	PG	sparse
G. wightii	Bundi	FT	12	G	sparse	5	G	very sparse
G. wightii	Kurakakaul	NB	30-45	G	present	20-30	G	present
G. max	Mendi	SH	24	PG	present	18	PG	sparse
G. max	Ialibu	SH	10	Y	abundant	9	Y	on 5% of plants, sparse
G. max	Bula nr Salamaua	NGL	30	DG	abundant	25	PG	very few
G. max	Goroka	EH	24	G	abundant	18	G	sparse
G. max	Korn Farm	WH	13	G	plentiful	10	G	few, small
G. max	Wabag	WH	13-16	G	abundant	11-16	G	sparse
Leucaena leucocephala	Kusi Village	B	9	G	abundant	5	YG	abundant to sparse
L. leucocephala	Ou Ou Creek	PL	36	G	present	12	G	sparse
L. leucocephala	Aropa Plantation	B	76	G	present	54	G	sparse
L. leucocephala	Kurakakaul	NB	54	DG	abundant	28	YG	sparse
L. leucocephala	Tapini	FT	8-10	DG	abundant	5-6	G-Y	sparse
L. leucocephala	Kubuna Estate	FT	66	DG	plentiful	30	LG	sparse
L. leucocephala	Popondetta	PL	72	DG	abundant	60	DG	abundant
L. leucocephala	Wasangabang Vill. nr Bogia	NGL	30	G	present	24	YG	on some plants
L. leucocephala	Goroka	EH	72	DG	present	42	MG	present
L. leucocephala	Bainyik	NGL	12	DG	large, plentiful	5		almost nil
L. leucocephala	Arawa Plantation (Site 1)	B	60	G	present	25	G	present
L. leucocephala	Arawa Plantation (Site 2)	B	65	G	present	50	G	present
L. leucocephala	Dumpu	NGL	60-72	DG	heavy	12	Y or dying	light
L. leucocephala	Ukua Estate via Kairuku	PL	60	G	present	48 (uneven)	G	present
Lupinus sp.	Ogelbeng	WH	26	BG	4-7 nods on 4 plants in 6	18	G	1-4 nods on 3 plants in 6
Phaseolus atropurpureus	Passam	NGL	3-9	PG	fairly abundant	2-4	PYG	sparse
P. atropurpureus	Bundi	FT	18x60	G	abundant	8x18	G&Y	sparse
Phaseolus vulgaris	Rabaul	NB	22	DG	abundant, pinkish	18	G	sparse, small greyish
Pueraria phaseoloides	Paruai Village	NI	60	G	plentiful, pink	24	G	some present, green
P. phaseoloides	Kwalakessi	NB	52	G	31 per plant	42	PG	7 per plant
Stylosanthes gracilis	Bisianumu	FT	up to 10½	G	10 per plant	up to 8	G	few small nods on larger plants
Vigna sinensis	Passam	NGL	22-35	DG	abundant	18-27	G	sparse

1 Readings taken at various periods after sowing; descriptive terms used are as given by the growers

2 Regions of Papua New Guinea:
PL Papuan Lowlands
NGL New Guinea lowlands
SH Southern Highlands
WH Western Highlands
EH Eastern Highlands
FT Foothills
NB New Britain
NI New Ireland
B Bougainville

3 G = green; Y = yellow; B = blue; D = dark; L = light; P = pale

Table 5.—Comparison of size, colour and nodulation of some inoculated hosts at different sites with performance of non-nodulated controls[1]

Host	Site	Region[2]	Inoculated			Uninoculated		
			Height (or spread) (in)	Colour of Plants[3]	Nodules	Height (or spread) (in)	Colour of Plants	Nodules
Desmodium intortum	Tari	SH	15	G	abundant	6-8	G	-
Desmodium sp.	Kompiam	WH	36	G	sparse	24	G	-
Dolichos lablab	Banz	WH	14	G	abundant	8	LG	-
Glycine wightii	Kokoda	FT	18	G	present	14	GY	-
G. max	Henganofi	EH	15	VDG	abundant	12	PG	-
G. max	Tente via Mendi	WH	10-26	G&Y	large on large plants	6-8	GY	-
G. max	Baiyer R.	WH	18-24		sparse large nods on 1 in 3 plants, pink inside	10		-
G. max	Wapenamanda	WH	13-22	BG	sparse to abundant	9	LG	-
G. max	Bula	NGL	15	DG	present	11½	G	-
Leucaena leucocephala	Ou Ou Creek (Site 1)	PL	36-48	G	abundant	12-24	YG	-
L. leucocephala	Ou Ou Creek (Site 2)	PL	12	G	sparse	4	YG	-
L. leucocephala	Kusi Vill.	B	29	G	fairly abundant	10	Y	-
L. leucocephala	Bakankani Vill.	B	37	G	many	11	Y	-
L. leucocephala	Kubuna Estate	PL	14	G	abundant	8	LG	-
L. leucocephala	Pakia Vill.	B	120	G	plentiful	48	LG	-
L. leucocephala	Boregaina	PL	2-18	G-BY	plentiful	2-12	DG-Y	-
L. leucocephala	Aiyura	EH	24	DG	35 nods per plant	24	DG	-
L. leucocephala	Aitape	NGL	15	G	present	5	G	-
L. leucocephala	Madang	NGL	4-6	DG	present	4-6	YG	-
L. leucocephala	Bainyik, Sepik	NGL	84		heavy	42		-
L. leucocephala	Goroka	EH	42	G	not very apparent (possibly left behind in soil)	18	G	-
L. leucocephala	Madang	NGL	180	G	numerous	108	MG	-
L. leucocephala	Ukua Estate nr Kairuku	PL	10	G	present	10	PG	-
L. leucocephala	Karimui	EH	8	G	large, pink	6	G	-
Phaseolus atropurpureus	Kagua	SH	6	G	med. to good	virtually nil		-
P. atropurpureus	Tarawa, Gilbert Islands (coral atoll)	-	3-4	G	present, pink inside, up to 3/16 inch diameter	1	LG-Y	-
Pisum sativum	Minj	WH	21	G	sparse	15	YG	-
Stylosanthes guianensis	Baiyer R.	WH	12	DG	sparse	12	LG	-
Trifolium pratense	Yamonti via Laiagam	SH	5	DG	abundant	1	Y	-
T. pratense	Laiagam	SH	6-8	DG	fairly big, v. plentiful	4-6	YG	-
T. pratense	Minj	WH	10	G	abundant	8	Y	-
T. repens	Banz	WH	18	LG	abundant	15	LG	-
T. repens	Yamara via Laiagam	SH	12	DG	abundant	1	YG	-
Vigna marina	Tari	SH	8-10	G	small, sparse	4	PG	-

1 Readings taken at various periods after sowings; descriptive terms used are as given by the growers
2 See Table 4
3 G = green; Y = yellow; B = blue; D = dark; L = light; P = pale; V = very; M = medium

of the department for discussion on various aspects; and to Dr D. O. Norris and Mr A. W. Charles for critically reading the manuscript.

Acknowledgement with grateful thanks is also made of the help in cultures and advice from some Australian workers, particularly Professor J. M. Vincent, University of N.S.W., Sydney; Dr D. O. Norris, CSIRO, Brisbane; Mr S. Sutton, former Chief Biologist, Department of Agriculture, Rydalmere, Sydney; Dr R. Date, formerly of U-DALS, Sydney; and officers of the Department of Primary Industries, Brisbane.

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(Accepted for publication November, 1971).

CORRIGENDA

p.22, *Table* 2: *Psophocarpus tetragonobolus* should be *Psophocarpus tetragonolobus.*

p.24, *Table* 4: *L. leucocephala,* Goroka, given as MG should be G.

p.25, *Table* 5. *L. leucocephala,* Boregaina, given as G-BY should be G-Y.

Some name changes have occurred with some of the species listed in *Tables* 2 and 4, and for these see text.