QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
DIVISION OF PLANT INDUSTRY BULLETIN No. 670

EVALUATING PERENNIAL GRASS/LEGUME SWARDS ON THE ATHERTON TABLELAND IN NORTH QUEENSLAND

By J. A. GARTNER, B.Agr.Sc., J. E. FERGUSON, B.Agr.Sc., Ph.D., R. W. WALKER, Q.D.A., and ELVIE A. GOWARD, B.A.

SUMMARY

Ten tropical legumes were sown with green panic (*Panicum maximum* var. *trichoglume* cv. Petrie) at 0 and 4 cwt of superphosphate per acre per year on each of six sites and grown under grazing for 3 years.

Dry-matter production in the juvenile sward and midsummer dry-matter yield after a rest from grazing are used to show temporal changes in sward composition and aspects of individual legume performance.

Generally, green panic dominated the sward in the first two seasons. Legume contribution increased strongly in the third season, particularly in plots fertilized with superphosphate. Broad-leaved weeds and inferior grass invaders were major components of the juvenile sward.

C.P.I. 13300 (*Glycine wightii*) was the most stable legume with wide edaphic adaptability. The Clarence cultivar of *G. wightii* was generally adaptable. The Tinaroo cultivar was unstable being specifically adapted to high-yielding environments. The ability of Greenleaf (*Desmodium intortum*) to exploit these environments was modified by insect attack. Stylo (*Stylosanthes guyanensis*) and Dalrymple vigna (*Vigna luteola*) were not adapted to the region.

I. INTRODUCTION

E. C. Tommerup (unpublished data) commenced testing legumes on the Atherton Tableland (17°10′S. to 17°40′S.) in 1938. At that time white clover (*Trifolium repens*) and lucerne (*Medicago sativa*) existed in favourable environments but these constituted only a very small proportion of the pasture land needing a legume component.

In 1949 *Glycine wightii* Q2056 performed well in plots at East Barron (W. G. Steele, personal communication). It was released in 1961 as the cultivar Tinaroo from the Queensland Department of Primary Industries Research Station at Kairi (Kyneur 1959, 1960; Tow 1960; Allen 1961). Subsequent performance was excellent in northern areas of the Tableland around Atherton and Kairi but establishment and growth were erratic in the central and southern dairying areas around Malanda and Millaa Millaa (Table 1). High soil fertility, particularly phosphorus availability, appeared as the major determinant of success (Kyneur 1962; Gartner 1965).

A thorough field evaluation of Tinaroo glycine and other legumes being tested at Kairi (Kyneur 1963; R. W. Walker, unpublished data) was essential if reliable pasture improvement recommendations were to be made for the

TABLE 1

MAJOR SUBDIVISIONS OF THE ATHERTON TABLELAND WITH AREAS AND ASSESSMENT OF PERENNIAL LEGUME GROWTH IN EACH IN 1964

District Centre	Approximate Farming Area (sq. miles)	Mean Annual Rainfall (in.)	District Frost Expectancy	Altitude at Each Centre (ft.)	Topography	Soil Origins*	Legume Growth		
							White Clover	Lucerne	Tinaroo Glycine
Atherton	75	57	Medium	2,466	Gently undulating	Basalt	Poor	Fair	Excellent
Malanda	150	66	Medium	2,405	Undulating	Basalt Metamorphic Granite	Poor	Poor	Erratic
Millaa Millaa	120	103	Low	2,692	Hilly	Basalt Granite Metamorphic	Fair	Nil	Erratic
Evelyn	60	55	High	3,650	Undulating	Basalt Acid volcanic	Good	Nil	Erratic

* After Best (1962) and de Keyser (1964).

TABLE 2

SITE HISTORY AND SOIL ANALYSIS COMPARED WITH A TYPICAL SOIL FROM THE RESEARCH STATION AT KAIRI

Site	Previous History	Soil Origin	Soil Analysis								
			pH (1:2.5 H_2O)	Available P (BSES)* (p.p.m.)	Ca^{++} (m.e. %)	Mg^{++} (m.e. %)	Na^{+} (m.e. %)	K^{+} (m.e. %)	Total Replaceable Bases (m.e. %)	Total N (%)	Organic Carbon (%)
1	Grassland	Basalt	5·9	13	4·5	1·7	0·30	0·57	7·07	0·30	3·4
2	Grassland	Basalt	6·2	11	3·1	1·8	0·29	0·42	5·61	0·32	3·2
3	Grassland	Metamorphic	5·6	3	2·0	1·1	0·19	0·50	3·79	0·30	3·2
4	Grassland	Metamorphic	5·6	5	1·6	0·7	0·22	0·50	3·02	0·29	3·3
5	Old cultivation	Basalt	5·0	8	..	..	..	0·23	..	..	..
6	Old cultivation	Metamorphic	5·1	6	..	..	..	0·25	..	..	..
Kairi	Maize/pasture	Basalt	6·8	56	5·4	2·3	0·16	1·26	9·12	0·23	3·8

* Kerr and von Stieglitz (1938).

whole region. This paper describes the first of several projects in which the technique of a constant set of species/varieties replicated by site as well as within site was adapted from that of the National Institute of Botany (Bandreth 1935; Sandison and Bartlett 1958).

II. MATERIALS AND METHODS

Design.—A split-plot design was used with 10 main plots (80 lk x 40 lk) for legumes each with two sub-plots (40 lk x 40 lk) for fertilizer, replicated twice at each of six sites. There was a 10 lk lane between adjacent main plots and between blocks but sub-plots were contiguous.

Sites.—The Tablelands region can be divided into four districts on the basis of climate, soils and topography (Table 1). The experimental sites were located in the eastern half of the Malanda district, where the soils are most variable. No two sites were more than 4·5 miles apart. Relevant information on soils and previous land use is shown in Table 2.

Species/Varieties.—The glycines under test (cv. Tinaroo, cv. Cooper, cv. Clarence, C.P.I. 13300, C.P.I. 23411 and C.P.I. 25422) were all accessions of *Glycine wightii.* Other species used were *Desmodium intortum* cv. Greenleaf, *D. uncinatum* cv. Silverleaf, *Stylosanthes guyanensis* cv. Schofield and *Vigna luteola* (Dalrymple vigna). The associate grass was green panic (*Panicum maximum* var. *trichoglume* cv. Petrie). Full descriptions of cultivars can be found in Barnard (1969, 1972).

Cultural.—Plots were sown in January 1965. Legume seeds, except for Greenleaf and Silverleaf desmodiums, were acid-treated to reduce the effects of hard-seededness and all were inoculated with appropriate *Rhizobium* before sowing. Seeding rates are shown in Table 3.

Superphosphate containing ·02% Mo at 4 cwt/ac/year was applied to half of each species plot at establishment. Maintenance applications of 4 cwt/ac of straight superphosphate were applied each summer; a total of 16 cwt/ac had been applied prior to the last harvest.

Management.—Plots were managed on the basis suggested by Gartner (1966), whereby the grass canopy in the juvenile sward was regularly removed by short periods of grazing, while weeds and rank growth were kept down by slashing. In the established sward, grazing occurred 3 or 4 times per year, generally to the extent that only legume runners and grass crowns were left at the end of the dry season. The range of cattle numbers used on the plot area of about 1 ac varied from 30 to 60 head for from 2 to 10 hr.

In December of each year all plots were mown to a height of 4 in. and cattle were excluded to allow a rest period of 8–10 weeks prior to harvest time in January-February, the middle of each summer growing season. This was the only harvest taken each year after the establishment year.

Data collection.—Grass and legume plants were counted in the quadrats from which the first yield estimates were made about 11 weeks after sowing. At all harvests herbage was cut to the bottom of the green layer from three 5 lk x 2 lk quadrats (7·5% of the datum area) placed in predetermined random positions. Dry-matter yields of legume, grass and weed components were determined by hand-sorting and drying in a forced-draught oven at 160°F.

Statistical analysis.—Analyses of variance were carried out to test for treatment differences in plant density and dry-matter yield. Adaptability parameters were calculated according to the method of Finlay and Wilkinson (1963); basic dry-matter yields were transformed to a logarithmic scale to

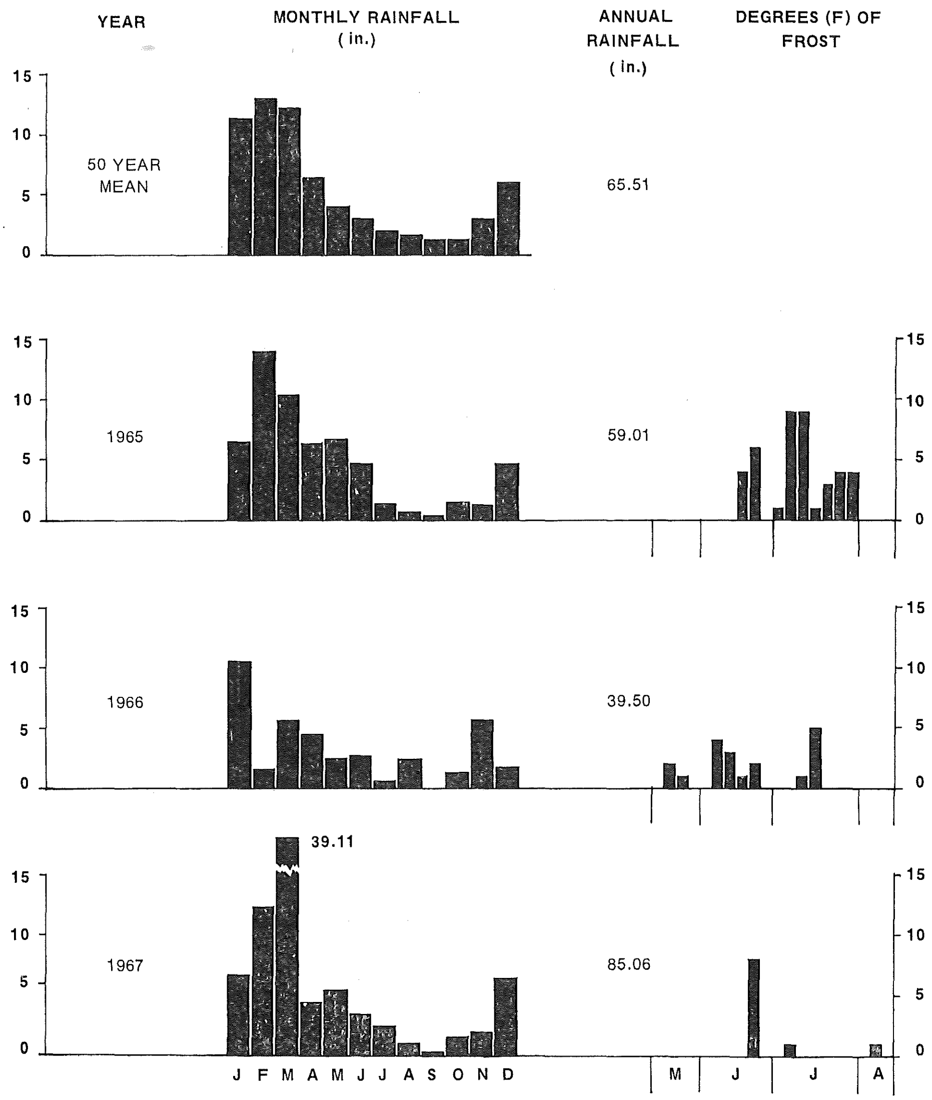

Fig. 1.—Rainfall at Malanda and frost at Kairi.

induce linearity in the regressions and homogeneity of experimental error. Mid-summer dry-matter yields of legumes from 1, 2 and 3-year-old swards on the four grassland sites were analysed in several combinations. These ranged from individual seasonal yields (n=8) to cumulative seasonal yields (n=8) provided by four sites × two fertilizer levels × three seasons.

Weather.—The official recording centre for the district is Malanda, situated 2–5 miles west of the experimental sites. The 50-year averages for monthly and annual rainfall, together with records for 1965, 1966 and 1967, are shown in Figure 1. Sixteen inches of rain fell in January 1969. Rainfall on individual sites was up to 10 in. per year more than that recorded at Malanda.

Frost occurred each year over the period May to August. Grass temperatures of 31°F or below are shown as degrees of frost in Figure 1. These were calculated from records at Kairi Research Station, 10 miles north-west of the sites. In practice it was found that farmers recorded at least light frosts when Kairi registered 35°F.

Pests.—Armyworms (*Spodoptera exempta*) defoliated grass at all sites in January 1966. Webworms (*Oncopera mitocera* and *O. brachyphylla*) caused damage in 1966 and 1967 to both grass and legumes, particularly the desmodiums. Plots were sprayed for webworm with trichlorphon at 8 oz. active ingredient per acre in each dry season. The desmodiums were also attacked by larvae of the weevil *Leptopius corrugatus*, which severely gouged their roots, a Melolonthid beetle, which defoliated aerial stems, and the paler field rat (*Rattus culmorum*), which severed stolons.

Weeds.—Broad-leaved weeds and inferior grass invaders were major components of the juvenile sward (Figure 3B, 1965). The former declined with time, while the latter were the main contributors in subsequent seasons.

Species differed at each site. Star burr (*Acanthospermum hispidum*) and cobbler's pegs (*Bidens pilosa*) dominated the old cultivation sites. On sites formerly under grass, weeds ranged from light on the metamorphic (site 4) to heavy on the basalt (site 1). The main species were summer grass (*Digitaria adscendens*), crowsfoot (*Eleusine indica*), stinking roger (*Tagetes minuta*), wild tobacco (*Solanum auriculatum*) and wild hops (*Nicandra physalodes*). The last-mentioned occurred only on basalt sites.

A severe invasion of fleabane (*Erigeron bonariensis*) occurred in the second season at site 2 (Fig. 3B, 1966). Carpet grass (*Axonopus affinis*) re-invaded most sites, particularly in unfertilized plots. Couch grass (*Cynodon dactylon*) grew strongly at times on the basalt sites.

III. RESULTS

(a) Initial Plant Densities

Legume density at 11 weeks was significantly greater at sites 3 and 4 than at sites 2, 5 and 6 (Figure 3A). Green panic density was significantly greater at site 3 than at other sites.

Experience suggested 100,000 legume plants per acre as an ideal density on which to build a legume sward in combination with a grass. On this arbitrary basis, stylo, Silverleaf and Greenleaf were in ample numbers for rapid establishment (Table 3); Clarence was satisfactory, but vigna, Cooper, C.P.I. 13300, Tinaroo and C.P.I. 23411 were sparse to very sparse; C.P.I. 25422 was a complete failure. Green panic densities were quite regular, varying around 100,000 plants per acre. Legume density was not correlated with grass density.

TABLE 3

Sowing Rate, Initial Plant Density and Dry-matter Yield (per acre and per plant) of Individual Legumes in the Juvenile Sward

Mean of two fertilizer regimes at six sites

Legume Species	Sowing Rate (lb/ac)	Initial Plant Density (1,000 plants/ac)	Dry-matter Yields	
			lb/ac	g/plant*
Stylo	4	220	164	0·3
Silverleaf	4	102	116	0·5
Greenleaf	2	100	74	0·4
Clarence	4	75	137	1·2
Vigna	6	49	169	2·9
Cooper	4	47	130	1·5
C.P.I. 13300	2	31	29	0·4
Tinaroo	4	21	30	0·6
C.P.I. 23411	2	17	28	0·8
C.P.I. 25422	2	1	..	..
S.E.	..	±18	±25	±0·4
L.S.D. 5%	..	50	72	1·1
1%	..	67	96	1·5

* Derived from per plot averages.

There was a suggestion in the data that legume density was depressed in fertilized plots. Specifically, vigna and stylo were significantly depressed ($P=1\%$) at sites 1 and 3 respectively.

(b) Sward Dynamics

The temporal movement of sward dry-matter production in midsummer and the contribution of the individual components are shown in Figure 2 for degenerate grassland (sites 1, 2, 3 and 4) and old cultivation land (sites 5 and 6). The swards of the former are built on initial densities varying round 106,000 grass plants per acre and 75,000 legume plants per acre; swards of the latter are built on initial densities varying round 90,000 grass plants per acre and 49,000 legume plants per acre.

Grassland sites.—Dry-matter production from the unfertilized sward rose markedly to a peak in the second and third seasons and fell sharply in the fourth season (Figure 2A). In the fertilized sward, production was at a much higher level throughout and much more even. The difference in production was due mainly to the strong response by grass in the first two seasons and by the legumes in the last two seasons (Figure 3B).

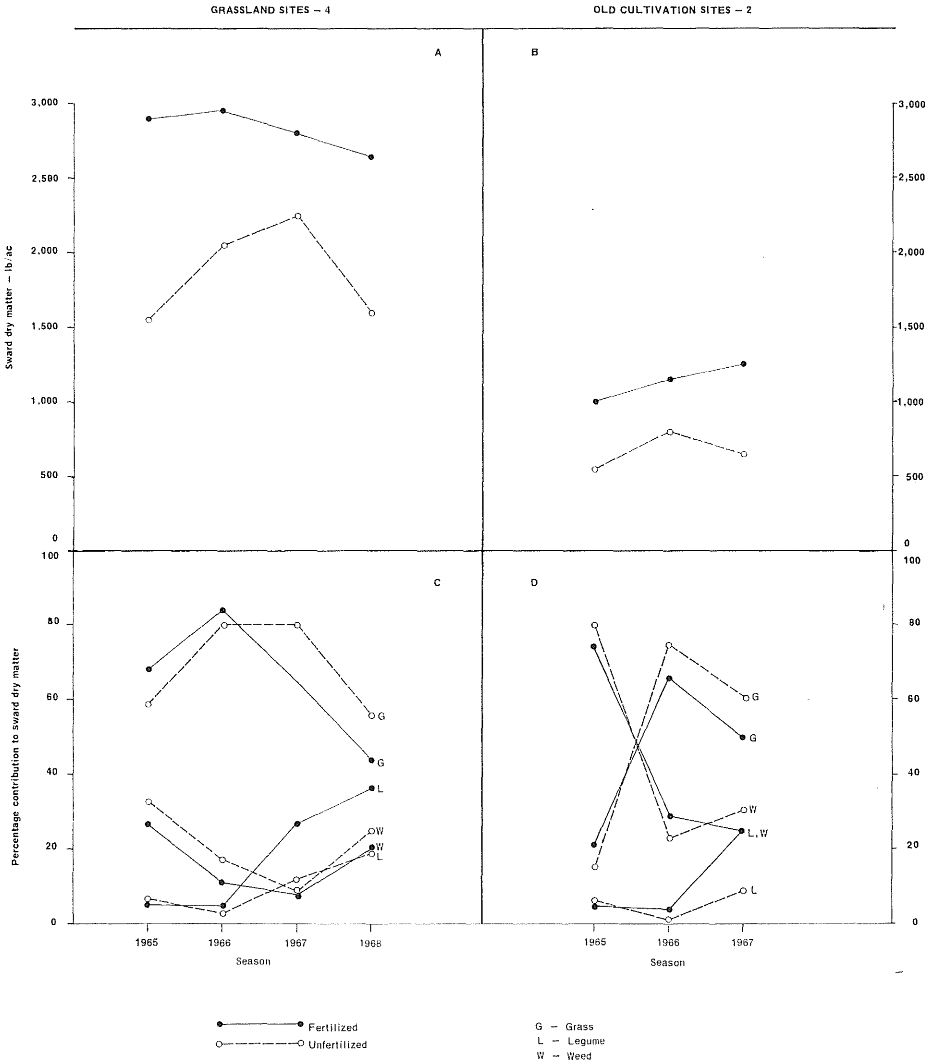

Fig. 2.—Mean sward dry-matter production in each season and the weighted mean percentage contribution to it by grass, legume and weed in pastures established on grassland and old cultivation sites. A. Sward dry matter, grassland. B. Sward dry matter, old cultivation. C. Percentage contribution, grassland. D. Percentage contribution, old cultivation.

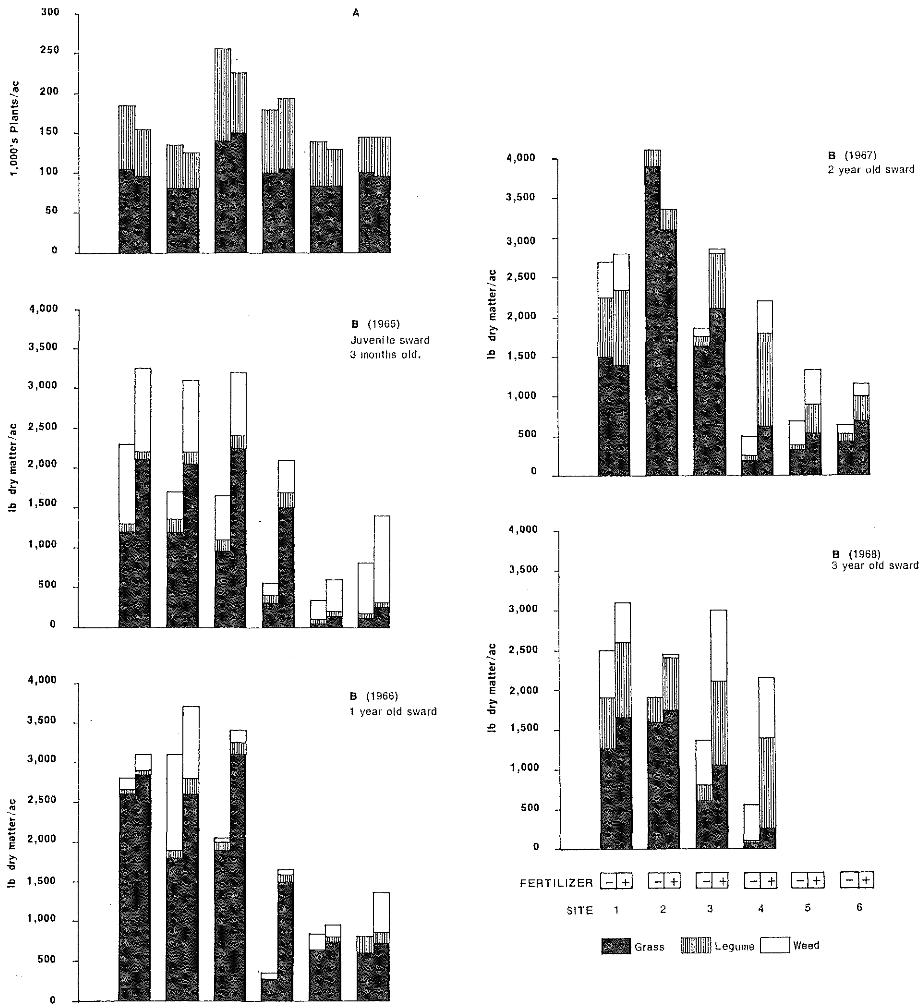

Fig. 3.—(A) Initial plant densities of grass and legume at each site; and (B) dry-matter yield of grass, legume and weeds in the juvenile sward and from one harvest in each summer season.

The percentage contribution by individual components of the sward to dry-matter production followed a similar pattern in both unfertilized and fertilized swards (Figure 2C). The juvenile sward was dominated by grass (mean = 64%) and weeds (mean = 30%) but in the second season grass (mean = 82%) dominated at the expense of the weeds. The legume (mean = 5%) made only a minor contribution in both seasons.

In the third season the proportion of legume increased strongly and this upward trend continued in the fourth season. It was much greater in the fertilized swards. The legume gain in these swards was essentially at the expense of the grass. This contrasted with the gain in the unfertilized swards, which was at the expense of the weeds (the grass remained at its peak of the previous year). The percentage dry-matter contribution by weeds was generally greater in the unfertilized sward.

In the fourth season, grass contribution to the fertilized sward continued to fall while that to the unfertilized sward had commenced to fall; this was of the same magnitude as the fall in the fertilized sward 12 months earlier. In each case the proportion of both legumes and weeds increased.

While the sward remained in a dynamic state at 3 years of age, the "establishment" phase of overwhelming grass dominance was passed between the second and third seasons in the fertilized sward and between the third and fourth seasons in the unfertilized sward. Concurrently, the successful stoloniferous legumes of the genera *Glycine* and *Desmodium* consolidated into a dense bed of rooted runners underneath a leafy canopy.

Old cultivation sites.—Essentially the sequence of change on these sites was the same as for the grassland sites. Differences are in degree and not in kind. There was a much lower level of sward dry-matter production (Figures 2B and 3B). In the juvenile sward, weeds (mean = 77%) contributed a far greater proportion to sward dry matter than grass (mean = 18%) (Figures 2D and 3B). Grass contribution to sward dry matter commenced to fall at the same time in both unfertilized and fertilized swards (Figure 2D).

(c) Midsummer Dry-matter Production

The average capacity of the different edaphic environments (site by fertilizer combinations) to produce dry matter in midsummer after a two-month rest from grazing is shown in Figures 2A and 2B. The highest yield was about 3,000 lb/ac from fertilized grassland. Grassland sites yielded about three times as much dry matter as old cultivation sites in the first three seasons. Fertilizing with superphosphate improved dry-matter yield by about 1·6 times in both situations over the same period.

Yields from specific environments and sward components are shown in Figure 3B and Table 4.

Green panic yielded as high as 3,900 lb DM/ac and as low as 70 lb DM/ac; its response to superphosphate was greatest at site 4. The highest weed yields were of the order of 1,000 lb DM/ac.

Legume yields were highest in fertilized grassland. Significant responses to superphosphate came mainly from Greenleaf, Silverleaf, Clarence, C.P.I.13300 and to a lesser degree, Cooper. In the 3-year-old sward, the top-ranking species when fertilized and otherwise suited to the environment yielded from 780 to 3,180 lb DM/ac (Table 4).

TABLE 4

MIDSUMMER DRY-MATTER PRODUCTION (LB/AC) AND PERCENTAGE CONTRIBUTION OF INDIVIDUAL LEGUMES TO TOTAL SWARD DRY MATTER IN A 3-YEAR-OLD SWARD ON FOUR GRASSLAND SITES

Legume	Site 1		Site 2		Site 3		Site 4	
	F0*	F16*	F0	F16	F0	F16	F0	F16
Clarence	1,235 (45)**	2,436 (71)	408 (21)	1,132 (35)	327 (22)	2,546 (80)	22 (3)	2,065 (76)
C.P.I. 13300	1,925 (62)	2,432 (62)	305 (11)	669 (24)	206 (15)	1,650 (37)	312 (52)	1,778 (70)
Greenleaf	441 (17)	360 (11)	125 (7)	559 (19)	658 (37)	2,036 (51)	37 (4)	3,182 (85)
Silverleaf	606 (22)	573 (19)	173 (11)	441 (20)	107 (7)	1,598 (49)	11 (2)	937 (60)
Cooper	268 (14)	779 (41)	456 (25)	963 (39)	70 (8)	456 (18)	40 (9)	966 (33)
Tinaroo	503 (18)	540 (14)	349 (17)	944 (44)	0 (0)	162 (7)	0 (0)	37 (5)
C.P.I. 23411	217 (8)	338 (12)	272 (23)	426 (21)	55 (5)	51 (2)	0 (0)	22 (2)
Stylo	4 (0)	209 (10)	180 (6)	92 (3)	107 (9)	0 (0)	47 (8)	110 (6)
S.E.	±139 (±5)		±187 (±6)		±274 (±3)		±127 (±4)	
L.S.D † 5%	455 (16)		611 (20)		895 (10)		415 (13)	
1%	661 (24)		889 (30)		1,302 (14)		603 (19)	

* F0 = nil superphosphate; F16 = cumulative superphosphate application of 16 cwt/ac.

** Percentage legume contribution in brackets.

† For testing between fertilizer levels only.

(d) Legume Species Performance

Seedling vigour.—Differences in seedling vigour were apparent in the juvenile sward (11 weeks old). Vigna and stylo produced most dry matter overall, while Tinaroo, C.P.I. 13300 and C.P.I. 23411 yielded negligible amounts (Table 3). However, because initial plant densities were widely different, yield per acre is an insensitive measure of vigour, and so dry-matter yield per plant was calculated. Vigna was the most vigorous, followed by Cooper and Clarence.

Persistence.—By midsummer 1968, when the experiment had been operative for 3 years, the swards had been exposed to a wide variety of environmental conditions. These included severe domination of the legumes by grass and weeds, a wide range of grazing pressures, heavy frosts (June–July 1965), a long period of below-average rainfall (1965-66), exceptionally high rainfall intensity (March 1967), a high incidence of pests and a good summer season in 1968.

At this stage a legume was considered persistent if it contributed more than 5% of sward dry matter. Such a low level of entry into the persistent class is designed to indicate presence in the sward regardless of useful productivity. This arbitrary standard was applied to the 1968 legume dry-matter yields from the eight habitats provided by the two fertilizer regimes at the four grassland sites (Table 5). Clarence, C.P.I. 23411 and stylo were regarded as unreliable and vigna was non-persistent. This persistence standard was also applied to the legume yields from the old cultivation sites when they were terminated in 1967 after 2 years. The pattern changed in that stylo was more reliable while Greenleaf and Silverleaf were unreliable.

TABLE 5

LEGUME PERSISTENCE ESTIMATES AT TWO LEVELS OF DRY-MATTER CONTRIBUTION TO THE SWARD AT THE 1968 (GRASSLAND) AND 1967 (OLD CULTIVATION) HARVESTS

Legume Species	No. of Times Legume DM is > 5% Sward DM		No. of Times Legume DM is > 25% Sward DM	
	Grassland* 3-year sward	Cultivation** 2-year sward	Grassland* 3-year sward	Cultivation** 2-year sward
Clarence	7	3	5	2
C.P.I. 13300	8	3	5	2
Greenleaf	7	2	3	0
Silverleaf	7	1	2	0
Cooper	8	4	3	1
Tinaroo	5	1	1	0
C.P.I. 23411	4	2	0	0
Stylo	5	3	0	1
Vigna	0	0	0	0

* Possible = 8.

** Possible = 4.

To assess whether these legumes persisted in a productive state, a minimum productivity standard was set at a level greater than 25% of sward dry matter and applied to the abovementioned legume yields (Table 5). On this basis Clarence and C.P.I. 13300 were the most reliable on grassland sites; Greenleaf, Silverleaf and Cooper were unreliable; Tinaroo reached the standard at only one site; while C.P.I. 23411 and stylo failed to reach the standard at any site.

On the old cultivation sites Clarence and C.P.I. 13300 were again the most reliable. Cooper and stylo were unreliable, while all other species were of no account.

Adaptability.—The regression coefficients (Table 6) and transformed mean yields were derived from the cumulative midsummer yields of seven legumes from the 2 and 3-year-old "established" swards. This analysis was used to depict the response of the individual species to the eight edaphic environments for two reasons. Firstly, when data from the 1-year-old sward were included in the analysis, regression coefficients for species with very low initial plant densities were inconsistent, but this deficiency had been overcome by the appropriate species when the swards became established; C.P.I. 13300 was the legume particularly affected. Secondly, when the full range of environments was analysed the edaphic effect was much stronger than the seasonal effect in the grading of the environments.

TABLE 6

REGRESSION COEFFICIENTS (" b ") AND MEAN DRY-MATTER YIELDS (LOG_{10} LB/AC) OF SEVEN TEST LEGUMES TOGETHER WITH THE STANDARD ERRORS FOR " b " AND THE SIGNIFICANCE TEST FOR LINEARITY

Legume Species	Regression Coefficient§ (" b ")	S.E. of Regression coefficient	F test for linearity	Mean Dry-matter Yield ($\log_{10}$ lb/ac)
Tinaroo	1·79 a	0·20	***	2·09
C.P.I. 23411	1·54 a b	0·24	***	2·07
Clarence	1·01 c b	0·12	***	3·02
Population mean	1·00		..	2·66
Cooper	0·82 c d	0·14	***	2·71
Greenleaf	0·66 c d	0·24	*	2·84
Silverleaf	0·66 c d	0·17	**	2·79
C.P.I. 13300	0·52 d	0·13	**	3·06

§ Regression coefficients not linked by a common letter are significantly different.
* $P < 0{\cdot}05$; ** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$.

The linear regression was significant for each legume. Complete error homogeneity was not induced; data from the unfertilized swards at sites 2, 3 and 4 caused the differences. Standard errors for "b" varied from 0·12 to 0·24. There were significant differences between the "b" values.

Figure 4 shows the effect of site and fertilizer in the grading of the environments. It also demonstrates diagrammatically three types of adaptability in the population under test.

With a regression coefficient very close to 1·0 (equal to that of the population mean), Clarence showed average stability. Its mean yield was well above the population mean of 2·66 (450 lb DM/ac) and it produced above-average yields in all environments. Therefore it is generally adapted to these environments.

Tinaroo had a regression coefficient significantly greater than that of Clarence. In contrast, C.P.I. 13300 had a regression coefficient significantly less than that of Clarence allied with a high mean yield and above-average yields in all environments. It is a stable species with wide edaphic adaptability.

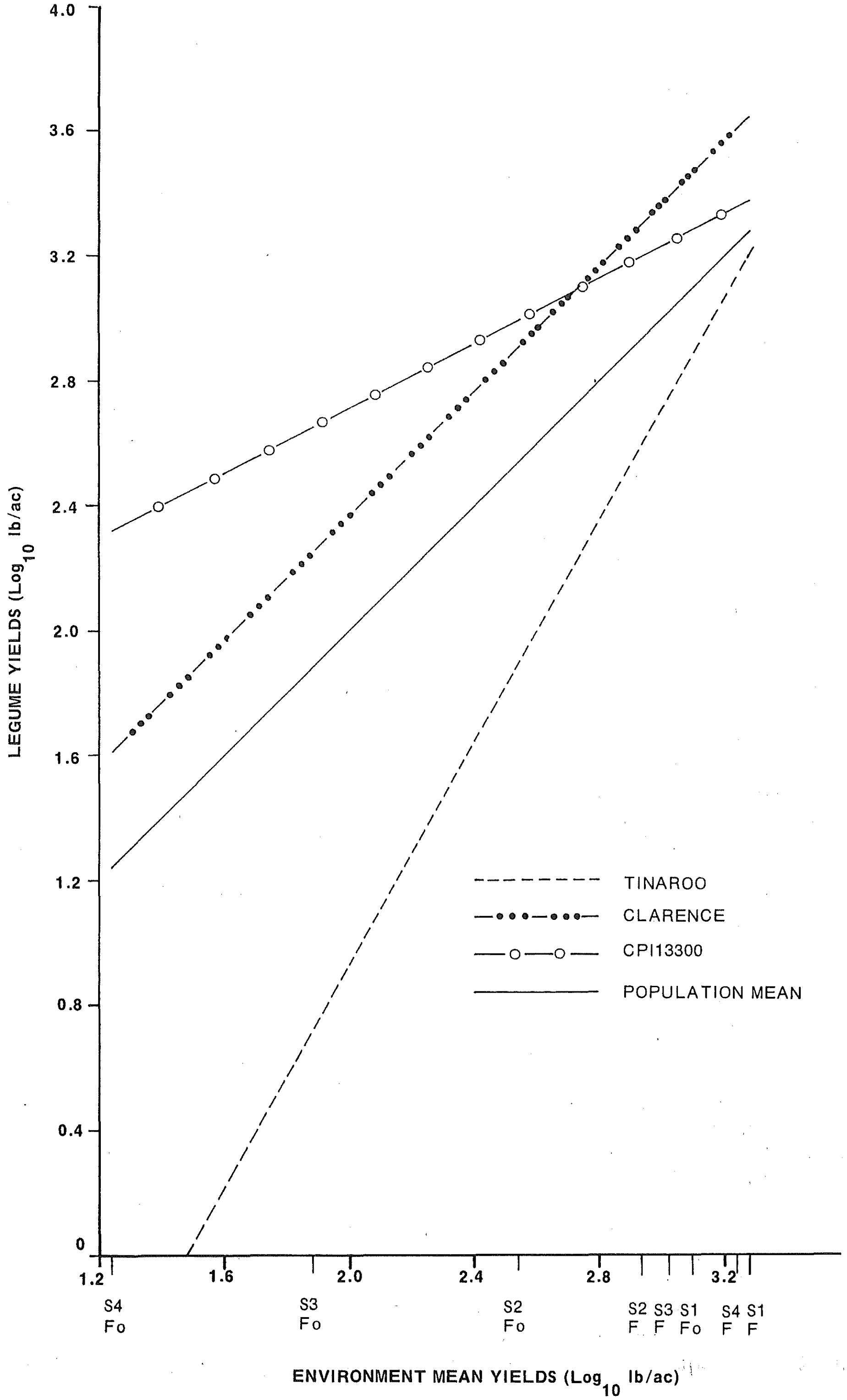

Fig. 4.—Regression lines showing the relationship between individual yields of three legumes and yields of the population mean of seven legumes grown in eight edaphic environments. S = site; Fo = unfertilised swards; F = fertilized swards.

The other four species responded as follows: C.P.I. 23411, an unstable species similar to Tinaroo, had a regression coefficient of 1·54, which, however, differed from that of Clarence at only a 10% significance level. Silverleaf, Greenleaf and Cooper had above-average stability and above-average yields even though their regression coefficients did not differ significantly from that of Clarence. (Greenleaf was not stable in the 1-year-old sward, where it had a regression coefficient of 1·65 and showed marked ability to exploit an improved edaphic environment).

IV. DISCUSSION

These results emphasize the importance of viewing the development of perennial grass/legume swards as a dynamic whole against an equally changeable and fluctuating natural environment. If one component is altered in the basic sequence of choosing a site, preparing the land, obtaining adequate plant densities of the right species, applying fertilizer and managing the sward, then all other components take on a new weight and different decisions may have to be made.

In this experiment the major difference between the sites is that some were under grass while others were old cultivations. When grasslands are cultivated, sufficient nitrogen is released to stimulate massive sown grass growth in the juvenile sward, particularly when superphosphate is applied; this was most pronounced on the more fertile basalt sites. Competition for light thus becomes critical in the juvenile sward, posing a serious management problem; it is aggravated by the fact that the relative growth rate of the tall-growing tropical grasses is up to twice that of the current suite of tropical legumes (Tow 1967; Ludlow and Wilson 1968). In old cultivations grass growth was not a problem, since nitrogen release is negligible due to the destruction of organic matter during the long history of cultivation and cropping associated with erosion and leaching under high-rainfall conditions.

Weeds also constitute a major proportion of the juvenile sward; they too respond to superphosphate. Like grass production, the structure of the weed component differed between grassland and old cultivation sites. On the former, vigorous, tall-growing broad-leaved weeds added to the legumes' competition for light. On the latter, the weed component contained different species of much shorter stature, with less vigour although in larger numbers.

Despite awareness of the importance of controlling grass and weed growth in the juvenile sward (Gartner 1966), the growth of both these components was much too far advanced in height and density at sites 1, 2, and 3, particularly in fertilized plots, before the first harvest was completed and grazing and slashing could commence. In this way any early legume response to superphosphate was masked by suppression of legume through heavy shading. Many of the legume seedlings included in the initial density count were pale and spindly and their survival was unlikely. At site 4, although the grass response to superphosphate was spectacular, growth was not as vigorous or as dense as at other grassland sites. Consequently grazing or "removal of the grass canopy" commenced before any serious competition for light occurred, and legumes were able to express their early growth potential relatively unimpeded; this resulted in visual responses to superphosphate. On old cultivations, grass growth was so weak that other plant growth in the sward offered no significant restraint to legume development.

Although the same rates of seed from the same sources were sown at each site, major differences in plant densities were recorded between sites and these cannot be adequately explained. Ample quantities of stylo, Silverleaf and

Greenleaf were sown; hence their strong initial densities. Seed rates were too low for adequate populations of C.P.I. 13300, C.P.I. 23411 and C.P.I. 25433 (due to a seed shortage). However, seed quality undoubtedly was a major factor in the failure of C.P.I. 25422 and in the low population of Tinaroo (Pure Live Seed = 47%).

Within the grassland sites, fertility other than nitrogen graded the sites in the order 1, 2, 3, 4, from the highest yielding to the lowest. This is typified by the stepwise decline of grass yields in the unfertilized swards of the juvenile pasture (Figure 3B, 1965) and the size of the response to superphosphate by the legumes in the established pasture (Figure 3B, 1968, and Figure 4). The distinctness of the order was modified slightly by the low grass populations at site 2 in comparison with those at site 3 in the juvenile sward (Figure 3A) and the later strong development of grass at site 2 which reduced legume yield and prevented any weed growth (Figure 3B, 1967).

The lower production of both grass and legume on the old cultivation sites reflects the poorer edaphic environment compared with the grassland sites. Either insufficient superphosphate had been used or some other element not already present in this fertilizer was deficient. Some physical effect reducing water entry or aiding drying out may also have been involved. Even so, the results in Table 5 show a similar ranking of legumes to that on grassland sites.

Clearly, such situations require plant types that have vigorous seedlings, are tolerant to shading and have wide edaphic adaptability. Vigna, Cooper and Clarence seedlings were the most vigorous. This agrees with the observations on vigna by Davidson (1966) and with a *Glycine wightii* seedling growth study by J. E. Ferguson (unpublished data). However, vigna was a non-persistent species, virtually disappearing in the second season due to severe frosts in the previous winter followed by a prolonged and severe dry season. In contrast, Cooper was the only legume to meet the persistence standard in all habitats. However, despite the tendency to phenotypic stability, its yields were only average; it responded to superphosphate but failed to exploit the high-yielding environments as well as other relatively stable species.

At the other end of the seedling vigour scale, stylo, despite well above average yields in the juvenile sward in almost all habitats, virtually disappeared for two seasons after the severe frosts of 1965. It reappeared at a low level of yield in the third season, doing better in unfertilized swards. Despite this apparent adaptation to low-fertility environments, it is poorly adapted to the total district environment, under which conditions it was sensitive to grass competition.

Greenleaf desmodium was also at the bottom of the seedling vigour scale. It has the smallest seedling of the test group but quickly overcame this disability. Throughout the first year and at the second season harvest, it was the most productive of all the legumes, responding strongly to superphosphate. In time it declined on the basalt and old cultivations sites due to insect attack, only showing its yield potential on the metamorphic sites. It is adapted to the district but its ability to respond to high-yielding edaphic environments is variable due to the unpredictability of insect attack, which in this experiment coincided with a long period of below-average rainfall. This explains the inconsistency in its regression coefficient for the first year data and that presented in Table 6. The performance of Silverleaf was almost identical with that of Greenleaf, but its level of yield was consistently lower except in the seedling stage.

Overall, *G. wightii* cv. Clarence and C.P.I. 13300 were the outstanding varieties. They were slower in their development than the desmodiums, but, once established in fertilized plots, their dry-matter production was high on all grassland sites. They were the only legumes both to persist and to produce reasonable yields on old cultivations. These two glycines are tetraploids; this warrants a closer investigation of a wider range of such material.

The unstable performance of Tinaroo typifies what has been observed in the district over the years since its release from Kairi Research Station, which is regarded as a high-yielding edaphic environment (Table 2); there it grows to perfection. In this experiment its low mean yield (Table 6) and below-average yields in all edaphic environments tested (Figure 4) suggest that none of these environments was sufficiently favourable for it to exhibit its full potential. The poor performance of C.P.I. 23411 should be treated with caution because of its exceptionally low initial plant density.

The measured results for seedling vigour, persistence, midsummer dry-matter production and adaptability provide a critical account of the performance that can be expected from the test legumes in association with a grass in the Malanda district. However, two aspects which have not been covered may modify the results to some extent. These are plant morphology and seasonal distribution of yield. The desmodiums (Silverleaf and Greenleaf) and to a lesser degree the tetraploid glycines (Clarence and C.P.I. 13300) are gross plants with low leaf/stem ratios. In a destructive harvest, where all material is taken to the bottom of the green layer, the effective forage yields of these plants tend to be inflated in comparison with those of the diploid glycines (Cooper, Tinaroo and C.P.I. 23411). These varieties have a fine, multiple-branched, leafy canopy. Cooper is outstanding in degree of branching (Ferguson 1969).

The reported dry-matter yields are biased towards early-season growers with midsummer peaks. Time and mode of flowering affect the length of the period of active growth at the end of the growing season. Silverleaf, Clarence, C.P.I. 13300 and Cooper commence flowering about mid April. The first three of these have terminal modes of flowering; vegetative growth ceases at peak flowering. In contrast, Cooper, C.P.I. 23411 and Tinaroo have axillary modes of flowering; vegetative growth continues from the primary meristems after peak flowering (Ferguson 1969). However, Tinaroo does not flower until early June; this makes it ideal for late-season growth. Again in contrast, Greenleaf has a terminal mode of flowering but it does not flower until late May. This lateness of growth is of more use than early-season growth, since rainfall is more reliable at the end than at the beginning of the season.

Of the two legumes with good late-season growth, Greenleaf has the wider edaphic adaptability; but since a certain amount of control can be exercised over soil fertility, Tinaroo's late-season ability may yet be exploited if its nutrient requirements can be determined and provided economically. Even so, it may be more useful to search for other natural variants of *Desmodium intortum* and of *G. javanica* which combine high yield with late-season growth and phenotypic stability over a range of edaphic environments; the latter character underpins the performance of a species in case nutrient requirements are not met. Both lines of approach are worth pursuing.

V. ACKNOWLEDGEMENTS

We wish to thank Mr. M. L. Everett and other officers of the Queensland Department of Primary Industries for field assistance. We are grateful to Dr. J. P. Ebersohn and Dr. B. Grof for criticism of the manuscript.

REFERENCES

ALLEN, G. H. (1961).—Tinaroo Glycine. *Qd agric. J.* 87:768.

BANDRETH, B. (1935).—County spring oats trials, 1931-33. *J. natn. Inst. agric. Bot.* 4:5-25.

BARNARD, C. (1969).—"Herbage Plant Species". (Division of Plant Industry, C.S.I.R.O.; Canberra.)

BARNARD, C. (1972).—"Register of Australian Herbage Plant Cultivars". (Division of Plant Industry, C.S.I.R.O.:Canberra.)

BEST, J. G. (1962).—"Atherton, Queensland Sheet E/55-5, B.M.R. 1:250,000." (Commonwealth Bureau of Mineral Resources:Canberra.)

DAVIDSON, D. E. (1966).—Five pasture plants for Queensland. *Qd agric. J.* 92:460-6.

DE KEYSER, F. (1964).—"Innisfail, Queensland Sheet SE/55-6 B.M.R. 1:250,000." (Commonwealth Bureau of Mineral Resources:Canberra.)

FERGUSON, J. E. (1969).—Observations on the growth characteristics of *Glycine javanica* L. *Qd J. agric. Anim. Sci.* 26:513-6.

FINLAY, K. W., and WILKINSON, G. N. (1963).—The analysis of adaptation in a plant breeding programme. *Aust. J. agric. Res.* 14:742-54.

GARTNER, J. A. (1965).—Progress notes on Atherton pastures. *Qd agric. J.* 91:356-61.

GARTNER, J. A. (1966).—Improving pastures on the Atherton Tableland. *Qd agric. J.* 92:356-61.

KERR, H. W., and VON STIEGLITZ, C. R. (1938).—The laboratory determination of soil fertility. *Tech. Commun. Bur. Sug. Exp. Stns, Qd* No. 9 of 1938.

KYNEUR, G. W. (1959).—Growth rates of lucerne (Hunter River) and *Glycine javanica* in a tropical highland environment. *J. Aust. Inst. agric. Sci.* 25:314-5.

KYNEUR, G. W. (1960).—Glycine on the Atherton Tableland. *Qd agric. J.* 8:507-13.

KYNEUR, G. W. (1962).—The role of fertilizers in establishing *Glycine javanica* on latosol soils. *Proc. North Queensland Agrostology Conference.* Paper 10/5. (Queensland Department of Primary Industries:Brisbane.)

KYNEUR, G. W. (1963).—Nutrient responses by tropical pasture legumes on latosol soils of the Atherton Tableland—North Queensland. *Proc. III Aust. Grasslands Conference.* Paper 5-3. (C.S.I.R.O.:Melbourne.)

LUDLOW, M. M., and WILSON, G. L. (1968).—Studies on the productivity of tropical pasture plants. I. Growth analysis, photosynthesis, and respiration of Hamil grass and Siratro in a controlled environment. *Aust. J. agric. Res.* 19:35-45.

SANDISON, A., and BARTLETT, B. O. (1958).—Comparison of varieties for yield. *J. natn. Inst. agric. Bot.* 8:425-7.

TOW, P. G. (1960).—Some ways of establishing glycine. *Qd agric. J.* 86:425-7.

TOW, P. G. (1967).—Controlled climate comparisons of a tropical grass and legume. *Neth. J. agric. Sci.* 15:141-54.

(Received for publication August 30, 1973)

J. A. Gartner and J. E. Ferguson were formerly officers of the Department of Primary Industries; R. W. Walker is an officer of the Agriculture Branch of the Department stationed at Walkamin Research Station; Elvie Goward is an officer of the Biometry Branch of the Department, stationed at Brisbane.