A COMPARISON OF SOIL NITRATE NITROGEN VALUES UNDER BARE FALLOW AND AFTER PLOUGHING IN VARIOUS PERENNIAL TROPICAL LEGUMES AND COWPEAS.

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SUMMARY.

1. Four perennial tropical legumes—Calopogonium mucunoides (calopo), Centrosema pubescens (centro), Pueraria phaseoloides (puero) and Stylosanthes guianensis (stylo)—after 18 months' growth were ploughed under in July at South Johnstone, on the wet tropical coast of Queensland, and soil nitrate nitrogen values were determined in four layers to a depth of 24 inches over the ensuing seven months.

2. The mean nitrate nitrogen values for the puero plots at each depth were significantly higher at the 1 per cent. level than the corresponding values for the other plots. In the top six inches of the puero plots, the mean value was 171.8 p.p.pm., and the maximum was 395.6 p.p.m. in early October.

3. The effects of yield, chemical composition of the plant material, soil moisture and temperature on nitrate nitrogen production are discussed. A high positive correlation beween precipitation and leaching of nitrate is shown.

4. Comparison with a ploughed-in area of giant cowpeas showed that only puero was superior to cowpeas in soil nitrate production.

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5. Under bare fallow, nitrate nitrogen production was not detected until mid-August and was slow until mid-September. The maximum content of 108.0 p.p.m. in the top six inches was reached in mid-January, and the mean value in that layer over seven months was 34.4 p.p.m.

6. The importance of perennial legumes as soil improving plants in the tropics is stressed and the particular value of puero and centro is indicated.

7. The implications of nitrate nitrogen production under bare fallow in relation to pasture and crop growth are discussed.

INTRODUCTION.

The problem of building up soil fertility is particularly important in coastal Queensland, where the climatic conditions favour erosion and the practice of monoculture is common. Two of the main limiting factors in satisfactory plant growth on worn-out soils are the low content of available nitrogen and the lack of that "crumb" structure in the soil which has been referred to as "the only structure having any agricultural value at all."

The subject of green-manuring under tropical conditions is one about which much has been written and concerning the value of which widely divergent views exist. Russell (1936) summed up the position as follows:—"Green manuring is very variable in its effects; indeed probably no other method of manuring the land has so wide a range of possibilities. It may be exceedingly effective, or on the other hand it may be almost useless." Joachim (1931) observed that in Ceylon green-manuring has come to be recognized as an essential agricultural operation on tea, and to a lesser extent on rubber plantations, and listed the chief advantages of the practice. Faulkner (1934) reported results obtained with the annual, *Mucuna utilis,* as a green manure at Ibadan, Southern Nigeria, where the rainfall is heavy and prolonged and the land light. Gethin Jones (1942) pointed out the promise shown by *Glycine javanica* as a permanent cover crop in Kenya.

The effects of the decomposition products of green manures on crop yields have been studied fairly extensively, but in tropical countries little has been done to examine the primary causes of subsequent increased crop yields, namely, the accretion of nitrogen and of humus supplies. The investigation reported in this paper was undertaken at the Bureau of Tropical Agriculture at South Johnstone in order to determine the effect of various green manures on the nitrate nitrogen content of the soil under the climatic conditions of the "wet belt" of coastal northern Queensland.

SCOPE OF THE INVESTIGATION.

The nitrate nitrogen values in the soil, at 6-inch depths down to 24 inches, which resulted from the ploughing under of four promising introduced perennial legumes—*Calopogonium mucunoides* Desv. (calopo), *Centrosema pubescens* Benth. (centro), *Pueraria phaseoloides* Benth. (puero) and

Stylosanthes guianensis Sw. (stylo)—allowed to grow for 18 months, were compared with the corresponding figures obtained from a bare fallow. A supplementary investigation included the determination of nitrate nitrogen figures following ploughing under of giant cowpeas (*Vigna unguiculata* Walp.) on an adjacent area. These determinations were carried out at intervals from the end of the wet season of 1940-41 to the onset of the next wet season, a period of about 7 months, as a first step in the intensive study of the relative merits of these plants as builders of soil fertility in the tropical "wet belt" and as components in a system of mixed farming.

Descriptions of the legumes, of the experimental area and of the soil and fertilizer treatments given, together with climatological data, have been given in previous papers (Schofield, 1941, 1944).

Under the climatic conditions of the wet tropical belt, calopo, centro and puero after satisfactory establishment (which generally entails inter-row scarification and hoeing until a thick cover is obtained) act as self-mulching covers, and do not form woody material. Stylo, when allowed to grow unrestrictedly, becomes very coarse and forms woody stems at the base; it is not to be expected, therefore, that this legume will be as satisfactory as the other three as a long-term green manure. All of the legumes may be ploughed under at any time after 18 months to fit in with the requirements of the rotation. They can also be used as grazing crops. This flexibility allows of their use over extended periods and for diversified purposes, and is a characteristic which is likely to prove of importance under the erratic climatic conditions of coastal Queensland.

TECHNIQUE.

Establishment.

In early February, 1940 duplicate plots of calopo, centro and puero were planted at the rate of 4 lb. of seed per acre, and of stylo at the rate of 2 lb. per acre. The plot size was 34 feet by 6 feet and planting was carried out in two parallel rows 3 feet apart. Fallow plots were included, and these were clean-weeded at intervals throughout the experiment. The layout was a 5 x 2 randomized block. Germination of the seeds was rapid and all of the legumes quickly established a thick cover. Weeding of the legumes was carried out twice before the heavy rains set in and the legumes were then left undisturbed, except for occasional weeding, until July, 1941.

Method of Soil Sampling.

Six days after the legumes had been ploughed under, soil samples were taken at four separate 6-inch depths—0-6 inches, 6-12 inches, 12-18 inches, and 18-24 inches—and similar sampling was carried out in the bare fallow plots. Four samples were taken from each plot at each depth and bulked. After collection, the samples were taken to the laboratory and treated immediately to arrest nitrification. Nitrate determinations were made by the phenol-disulphonic

Table 1.

Nitrate Nitrogen (Mean of two determinations) in each Layer of Soil in each Treatment during a period of Seven Months.

Treatment.	Soil Layer. Inches.	Date of Sampling and Nitrogen in Parts per Million.														
		July 8	Aug. 4	Aug. 14	Aug. 28	Sept. 9	Sept. 19	Oct. 1	Oct. 13	Oct. 27	Nov. 11	Nov. 28	Dec. 24	Jan. 13	Feb. 2	Mean.
Fallow	0– 6	nil	nil	5·2	8·4	11·8	22·4	40·0	51·9	85·0	10·1	18·7	77·1	108·0	42·7	34·4
	6–12	nil	nil	4·1	4·6	10·9	17·6	29·9	18·7	25·0	41·7	18·2	46·2	42·4	38·3	21·3
	12–18	nil	nil	1·2	nil	2·2	4·1	10·9	5·0	5·4	20·5	13·3	27·5	18·3	26·9	9·7
	18–24	nil	nil	nil	nil	nil	1·4	2·7	3·6	4·4	4·9	4·7	8·5	6·3	13·8	3·6
Calopo	0– 6	4·3	3·5	39·2	49·0	42·0	81·6	96·7	103·2	119·8	22·8	42·0	121·5	187·0	21·6	66·7
	6–12	2·6	17·1	34·3	44·0	55·7	92·0	83·6	73·0	95·0	151·2	57·0	120·5	128·5	63·5	72·7
	12–18	1·6	4·5	7·2	4·8	15·3	17·0	21·2	11·5	10·8	56·1	26·8	48·3	56·1	38·6	22·8
	18–24	2·4	nil	1·2	3·4	2·6	13·5	5·5	4·1	13·1	12·0	7·2	18·6	13·1	14·4	7·9
Centro	0– 6	15·2	5·3	20·2	30·5	40·4	73·7	203·2	219·5	141·3	31·5	15·2	74·3	91·4	42·4	71·7
	6–12	9·1	13·8	26·4	26·6	61·7	67·7	88·0	64·5	46·3	102·2	49·0	82·3	70·3	71·0	55·6
	12–18	3·3	6·5	7·4	7·9	12·2	17·3	34·6	8·9	10·3	51·2	17·9	43·4	35·6	41·7	21·3
	18–24	2·4	1·6	3·3	2·7	4·5	10·9	13·0	11·1	4·6	17·6	5·0	10·3	7·0	20·8	8·2
Puero	0– 6	9·8	69·0	110·0	169·0	130·0	144·2	395·6	378·2	335·0	48·4	120·0	198·5	253·5	43·7	171·8
	6–12	8·5	90·0	90·6	143·0	164·5	180·0	151·0	167·5	125·2	255·0	262·0	146·5	199·0	190·7	155·2
	12–18	4·1	10·8	16·3	14·1	24·9	33·8	30·9	39·6	29·0	134·7	130·5	78·0	79·5	115·0	52·9
	18–24	4·0	3·3	4·0	14·9	5·0	10·3	22·6	48·3	12·9	22·8	35·8	26·1	19·5	44·2	19·5
Stylo	0– 6	2·1	2·0	22·3	27·5	33·5	82·8	85·0	80·0	120·7	42·5	9·1	94·7	134·5	26·2	54·5
	6–12	2·1	13·7	66·6	32·4	59·7	97·2	76·8	86·2	47·8	67·0	38·9	69·0	67·8	61·2	56·2
	12–18	1·5	nil	7·0	5·4	30·1	29·1	23·1	23·0	13·4	35·2	24·5	34·2	32·4	41·2	21·4
	18–24	0·8	nil	nil	5·5	nil	11·9	7·4	20·3	5·3	11·5	3·8	9·2	4·3	12·0	6·6
Rainfall between Sampling Dates in Inches		nil	1·73	nil	nil	1·13	nil	nil	0·02	nil	5·14	1·09	2·01	0·72	5·72	..

acid method, the results being expressed as parts per million of nitrogen in the dry soil. Sampling at intervals ranging from 10 days to 27 days was continued for a period of approximately seven months, at the end of which time the heavy rains characteristic of the beginning of the wet season in the South Johnstone area commenced.

A similar system of soil sampling to that employed for the perennial legumes was carried out on alternate dates on an adjacent area of giant cowpeas which had been ploughed under. The cowpeas formed a good cover, with green matter estimated at 12-15 tons per acre.

COMPARISON OF NITROGEN AFTER PERENNIAL TROPICAL LEGUMES AND UNDER BARE FALLOW.

The legumes were ploughed under on July 2, 1941, and the first nitrate determinations were made six days later. Table 1 summarizes the results and a graphical representation of nitrate nitrogen at each depth throughout the experiment is shown in Figures 1-4.

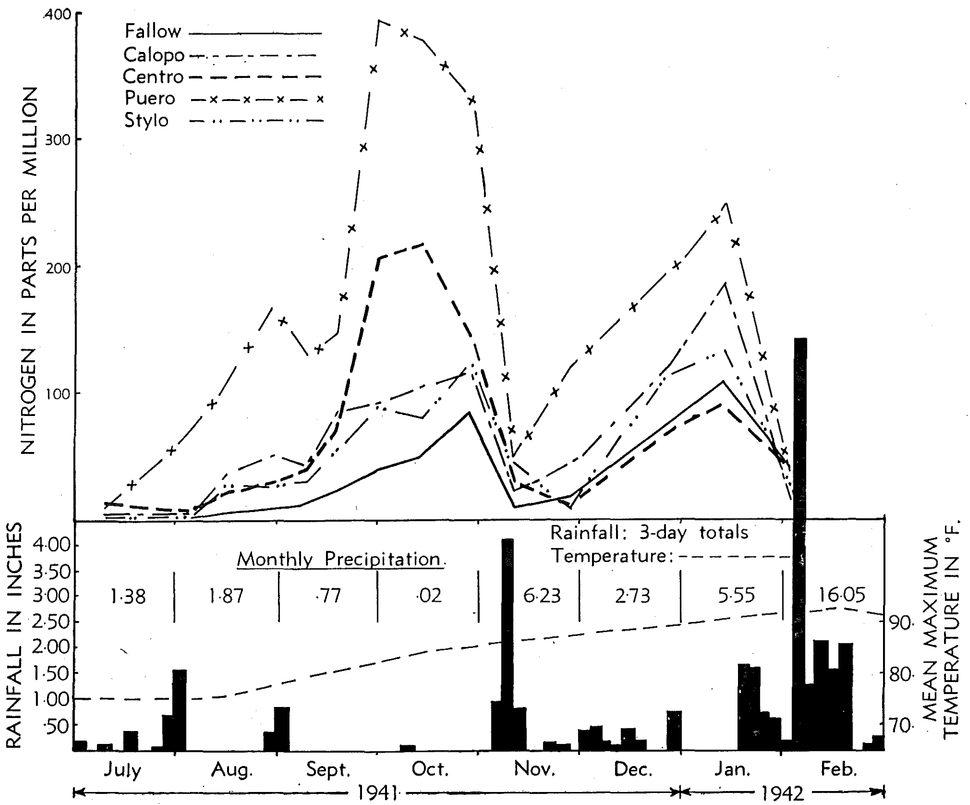

Figure 1.

Showing nitrate nitrogen in the 0-6 inch layer of soil in each treatment, with rainfall in 3-day totals and the mean maximum monthly temperatures.

Nitrate Nitrogen in the 0–6 inch Layer.

On August 4, the mean nitrate nitrogen figure obtained from the puero plots was 69 p.p.m., compared with calopo 3·5 p.p.m., centro 5·3 p.p.m., stylo 2·0 p.p.m. and bare fallow nil. Ten days later, the soil in the puero plots contained 110 p.p.m., compared with calopo 39.2 p.p.m., centro 20·2 p.p.m., stylo 22·3 p.p.m. and bare fallow 5·2 p.p.m. By August 28, the first peak was reached in the puero plots, the mean figure being 169 p.p.m. Between August 28 and September 9—the next sampling date—1·13 inches of rain were recorded, and this precipitation was responsible for leaching nitrates from the 0-6 inch layer to the deeper layers (see Figures 1 and 2).

On October 1—a little more than 12 weeks from the date of ploughing-in the green manures—the second and highest peak value for nitrate nitrogen in the puero plots was reached, namely, 395·6 p.p.m. Centro attained its peak with a figure of 219·5 p.p.m. on October 13. The corresponding values on October 1 in the other treatments were :—Calopo 96·7, centro 203·2, stylo 85·0 and bare fallow 40·0. Nitrate production remained at a high level in all treatments throughout October, November, December and January, months of high temperature and relatively low precipitation, until the commencement of the wet season in early February. Between October 27 and November 11, rainfall amounting to 5·14 inches was recorded, and considerable leaching of surface nitrates occurred, especially in the puero plots. On October 27 there were 335 p.p.m. of nitrate nitrogen in the surface 6 inches of the puero plots, but by November 11 the figure had receded to 48·4 p.p.m., whereas the corresponding values in the 6-12 inch layer were 125·2 and 255·0 p.p.m. respectively.

It is of interest to note the high positive correlation which exists between precipitation and the leaching of nitrate nitrogen from the surface 6 inches to the lower layers of soil as shown by a comparison of Figures 1, 2 and 3. Each reduction in nitrate nitrogen caused by rainfall-leaching in Figure 1 is represented in Figure 2 by a proportionate increase, and after heavy rainfall—as, for example, during the first fortnight of November, when 5.96 inches were recorded—there is a marked peak in the 6–12 inch and 12–18 inch layers, as shown in Figures 2 and 3. A third peak was reached in the puero plots on January 13, with 253·5 p.p.m.; the corresponding values in the other treatments were calopo 187, centro 91·4, stylo 134·5 and bare fallow 108. This last value approximates to the figure of 105 p.p.m. found by Thompson and Coup (1943) in the soil of a bare-ground control plot under New Zealand conditions.

A further point is that a peak of nitrate nitrogen in all plots is reached before October 27, but centro and puero are distinctly more effective during this period than are calopo and stylo. The plots of the first two legumes reached their maximum content of nitrate nitrogen before mid-October, whereas the calopo and stylo plots do not attain their maxima until January 13, a date which also marks the zenith nitrate nitrogen value for bare fallow.

The mean values for nitrate nitrogen in the different treatments have been examined by the method of analysis of variance, and the F value for varieties was found to be 16·94, which is highly significant. The results are summarized in Table 2. Figure 1 shows the pattern of nitrate nitrogen content from July to February, together with the rainfall and temperature data for that period.

Table 2.

MEAN VALUES FOR NITRATE NITROGEN IN THE 0–6 INCH LAYER OF SOIL IN THE VARIOUS TREATMENTS.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	34·4	43·1
Calopo			66·7	83·6
Centro			71·7	89·9
Puero			171·8	215·2
Stylo			54·5	68·3
General Mean	..	..	79·8	100·0
S.E. Mean of two ..	..	..	13·0	16·2

Sig. diff. P. = 0·05 .. .. 63·8
Sig. diff. P. = 0·01 .. .. 105·8

Conclusion : Puero > all others (1 % level).

Reference to Table 1 shows that, apart from the first and last sampling dates (July 8 and Feb. 2), nitrate nitrogen values in the puero plots at each depth are much higher than the corresponding values for other treatments. The mean value for the puero plots at each depth exceeds the highest of the other treatments by over 100 per cent. Cochran (1938) has pointed out that it is a good rule "to omit from the main analysis treatment which yield consistently more than double or less than half the main group of treatments." This method has been applied to the figures in this experiment, but no additional information of value was obtained.

The outstanding points of interest relative to the nitrate nitrogen content of the 0–6 inch layer which may be deduced from an examination of the data are as follows:—

(1) The very rapid rate of production of large amounts of nitrate nitrogen in the puero plots throughout the experiment, which extended over nearly seven months.

(2) The high production during October in the puero and centro plots.

(3) The relatively high production during January in the calopo plots.

(4) The increase from October to January which occurs in the fallow plots.

(5) The considerable amount of leaching from the surface 6 inches to the lower soil layers caused by rainfall on the light silty soil (40 per cent. fine sand, 31 per cent. silt, 16 per cent. clay).

Nitrate Nitrogen in the 6–12 inch Layer.

The nitrate nitrogen determinations on samples taken at 6–12 inches below the surface are summarized in Table 3 and the results are shown graphically in Figure 2. The means have been analysed statistically and the F value for varieties was found to be 209·97, which is very highly significant.

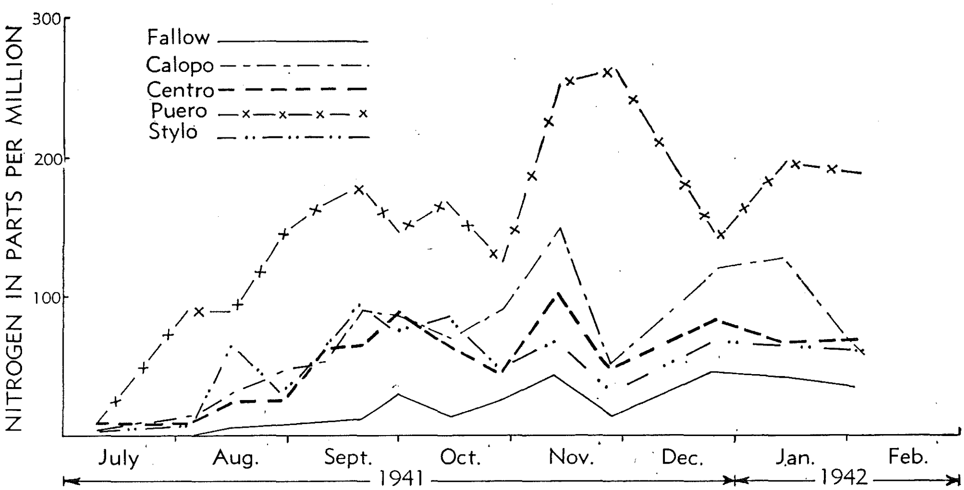

Figure 2.

Showing nitrate nitrogen in the 6-12 inch layer of soil in each treatment.

Table 3.

Mean Values for Nitrate Nitrogen in the 6–12 inch Layer of Soil in the Various Treatments.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	21·2	29·4
Calopo			72·7	100·7
Centro			55·6	77·1
Puero			155·2	215·0
Stylo			56·2	77·8
General Mean	..	..	72·2	100·0
S.E. Mean of two ..	..	..	3·5	4·8

Sig. diff. P. = 0·05 .. .. 18·8
Sig. diff. P. = 0·01 .. .. 31·1

Conclusions : (1) Puero > all others (1% level) ; (2) Calopo, Centro, Stylo > Fallow (1% level) ; (3) Calopo > Centro, Stylo (5% level).

The nitrate nitrogen content in all treatments follows the same general trend throughout. The very high concentration in the 6–12 inch layer from late July to early February, and in particular from November to early February, indicates the remarkably high degree of nitrification which is occurring in the puero plots. A maximum content of 262 p.p.m. was reached on November 28, following heavy rains in the first half of the month.

The nitrate nitrogen content in the calopo plots follows a similar pattern to that of the puero plots, but the level is much lower. The maximum content was reached on November 11, when 151·2 p.p.m. was registered. The centro plot reached its maximum on the same date, with 102·2 p.p.m. The stylo plots, however, attained their maximum on September 19, with 97·2 p.p.m. The fallow plots show a steady increase from early August to early February, with peaks of 29·9 p.p.m. on October 1, 41·7 p.p.m. on November 11, and 46·2 p.p.m. on December 24.

Nitrate Nitrogen in the 12–18 inch Layer.

The means of the determinations of nitrate nitrogen in the 12–18 inch layer are given in Table 4 and the data is shown graphically in Figure 3. The figures have been statistically analysed: the F value for varieties was found to be 29·42, which is highly significant.

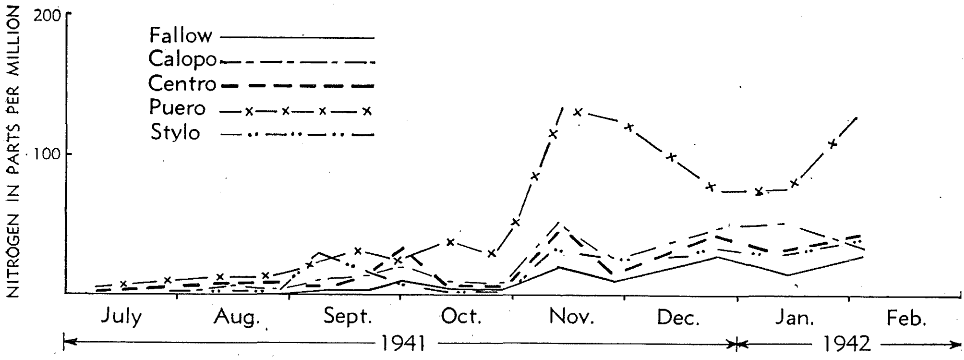

Figure 3.

Showing nitrate nitrogen in the 12-18 inch layer of soil in each treatment.

Table 4.

Mean Values for Nitrate Nitrogen in the 12–18 inch Layer of Soil in the Various Treatments.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	9·6	37·6
Calopo			22·8	89·1
Centro			21·3	83·0
Puero			52·9	206·4
Stylo			21·5	83·8
General Mean	..	..	25·6	100·0
S.E. Mean of two ..	..	..	3·0	11·6

Sig. diff. P. = 0·05 .. .. 45·6

Sig. diff. P. = 0·01 .. .. 75·6

Conclusions : (1) Puero > all others (1% level); (2) Calopo, Stylo > Fallow (5% level); (3) difference between Centro and Fallow is approaching significance (5% level).

Nitrate Nitrogen in the 18–24 inch Layer.

Table 5 shows the means of nitrate nitrogen content in the 18–24 inch layer, and the data are shown graphically in Figure 4. The F value for varieties was found on statistical analysis to be 47·21, which is highly significant.

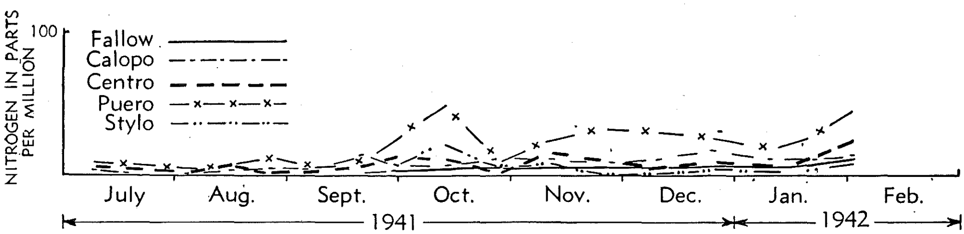

Figure 4.

Showing nitrate nitrogen in the 18-24 inch layer of soil in each treatment.

Table 5.

MEAN VALUES FOR NITRATE NITROGEN IN THE 18–24 INCH LAYER OF SOIL IN THE VARIOUS TREATMENTS.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	3·6	39·2
Calopo			8·0	87·1
Centro			8·2	89·2
Puero			19·6	212·7
Stylo			6·6	71·8
General Mean	..	..	9·2	100·0
S.E. Mean of two ..	..	..	0·9	9·6

Sig. diff. P. = 0·05 .. .. 37·8
Sig. diff. P. = 0·01 .. .. 62·6

Conclusions : (1) Puero > all others (1% level) ; (2) Calopo, Centro > Fallow (5% level).

DISCUSSION OF FACTORS AFFECTING NITRATE PRODUCTION.

The main factors which affect nitrification, apart from the soil type, are the bulk and the composition of the green manure at the time of ploughing under (both of which are influenced by the efficiency of the associated symbiotic nitrogen-fixing organisms), and the soil moisture content and temperature throughout the period of decomposition.

Yield.

Duplicate quadrat cuts from each plot of the four legumes were made on July 2, 1941 so that an estimate of the yield of green matter could be calculated before the legumes were ploughed under. The respective yields of green matter in pounds per plot calculated from the mean of four quadrat cuts for each legume are given in Table 6.

Table 6.

CALCULATED YIELD OF GREEN MATTER.

Legume.	Yield in Lb. of Green Matter per Plot.	Percentage of Mean.
Calopo	286	87·6
Centro	239	73·2
Puero	527	161·4
Stylo	254	77·8

These figures include a small, but practically negligible amount, of dead leaves which had accumulated under the legumes, particularly in the calopo, centro and puero plots. The quantity of dead foliage was very small for two reasons: (1) the quadrat cuts were taken at the end of the wet season, and (2) the legumes had been established for less than 18 months.

An outstanding feature of the yields is the large amount of green matter obtained from puero in comparison with the other legumes. As a matter of interest, it may be mentioned that yields varying from 7·0 to 9·1 tons of green matter per acre have been recorded at South Johnstone for stylo at the fourth cut, 18 months after planting; and that after 5 years (in February, 1945) puero carried foliage estimated (mean of five quadrat cuts) at 11·5 tons of green matter and provided 18.8 tons of mulch per acre.

Chemical Composition of the Plant Material.

Chemical analyses of the perennial legumes employed have been carried out at the Bureau of Tropical Agriculture and in the Agricultural Chemical Laboratory of the Department of Agriculture and Stock on numerous occasions, and typical figures are set out in Table 7.

Table 7.

PERCENTAGE COMPOSITION ON A MOISTURE-FREE BASIS OF CALOPO, CENTRO, PUERO, AND STYLO GROWN AT SOUTH JOHNSTONE.

Legume.	N.	Protein. (N. x 6·25)	Fat.	Carbo-hydrates.	Fibre.	Ash.	CaO.	P_2O_5
Calopo	3·1	19·5	1·2	40·2	31·1	8·0	2·117	0·584
Centro	3·0	18·7	3·0	38·4	30·3	9·6	2·590	0·802
Puero	3·1	19·5	1·2	38·6	34·2	6·5	1·047	0·607
Stylo (old)	2·3	14·6	1·3	37·8	38·6	7·7	1·505	0·570

The figures show that calopo, centro and puero contain considerably more nitrogen than stylo, but that stylo possesses the highest fibre content. Waksman (1932) stated:—"Whenever a readily available source of nitrogen is wanted immediately, substances containing less than 2 per cent. nitrogen cannot be profitably used. The greater the nitrogen content of a material, the greater is its value as an immediate source of nitrogen." Parbury and Swaby (1942), reporting the results of experiments with a large number of plants, stated that "an early return of nitrogen, coinciding with the demands of crops planted soon after their incorporation, was secured only when the nitrogen content of materials was above 2·5 per cent."

The carbon : nitrogen ratio of the plant material also affects nitrate production, and Akhurst (1932) suggested that a ratio considerably below 18 :1 is necessary under tropical conditions for nitrification to take place. For Calopogonium and Centrosema he has calculated ratios as shown in Table 8. No figure is available for puero, but the fact that this legume produced extremely large quantities of nitrate nitrogen when turned under indicates that the relatively large amount of green matter was readily decomposed.

Table 8.

C : N RATIO OF THE LEAVES AND STEMS OF CALOPOGONIUM AND CENTROSEMA (FROM AKHURST, 1932).

Leaves.			Stems.		
Per Cent. N.	Plant.	C/N.	Per Cent. N.	Plant.	C/N.
4·47	Calopogonium	10·3	2·52	Calopogonium	17·3
4·38	Centrosema	10·6	3·03	Centrosema	14·2

The equivalent weights of nitrogen, P_2O_5 and CaO per plot have been calculated on the basis of a 35 per cent. dry matter content (dry matter figures exceeding 35 per cent. have been recorded for some of the legumes at South Johnstone for the drier months of the year) and the results are given in Table 9.

Table 9.

EQUIVALENT DRY MATTER WEIGHTS PER PLOT OF N, P_2O_5 AND CaO FOR CALOPO, CENTRO, PUERO AND STYLO.

Legume.	Yield of Dry Matter in Pounds per Plot. (35 Per Cent. Basis.)	Equivalent Weight in Pounds per Plot.		
		N.	P_2O_5	CaO.
Calopo	100·1	3·1	0·58	2·12
Centro	83·6	2·5	0·67	2·16
Puero	184·4	5·7	1·12	1·93
Stylo	88·9	2·0	0·51	1·34

These figures demonstrate the remarkably high nitrogen and P_2O_5 equivalent weights obtained from puero. The CaO figure for puero is rather low at 1.047 per cent., as contents approximating to 2·0 per cent. have been obtained in a number of analyses.

It is well known that nitrification may be adversely affected by a relative poverty in available phosphoric acid, and it can be expected, therefore, that a high concentration of P_2O_5 in the green material turned under in the puero plots will assist nitrification to a considerable degree, even though this soil is low in phosphate. Similarly, the lime application referred to previously and the lime content of the legumes will assist nitrification.

Symbiotic Nitrogen Fixation.

No investigation of the efficiency of the nitrogen-fixing organisms associated with the various legumes was made. Trials carried out prior to the initiation of the experiment (Schofield, 1941) indicated that inoculation of the seed of the species used in the experiment did not result in increased growth or vigour as compared with plants raised from uninoculated seed. It was concluded that the soil did not lack appropriate strains of Rhizobia.

In this connexion, it is of interest to review briefly published work on the status of root nodule bacteria of the species of legumes concerned. Allen and Allen (1936, 1939) placed stylo in the cowpea group. Beeley (1938), working in Malaya, showed that Rhizobium isolated from puero produced no nodulation or other beneficial effect when inoculated on the roots of centro. Aquina and Madamba (1939) in the Philippines demonstrated that nodule bacteria from calopo produced fairly abundant nodules on cowpea. Posadas (1941) placed puero in the cowpea group, and showed that the puero strain of Rhizobium fixed less nitrogen than strains isolated from two species of *Crotalaria* and two species of *Tephrosia.*

Temperature and Moisture.

Joachim (1926), working in Ceylon on a sandy loam with a sand content of 75 per cent. and adding the equivalent of 10 tons of various green manures per acre, found that (1), maximum nitrification occurred at the end of the sixth week; (2), provided sufficient rainfall is experienced and under ordinary tropical conditions, the effects of green-manuring from the nitrogen standpoint last only about six months; (3), the amount of nitrate present at any particular time in the green manure plots is dependent on the rainfall in the previous fortnight; and (4), the temperature curve, so far as was obtainable, follows the nitrate curve.

At South Johnstone, the low monthly mean temperature in July and the gradual increase to a maximum in February, together with the considerably greater quantities of green manures turned in under relatively dry winter conditions, resulted in nitrification reaching its peak in the puero plots after 12 weeks and in the centro plots after 14 weeks; with the other legumes the first peak occurred after 16 weeks and maximum nitrification did not take place until 27 weeks had elapsed, after which the wet season commenced.

Jenny (1941) pointed out that published nitrogen analyses of tropical soils show that some soils are low in organic matter because high temperatures hasten the decomposition of plant residues, whereas other soils in low latitudes are exceptionally rich in humus as a consequence of high yields of luxuriant flora. He stated that "reasoning based on van't Hoff's law should deal with soil types of comparable moisture and kinds of vegetation." With large quantities of green manure—such as are obtained from puero—and a gradual rise of mean maximum temperature from 75·3 deg. F. in July to 92·7 deg. F. in February, an increasing rate of decomposition can therefore be expected.

No soil moisture determinations were made during the course of this experiment, but it is clear that there was sufficient moisture in the soil after the wet season, together with the rainfall experienced during July to November, to enable cconsiderable nitrification to occur. From November to early February the increased rainfall affected nitrification by depressing it immediately after heavy falls, and by producing a rapid rise in the rate of nitrification within three or four weeks after heavy rain until the wet season commenced.

Table 10.

Nitrate Nitrogen (Mean of Two Determinations) in each Layer of Soil in Each Treatment Compared With Cowpea.

Treatment.	Soil Layer.	Date of Sampling and Nitrogen in Parts per Million.						
		Aug. 14.	Sept. 9.	Oct. 1.	Oct. 27.	Nov. 28.	Jan. 13.	Mean.
	Inches.							
Fallow ..	0–6	5·2	11·8	40·0	85·0	18·7	108·0	44·8
	6–12	4·1	10·9	29·9	25·0	18·2	42·4	21·7
	12–18	1·2	2·2	10·9	5·4	13·3	18·3	8·5
	18–24	..	..	2·7	4·4	4·7	6·3	3·0
Calopo ..	0–6	39·2	42·0	96·7	119·8	42·0	187·0	87·8
	6–12	34·3	55·7	83·6	95·0	57·0	128·5	75·7
	12–18	7·2	15·3	21·2	10·8	26·8	56·1	22·9
	18–24	1·2	2·6	3·5	13·1	7·2	13·1	6·8
Centro ..	0–6	20·2	40·4	203·2	141·3	15·2	91·4	85·3
	6–12	26·4	61·7	83·0	46·3	49·0	70·3	56·1
	12–18	7·4	12·2	34·6	10·3	17·9	35·6	19·7
	18–24	3·3	4·5	13·0	4·6	5·0	7·0	6·2
Puero ..	0–6	110·0	130·0	395·6	335·0	120·0	253·5	224·0
	6–12	90·6	164·5	151·0	125·2	262·0	199·0	165·4
	12–18	16·3	24·9	30·9	29·0	130·5	79·5	51·8
	18–24	4·0	5·0	22·6	12·9	35·8	19·5	16·6
Stylo ..	0–6	22·3	33·5	85·0	120·7	9·1	134·5	67·5
	6–12	66·6	59·7	76·8	47·8	38·9	67·8	59·6
	12–18	7·0	30·1	23·1	13·4	24·5	32·4	21·7
	18–24	..	..	7·4	5·3	3·8	4·3	3·5
Cowpea ..	0–6	38·5	40·5	91·5	132·0	29·3	179·5	85·2
	6–12	31·7	27·0	51·0	27·2	44·3	89·2	45·1
	12–18	4·3	1·6	8·4	6·6	18·1	25·3	10·7
	18–24	1·8	1·4	8·4	5·7	7·7	8·1	5·5
Rainfall (Between Sampling Dates) in Inches ..		1·73	1·13	nil	0·02	6·23	2·73	..

COMPARISON OF NITROGEN AFTER COWPEAS AND AFTER TROPICAL PERENNIAL LEGUMES AND UNDER BARE FALLOW.

Concurrently with the soil sampling carried out in the perennial tropical legume plots described previously, samples were taken from two plots in an adjacent area of giant cowpeas. The cowpeas were ploughed under in June and the soil sampling was carried out in the same manner as with the tropical legumes but on alternate dates only from August 14, 1941, to January 13, 1942, giving a total of six samples at each of four different depths. Although the cowpeas were situated adjacent to the perennial tropical legume experiment they did not form part of it, and therefore the results cannot be examined statistically against the corresponding figures for the legume plots. However, as the soil type, the climatic conditions and the sampling dates were identical, it is of interest to compare the nitrate nitrogen values of the six samplings in the cowpea plots with the values calculated for the perennial tropical legumes and bare fallow on the same six dates. The values are shown in Table 10. The mean figures for calopo, centro and giant cowpeas in the 0–6 inch layer are practically the same; in fact, there is little difference between the nitrate nitrogen content for any layer—with the exception of the low figures for cowpeas in the 6–12 inch and 12–18 inch layers—of any of these three legumes or of stylo. Table 11 shows the mean nitrate nitrogen at four different depths for the four perennial tropical legumes, giant cowpeas and bare fallow for six sampling dates.

These figures suggest that (1), puero after 18 months' growth is greatly superior to giant cowpeas grown as a short-term summer green manure as a source of nitrate nitrogen under the conditions in the two plots; and (2), cowpeas are not superior to calopo, centro or stylo when the perennial legumes are grown for a period of 18 months. These results cannot be tested statistically, however, and a definite statement as to the relative merits of cowpeas and the various tropical perennial legumes must await further field experimentation.

NITROGEN CHANGES UNDER BARE FALLOW IN THE WET TROPICS.

From the results of the nitrate nitrogen determinations, summarized in Table 1, the following conclusions relative to the bare fallow plots may be drawn:—

(1) Nitrate nitrogen production did not commence until mid-August; i.e., 2½ months after the close of the wet season at the end of May.

(2) Production was slow until mid-September.

(3) The first peak in the surface 6 inches—equivalent to 85 p.p.m. of nitrogen—was reached at the end of October.

(4) Rainfall amounting to 6·23 inches in November caused heavy leaching from the surface 6 inches to lower soil layers and served to depress production of nitrate temporarily.

(5) The highest peak (108 p.p.m.) occurred on January 13—21 weeks from the time at which production commenced.

(6) The mean monthly maximum temperature increased steadily during this period of increasing nitrate content from 80·2 deg. F. in September to 91·3 deg. F. in January.

(7) From November onwards the increase in rainfall caused a considerable increase in soil moisture content, and after the temporary reduction in nitrate production referred to in (4) there followed a rapid rise in nitrate nitrogen content until the wet season commenced in February.

(8) The wet season served to inhibit the various factors which promote nitrate nitrogen production.

Table 11.

MEAN VALUES FOR NITRATE NITROGEN FOR SIX SAMPLING DATES AT FOUR DIFFERENT DEPTHS FOR ALL TREATMENTS.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen p.p.m.			
			0–6 Inches.	6–12 Inches.	12–18 Inches.	18–24 Inches.
Fallow	14–8–41 to 13–1–42	6	44·8	21·8	8·6	3·0
Calopo			87·8	75·7	22·9	7·1
Centro			85·3	56·9	19·7	6·3
Puero			224·0	165·4	51·9	16·6
Stylo			67·5	59·6	21·8	3·5
Cowpea			85·2	45·1	10·7	5·5

The production of nitrate nitrogen in bare-fallowed soils may be ascribed to several factors, including the decomposition of residues of weeds and previous crops, the decomposition of humus, the deposition of inorganic nitrogen by rainfall, and the fixation of nitrogen by non-symbiotic bacteria. The quantity of nitrogen added as ammonia and nitrates through the agency of rain may be estimated at from 7 to 10·5 lb. per acre per annum, judging by results obtained in Ceylon (Koch, 1941, 1943) and in other parts of the tropics (Vageler, 1933). The data obtained in this experiment do not permit any estimate being made of the other three factors listed. It must be pointed out, however, that the periodic weeding of the bare fallow plots provided plant material in a readily decomposable form, and that the lime and fertilizer applications made before the experiment commenced provided conditions favourable to bacterial activity. The high content of nitrate nitrogen—108 p.p.m.—in the bare fallow plots on January 13 suggests that non-symbiotic nitrogen-fixing organisms may have been active during the summer months. Additions of available nitrogen variously estimated at from 15 lb. to 40 lb. per acre per annum under favourable conditions have been credited to various bacteria, including *Azotobacter* spp., although the figure is usually not more than 10 lb. No examination of the microflora of the soil of the experimental area was made, but neither soil nor climatic conditions would rule out the occurrence of nitrogen-fixing bacteria, as a species of Azotobacter capable of fixing nitrogen in acid soils is known (Starky and De, 1939), and Azotobacter has a wide distribution in the tropical region of Malaysia (Corbet, 1935). But, as Waksman (1932) has pointed out: "in many cases, the actual amount of nitrogen fixed falls within the probable error for the determination of total nitrogen."

With respect to leaching, it is of interest to note that following five falls of rain totalling 5·14 inches spread over seven days prior to the sampling on November 11, the nitrogen content in the 12–18 inch layer was 20·5 p.p.m., an increase of 15·1 p.p.m. over the corresponding figure on October 27. On February 2, after eight falls of rain aggregating 5·72 inches spread over 15 days, the nitrate nitrogen content of the 12–18 inch layer was 26·9 p.p.m. and of the 18–24 inch layer 13·8 p.p.m.; these represent increases of 8·6 p.p.m. and 7·5 p.p.m. respectively over the corresponding values on January 13.

GENERAL DISCUSSION.

The outstanding facts which emerge from the investigation are:—

(1) The very high production of nitrate nitrogen which occurred over a period of seven months—from July to February—when a crop of puero 18 months old was ploughed under on a silty soil in the "wet tropics."

(2) The considerable nitrate nitrogen production which took place from mid-August to February in the bare fallow plots.

The effects of yield, composition, soil moisture and temperature on the rate and degree of nitrification have already been discussed in some detail. It remains, therefore, to consider the main implications of these results and their possible application.

A point of considerable importance in the building up of soil fertility under tropical conditions is the length of life of the legumes available for soil improvement purposes. Annuals are useful as temporary weed-smother crops and provide some available nitrogen for subsequent crops, and biennials offer distinct advantages over annuals; but loss of soil fertility under tropical conditions is often such that the most satisfactory method of bringing the soil back to good physical condition is by means of perennial legumes used as green manures. Furthermore, the fundamental importance of the grazing animal in building up soil fertility suggests that the optimum value of these perennial tropical legumes will probably be obtained when they are grazed under satisfactory management. Therefore, the ploughing under of perennial legumes should be preceded wherever possible by rotational grazing.

A further logical development would be the establishment of a temporary ley (Stapledon, 1939) to complete the building up of soil fertility before putting the land under crop again. Even under temperate conditions there is a necessity "for land being put down to grass for long periods if any prolonged gain in fertility is to result" (Richardson, 1938), and in the tropics the need is still more urgent.

Under conditions in the "wet tropics," puero—which is closely related to kudzu and is in fact its tropical counterpart—has proved to be a legume of outstanding value. It is used extensively in Malaya and Sumatra as a plantation cover crop to assist in maintaining soil fertility and in the prevention or control of erosion, and its ability to withstand light shade has extended its usefulness considerably. The results obtained in this experiment demonstrate that large quantities of nitrate nitrogen are produced rapidly during its decomposition after ploughing under a crop grown for 18 months; and this is quite apart from its value as a source of humus, which would not be inconsiderable.

Puero is easy to establish from seed or cuttings, and it is so aggressive that it has been used successfully as a weed-smother crop. Puero roots freely at the nodes under suitable conditions and forms a carpet over 2 ft. deep, completely covering the soil, shading it from the sun, preventing the direct impact of rain, and ensuring adequate protection against soil erosion. It is a rather shy seed-bearer, and thus little trouble from self-regeneration occurs when an area of the crop is ploughed and the land placed under cultivation. The beneficial effect on soil structure of the organic residues from the various legumes, especially puero, is a further factor of the utmost importance. West and Howard (1938) have pointed out that the structure of the soil under legumes was definitely better than under clean cultivation.

Puero is palatable and may be of special value as a pioneer legume in the rehabilitation of rain-forest areas which have been opened and planted to grass, but where the topography precludes ploughing as a means of overcoming weed-infestation prior to replanting. It may in addition be used with advantage on areas where ploughing can be undertaken, but where the soil is low in nitrogen and humus and weeds have taken possession; that is on worked-out, washed-out, "dead" soils. Experimental work has indicated that the planting of single or double-furrow strips, 10 ft. to 15 ft. apart on the contour, may be sufficient to allow puero to become established and smother out the weeds.

The results of this experiment indicate the unsuitability of stylo as a green-manure crop; it is, however, a very promising pasture legume. Calopo grows rapidly and seeds freely under conditions in the "wet belt" of coastal northern Queensland, and it shows promise as a short-term, summer-growing green manure. Centro possesses a wide climatic range of tolerance. Its ability to form a carpet of cover within six months on some of the poorer soils of the coastal belt as far south as Brisbane without fertilizer application, combined with its aggressive hardy nature and capacity to withstand coastal frost (although the young foliage and stems are killed), demonstrate the potential value of this species for erosion prevention or control, green-manuring and pasture work along the coastal fringe of Queensland.

The data given in this experiment for nitrate nitrogen production under bare fallow offer a partial explanation of the extremely rapid vegetative growth which is typical under coastal conditions in northern Queensland from November to March (Schofield, 1944). The steady increase of nitrate nitrogen from mid-August to mid-January, when the maximum is reached, combined with increased temperature, length of day, and rainfall, appear to be the factors which determine this rapid vegetative growth.

It is a matter of common observation in the maize-growing area of northern Queensland that, should there be even a slight delay in the planting of maize after the first good rain, the subsequent crop is much inferior to that planted immediately after good rain. The high concentration of nitrate nitrogen in the 0–6 inch and 6–12 layers of the soil prior to heavy rain, and the subsequent leaching effect which occurs when the heavy rains of the wet season commence, may explain this difference in growth.

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