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SOURCES OF NITROGEN FOR QUEENSLAND PASTURES

E. F. HENZELL*

INTRODUCTION

Three sources of nitrogen are discussed in this paper: (1) soil nitrogen, i.e. nitrogen accumulated in soil organic matter at some time in the past, (2) the nitrogen fixed by nodulated legumes, and (3) fertilizer nitrogen produced by industrial synthesis. The general practical experience, in Queensland and elsewhere, has been that high levels of pasture production invariably require a substantial supply of nitrogen from one or more of these three sources. They are not the only sources of nitrogen for pastures, e.g. it is known that some nitrogen is added to pasture soils by blue-green algae growing on the soil surface, by bacteria associated with decaying organic matter, and in rainfall, but they are far the most important.

The pastures of north-eastern New South Wales are also discussed in this paper, because that area, which lies to the east of the New England Plateau and extends south to about Coff's Harbour, forms part of the same ecological region for growth of pasture plants as south-eastern Queensland.

SOIL NITROGEN

This has been the main source of nitrogen for Queensland pastures from the time of first settlement to the present day. Most of the existing pastures can be classified as (1) native pastures, or (2) sown grasslands.

1. Native pastures. This group comprises the natural grasslands, such as the Mitchell grass (*Astrebla* sp.) pastures that grow in western Queensland and the grasslands that grow among the trees in the open woodlands of the spear grass (*Heteropogon* sp.) country, and the induced grasslands that develop when some or all the trees are killed. These pastures are all dominated by native Australian plants, though the proportion of the different species may have changed since first settlement, as a result of clearing, grazing, and regular burning.
2. Sown grasslands. These grasslands are found in areas that formerly carried dense forest or scrub without much or any native grass beneath the trees. They consist mainly of introduced grasses such as Rhodes (*Chloris gayana*), green panic (*Panicum maximum* var. *trichoglume*), paspalum (*Paspalum dilatatum*), mat grass (*Axonopus affinis*), Kikuyu (*Pennisetum clandestinum*), and buffel grass (*Cenchrus ciliaris*). Most of the pastures in the new brigalow developments fall in this group, as do most of the pastures used for dairying nearer to the coast.

One of the common features of both the native pastures and the sown grasslands of this State is that they are dominated by perennial grasses. The amount of native legume that occurs in unfertilized native pastures is almost always too low to supply a useful amount of nitrogen to the pasture. The legume content of the sown grasslands is also usually quite low, though some rain forest areas have grown good white clover (*Trifolium repens*), when they were newly-cleared. The sowing of fertilized grass-legume mixtures is a relatively recent development in Queensland and the area sown so far is quite small in relation to the total area of grazing land in the State. Even now, large areas of land are being sown to pure stands of grasses in the brigalow region.

*C.S.I.R.O. Division of Tropical Pastures, St. Lucia, Brisbane, Queensland 4067.

Another common feature of Queensland pastures is their relatively low protein content at most times of the year, and the large increases in growth that usually occur when nitrogen fertilizers are used. Brünnich (Anon., 1931) was the first to draw attention to the low protein content of Queensland grasslands and its consquences for animal production. The important effect of protein deficiency on livestock production in winter was clearly stated by Davies (1940), Miles (1939, 1949), and Christian and Shaw (1951). In contrast, the effect of nitrogen deficiency on total yield became obvious only during the last ten or fifteen years, when experiments showed that Rhodes grass, Kikuyu, and some of the native and naturalized grasses such as blue couch (*Digitaria didactyla*) and spear grass (*Heteropogon contortus*), can give much higher yields if they are supplied with adequate amounts of nitrogen and other nutrients. All this indicates that most Queensland pastures are very nitrogen-deficient.

The native pastures may have been nitrogen-deficient when the first sheep and cattle reached Queensland. The historical records are of little help because no scientific studies were made until the present century. Most of the changes in the pastures noted by the early settlers may have been caused by grazing alone, rather than nitrogen deficiency. However, one thing is certain: there has been very little change over the last 50 or 60 years, judging by the crude protein content of grass samples analysed by J. C. Brünnich, who was Agricultural Chemist with the Queensland Department of Agriculture and Stock from 1897 to 1931 (Anon., 1931). For instance, Brünnich (1929) recorded that 15 samples of mixed pasture analysed in 1914 contained an average of 6.3% crude protein, i.e. about 1.0% of nitrogen. Similar figures could be quoted for nitrogen-deficient grasses in Queensland in 1967.

On the other hand, some of the sown grasslands of paspalum, Kikuyu, and Rhodes grass apparently were well supplied with nitrogen when they were first planted on newly-cleared forest land. There are many records indicating that the rain forest lands of north-eastern New South Wales, southern Queensland, the Atherton Tableland, and the brigalow and softwood scrubs of the Burnett and Callide Valleys, grew good crops of grass when first cleared, and some of the rain forest areas grew good white clover too. But the story ever since has been one of declining production, accompanied by the ingress of less-productive grasses and unpalatable weeds (Davies, 1940; Hudson and Bird, 1964; Cassidy, 1966). There is no doubt that a declining nitrogen supply from the soil and from white clover is one of the main factors in this story, though deficiencies of phosphorus, potassium, and some of the trace elements are also involved (Colman, 1964; Jones, 1966a; Luck and Douglas, 1966; White, 1967).

Why are these Pastures so Nitrogen-Deficient?

The question is, why do pastures become so nitrogen-deficient when they are dependent on soil organic matter as a source of nitrogen. To answer this question, we need to make a clear distinction between the total quantity of nitrogen in a soil, most of which is inert, and the relatively small fraction of it that is converted to a mineral form (usually ammonium or nitrate) during a single growing season. Pasture growth depends directly on the availability of mineral nitrogen and is only indirectly related to the total quantity of soil nitrogen.

The suggestion has often been made that the declining productivity of sown grasslands in Queensland has been caused by the removal of nutrients in animal products, but I am sure this is not the reason why these grasslands become nitrogen-deficient. For instance, the quantity of nitrogen retained in the bodies of cattle is about 2.4 lb per 100 lb liveweight (Agricultural Research Council, 1965). Combining these figures with practical carrying capacities and rates of turn-off for unfertilized grassland makes it clear that the drain of nitrogen from sale of cattle is always less than 10 lb an acre a year and often less than 5 lb. The removal of nitrogen from sale of whole milk is a little higher but still likely to be less than 10 lb an acre a year.

This rate of loss is too slow to have much effect on the total nitrogen content of soils in less than a hundred years or so.* G. D. Hubble and A. E. Martin (unpublished data) have calculated the total amount of nitrogen contained in the profile of representative Queensland soils; their figures range from 4100 lb an acre for the podzolic and podzol soils found in coastal Queensland to 21,600 lb an acre for some red kraznozem soils under rain forest.

There is no evidence that the total amount of nitrogen in nitrogen-deficient grassland soils ever falls to a very low level. McGarity (1959) found that the total nitrogen in the surface horizons of the red soils (kraznozems) used for dairying at Lismore decreased by about 20% during a period of 60–80 years after clearing from rain forest. Most of the decrease apparently occurred just after clearing, and 60–80 years later the soil still contained about 10,000 lb of nitrogen an acre in the surface horizon.

The real problem is that soil nitrogen is mineralized too slowly to satisfy the requirements of (potentially) high-yielding pasture grasses. The problem is not restricted to grassland soils. It is now clearly recognized in many parts of the world that soil nitrogen is insufficient for maximum crop yields, even in areas with soils that were initially very fertile. Because perennial pastures occupy the ground all year, they have a higher potential yield and a higher potential nitrogen requirement than most annual crops. In particular, the tropical grasses have a remarkable capacity for rapid growth and high yields. Furthermore, there are indications that grasses tend in some way to reduce the amount of mineral nitrogen that is available for plant growth in grassland soils.

The rate of mineralization of soil nitrogen under grassland (calculated for the whole profile) may be less than one percent per annum. For example, in experiments with blue couch grass at Samford (my own unpublished results) and the run-down paspalum pasture at Lismore (McGarity, 1959) less than one percent of the soil nitrogen was released annually for grass growth. At Katherine, where the soil profile contains about 3000 lb of nitrogen an acre, Norman (1966) found that only about 7 lb per annum were available for pasture growth.

Thus the practical conclusion is that soil nitrogen will not maintain high levels of grass production, except for short periods on well-fallowed or newly-cleared land. In fact it is one of the axioms of pasture research that high production can be maintained only by a continual input of nitrogen either from legumes or fertilizers.

NITROGEN FIXATION BY NODULATED LEGUMES

The main emphasis of pasture research in Queensland has been on the search for and development of tropical legumes that will provide a cheap source of nitrogen for pasture improvement. This research has now reached the stage where the use of legume-based pastures is profitable (Haug and Hirst 1967; Moore 1967), and significant areas of plants such as Townsville lucerne (*Stylosanthes humilis*) and Siratro (*Phaseolus atropurpureus* cv. Siratro) are being sown commercially.

*Loss of nitrogen by leaching or by volatilization into the air is more likely to have an important effect, particularly when nitrogen is transferred in dung and urine from pasture land to camps or night paddocks.

First, the role of legumes in legume/grass pastures needs to be defined. The increased rates of liveweight gain that occur, for example, when Townsville lucerne is introduced into spear grass pasture and fertilized with, say, molybdenized superphosphate, can be attributed to the effects of:

1. The legume as a feed, supplying more protein, energy, and minerals than the spear grass.
2. Changes in the feed value of spear grass and weeds caused by:
   (a) An increased nitrogen supply originating from the legume.
   (b) The effect of the fertilizer added for the Townsville lucerne.
   (c) A different frequency and intensity of grazing in the new situation.

Only the protein components of factor 1 and factor 2a are directly concerned with nitrogen. Consequently, a simple, direct relationship between animal production and nitrogen fixation in legume-based pastures would not be expected. A small amount of legume often seems to have an effect on animal production out of all proportion to the rate at which it fixes nitrogen, probably because it corrects a dietary protein deficiency.

How Much Nitrogen is Fixed?

Instead of listing the results of specific experiments, I have chosen to present a general argument that indicates the range of nitrogen fixation rates to be expected from tropical pasture legumes.

Consider the nitrogen in the legume plants, which comes either from the air (i.e. nitrogen gas fixed in root nodules) or from the soil (i.e. mineral nitrogen absorbed by the roots). If one measures the gross amount of nitrogen taken in by the legume plants during a season's growth, and measures how much of this has come from mineral nitrogen in the soil, nitrogen fixation can then be determined by difference. First, we need to know how much nitrogen is accumulated by pasture legumes from both sources. This can be calculated from dry matter yields and percentage nitrogen contents.

Table 1 lists the dry matter yields of legumes in fourteen experiments or sets of experiments carried out in Queensland or north-eastern New South Wales. These figures are for established pastures that were intermittently grazed or mown, and they refer to yields of tops. They all fall within the range 100–8000 lb an acre a year, except for the Peru variety of leucaena (*Leucaena leucocephala* cv. Peru), which yielded 11,200 lb an acre a year at Samford (Hutton and Bonner, 1960). The figures in Table 1 are quite variable. I have used 1000–5000 lb an acre a year as the average range of yields under practical grazing conditions, and 8000 lb as representing very good legume growth. Account must also be taken of the nitrogen accumulated in the stubble and roots. Precise figures for yields of stubble and roots are not available, but some measurements on Siratro in pots (Henzell *et al.*, 1968) indicate that the top yields might need to be increased by about 50% to convert them to a whole-plant basis. Using this figure of 50% gives estimated whole-plant yields of 1,500–7,500 lb an acre a year for average legume growth and 12,000 lb for good legume growth.

Analyses of Siratro and Townsville lucerne plants, including roots, indicate that the nitrogen content of these legumes usually falls within the range 2.0–3.0%.

TABLE 1

Dry matter yields from tropical pasture legumes

Legume	Site	Yield (lb an acre a year)	Remarks	Reference
Townsville lucerne	Rodd's Bay	200 – 800	Cut in April; three years' data	Shaw, 1961
" "	"	1,300 – 5,800	Single cut; two years' data	Shaw, Gates and Wilson, 1966
" "	Lansdown	100 – 5,000	Two years, one very dry; low yield on solodic soil	Cameron, 1967
Siratro	Samford	5,600 – 7,900	F_3 families; one year	Hutton, 1962
"	"	1,400 – 6,500	Yield increased with interval between cuts	Jones, 1967a
"	Howard	7,700	Average for three years	Evans, 1967a
Lotononis	Beerwah	up to 4,600	One cut at end of summer	Bryan, 1961
"	Samford	2,600	Average for four years	Jones, Griffiths Davies and Waite, 1967
"	Howard	4,700	Average for three years	Evans, 1967a
Clarence glycine, desmodiums, Siratro, lotononis	Richmond-Tweed	1,500 – 4,500	–	Mears, 1967
Silverleaf desmodium	Beerwah	up to 4,500	When well-established	Andrew and Bryan, 1958
Glycine javanica introductions	Lawes and Lansdown	900 – 4,500	Averages for three or five years	Edye, 1967
Leucaena-Hawaii	Samford	1,300	One year; stems 0.25 in. or less in diameter were harvested	Hutton and Bonner, 1960
" - Peru	"	11,200	"	"
Leichardt dolichos	North Queensland	Up to 6,000	–	Staples, 1966

Adopting a figure of 2.5%, and multiplying by the dry matter yields quoted above, gives the following estimates of gross nitrogen yield:

Average legume growth: 37.5–187.5 lb of nitrogen an acre a year.

Good legume growth: 300 lb of nitrogen an acre a year.

Next, we need to know how much of this nitrogen has been taken up in mineral form from the soil. The rate of release of old soil nitrogen has already been discussed; it is usually less than one percent per annum, provided one is not dealing with fallowed or newly-cleared land. Let us assume that 0.5% is made available annually. Since most Queensland soils contain less than 10,000 lb an acre to the depth of root penetration, 50 lb an acre a year is the upper limit for mineralization of soil nitrogen. To this must be added the mineral nitrogen that becomes available from animal excreta and from decay of plant material.

The flow of nitrogen in grazed pastures is a complex process. Only part of the nitrogen taken up by the pasture plants is consumed by stock, and only part of the ingested nitrogen (usually less than three-quarters of it) is digested and returned in an available form as urine. The nitrogen in the ungrazed stubble and roots is mineralized more slowly than the nitrogen that is eaten. To add to the complexity of the system, some nitrogen can be cycled through the soil-plant-animal system more than once per annum.

Nevertheless, there is practical evidence that the largest part of the mineral nitrogen that is made available from animal excreta and plant material can be traced back to the legume plants, and that the total amount of mineral nitrogen from these sources has an upper limit equal to, on an annual basis, about half the gross annual yield of nitrogen in the legume component of the pasture. This gives upper limits for total available mineral nitrogen equal to*:

68.75–143.75 lb an acre a year for average legume growth,
and 200 lb an acre a year for good legume growth.

Only part of this mineral nitrogen is taken up by the legume. There is an increasing amount of evidence that the legume often gets less than its share of the available nitrogen in the soil, less than would be expected on the basis of its contribution to the total yield of the pasture. For instance, in two experiments at Samford, in which the isotope nitrogen–15 was used to trace the uptake of soil nitrogen (M. A. Owen and E. F. Henzell, unpublished results), Siratro took up 1.2–9.5% of the labelled nitrogen, even though it comprised 7.1–17.3% of the dry matter yield. Siratro took up less than 10% of the labelled nitrogen in another pasture at Samford, as did Townsville lucerne in a Townsville lucerne-spear grass pasture at Rodd's Bay (I. Vallis, personal communication). In these pastures the legume contributed up to 34.8% of the total yield of dry matter.

The results that have been obtained so far indicate that the legume probably gets only 10–20% of the available mineral nitrogen if the pasture contains less than 50% of legume (by weight), though it must be expected that the legume will gain an increasing percentage of the available nitrogen as the proportion of legume increases towards a pure stand.

Adopting the figure of 20%, the estimated uptake of mineral nitrogen by the legume has a maximum value of 40 lb an acre a year. For average legume growth the values are 13.75 and 28.75 lb an acre a year. Subtracting these values from the gross yield of nitrogen in the legume, and rounding off, provides the following estimates of rates of nitrogen fixation:

Average legume growth: 20–160 lb an acre a year

Good legume growth: 260 lb an acre a year.

If the legume took up only 10% of the available mineral nitrogen, then the upper limit for nitrogen fixation by a good growth of tropical legume would be 280 lb an acre a year.

How Much Nitrogen is Available to Grasses and Weeds?

If the legume usually gets 10–20% of the available mineral nitrogen, then the grasses and weeds get the other 80–90%.† Taking 80% of the values for mineral nitrogen in the previous section, 55–160 lb of nitrogen are available per annum for grasses and weeds. Compare these estimates with the amounts of fertilizer nitrogen used to obtain high yields of tropical grasses, which range from 300 to 1000 lb an acre a year (Table 2), and one can see why the grasses in many of our legume-based pastures still show symptoms of nitrogen deficiency. In fact, fertilizer nitrogen is the only source presently available in Queensland that is capable of maintaining maximum growth rates in tropical grasses.

How Much Nitrogen is Added to the Soil?

The direction and rate of change of total soil nitrogen under pasture depends on the balance between gains and losses. Significant losses of nitrogen do occur from grazed pastures and may more than balance the gains from legumes, algae, rainfall, and other sources. For instance, Bruce (1965) recorded that a rain

* $50.0 + 37.5/2 = 68.75$ etc.
† Normally almost all the available mineral nitrogen is used by the pasture. Large amounts of mineral nitrogen are rarely found in pasture soils in Queensland.

forest soil in north Queensland lost nitrogen at the rate of 100 lb an acre a year, and a Townsville lucerne pasture at Rodd's Bay lost at least 23 lb of nitrogen an acre a year during three dry seasons (I. Vallis, personal communication). Thus, a legume can be fixing nitrogen, yet there may be no net increase in total soil nitrogen, as Bruce (1965) discovered with centro (*Centrosema pubescens*) in north Queensland. In other experiments, at Beerwah (Henzell, Fergus, and Martin, 1966) and Innisfail (Bruce, 1967), tropical legumes increased soil nitrogen by 30–130 lb an acre a year.

The question might be asked: is there any great benefit to be gained by aiming for a rapid build-up of total soil nitrogen, in view of what was said earlier about the low availability of old soil nitrogen? Certainly, much of the available nitrogen supply in both permanent pasture and ley farming systems comes from recent additions of animal excreta and plant residues, not from old soil organic matter. However, with many pasture soils, specially those with a relatively low total nitrogen content, addition of readily available forms of nitrogen leads inevitably to a build-up of relatively unavailable nitrogen in soil organic matter. No way has yet been found of preventing or limiting the accumulation of unavailable soil nitrogen without limiting the supply of mineral nitrogen too.

NITROGEN FROM INDUSTRIAL SYNTHESIS

Up to the present, research with nitrogen fertilizers for animal production has been more an act of faith in the future than the pursuit of a visible economic objective. Nitrogen has been so expensive relative to the prices received for animal products that its use as a source of nitrogen for pastures usually has been quite unprofitable. The hope for the future is cheaper nitrogen, which might be achieved by:

1. Construction of large, efficient synthetic nitrogen plants in Australia. This is now taking place;

and

2. Long-term price trends reducing the price of nitrogen in relation to the returns from pastoral production. This kind of trend has operated for many years in the Northern Hemisphere (Tanner, 1966).

Figures will be presented in this paper which suggest that synthetic nitrogen needs to become a good deal cheaper yet (on 1967 prices) to warrant its general use on Queensland pastures.

Yields of Grass in Cutting Trials

Experiments with nitrogen fertilizers on pastures were carried out in Queensland as long ago as the 1920's (Coleman, 1931) but the quantities of nitrogen used were so small that the experiments failed to show just how spectacular the responses could be.

The first trials with adequate rates of nitrogen fertilizers in Queensland were carried out by Mr. T. B. Paltridge at Lawes (Dr. R. Milford, personal communication) and by Brett (1955) at a site near Caboolture. A number of others have been completed since then and some of the results are shown in Table 2. These trials were carried out in areas with good rainfall or with irrigation, using at least 300 lb of elemental nitrogen an acre a year, plus other fertilizers. The yields ranged from 6,400 to 28,500 lb of dry matter an acre a year (Table 2).

These are very high yields. In fact, it is now accepted that well-fertilized tropical grasslands form one of the most productive types of vegetation found

TABLE 2

Dry matter yields from grasses fertilized with heavy rates of nitrogen

Grass	Site	Yield (lb an acre a year)	Rate of Nitrogen (lb an acre a year)	Remarks	Reference
Paspalum and mat grass	Caboolture	12,500 – 13,000	400	One year	Brett, 1955
Rhodes grass	Samford	16,800	400	Average over seven years	Henzell, unpublished
Scrobic	„	18,400	400	Two years	Henzell, 1963
Eighteen species of *Paspalum*	„ (irrigated)	6,400 – 28,500	412	Yield increased with interval between cuts; large differences between species	Shaw *et al.*, 1965
Pangola grass	Beerwah	7,500 – 18,700	300	Average for two years; yield increased with interval between cuts	Bryan and Sharpe, 1965
		10,100 – 21,600	500	„	„
Pangola grass	Wollongbar	18,000	400	Results for 1964–65	Colman, 1966
Rodd's Bay plicatulum	„	10,300	„	„	„
Kazungula setaria	„	15,900	„	„	„
Kikuyu	„	21,400	500	Results for 1965–66	„
„	„	26,800	1,000	„	
Kikuyu and other grasses	Atherton Tableland	11,000	400	Four harvests over eight months	Gartner, 1966
Paspalum	North Deep Creek (near Gympie)	13,000	600	Average for two years	Roe and Jones, 1966
Kikuyu	„	25,800	„	„	„
Elephant grass	Biloela (irrigated)	17,200	500	One year	Grof and Courtice, 1962

anywhere in the world. At first, their high productivity was attributed to the high light intensities and high temperatures that occur in the tropics (Blackman and Black, 1959), but recent research suggests that these grasses are more efficient at photosynthesis than other forms of vegetation (among others — Murata, Iyama and Honma, 1965; Hesketh and Baker, 1967; Ludlow and Wilson, 1968).

Other small-plot trials implicated nitrogen deficiency, not drought, as the major factor limiting grass growth in the coastal areas of south-east Queensland. In Figure 1 yields of Rhodes grass over the last seven years in an experiment at Samford (receiving 400 lb of nitrogen an acre a year) are plotted against the proportion of drought days (G. B. Stirk and E. F. Henzell, unpublished results). "Drought days" are calculated from meteorological data; measured rainfalls and estimates of evaporation are used to calculate the amount of available water in the soil — a drought day occurs when the calculation shows that all the available water has been used up. They provide a good index of the effects of drought, but do not predict the exact onset of wilting. The long-term probability of drought at Samford is also indicated on the figures (Henzell and Stirk, 1963). Clearly, yields of nitrogen-fertilized grass at Samford (annual rainfall 42 inches) are not seriously restricted by drought in most years. Over a long period the average yield is expected to be about 70% of the maximum yield that occurs in a wet summer.

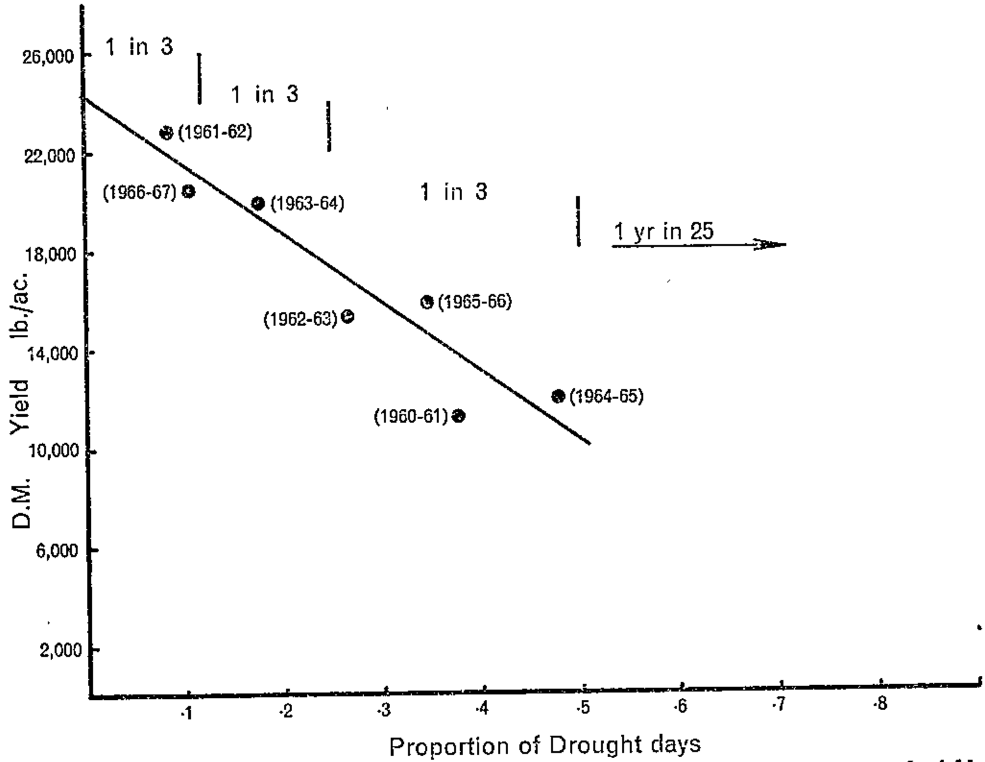

FIGURE 1.—The relation between calculated proportion of drought days and annual yield of Rhodes grass in an experiment at Samford during the period 1960–67. The vertical lines mark the long-term expected frequency of yields, e.g. more than 21,000 lb an acre can be expected about one year in three, less than 10,000 lb an acre can be expected about one year in twenty-five.

Animal Production

These cutting trials were followed by a number of grazing experiments, the results of which are summarized below (further details can be obtained from the original papers).

1. Lawes. An experiment was carried out with *Sorghum almum* pasture during the period 1959–61 (Yates *et al.,* 1964). Urea, at the rate of 200 lb of nitrogen an acre a year, had virtually no effect on liveweight gains of Hereford steers stocked at one beast per acre and only a small effect when the pasture was stocked at two beasts per acre.

   Points to note about this experiment are: the high rate of production on *S. almum* without nitrogen (annual liveweight gains of over 300 lb an acre, at one beast per acre); the fact that the experiment ran for only just over two years from sowing (the effect of fallowing on available nitrogen may not have disappeared completely); and the poor performance of cattle during winter, with or without nitrogen. This latter point is highlighted by the very good performance of cattle during winter when they had access to lucerne in another, more-recent experiment with *S. almum* at Lawes (Coaldrake *et al.,* 1967).

2. Rocklea. This experiment was carried out on paspalum–white clover pasture during the period 1960–64 (Moir, Ryley, Pepper, and Middleton, quoted by Ryley, 1966). For the first two years, nitrogen was applied in spring (75 lb

of nitrogen an acre, as ammonium sulphate); during the next two years it was applied in spring and autumn (65 lb an acre each time). Liveweight responses with Hereford heifers were very small: 6 lb an acre a year at one heifer per acre and 26 lb an acre a year at two heifers per acre.

Points about this experiment are: the cattle gained weight faster in spring (September 4–November 4) on pastures without nitrogen and this offset the advantage from nitrogen at other times of the year; nitrogen decreased the yield of clover; nitrogen at these rates had little effect on total yield of pastures; and live-weight gains of up to 300 lb an acre a year were recorded without nitrogen (Anon., 1964a).

The main effect of nitrogen in this experiment was to replace white clover, which is probably the world's best pasture plant, with grass of inferior feeding value.

3. Samford. A grazing experiment was conducted with Nandi setaria and Samford Rhodes grass pastures during 1962–66 (Jones, 1966b; Jones, 1967b, and personal communication). Urea was applied at the rate of 300 lb of nitrogen an acre a year. For the last three years of the experiment it was stocked at one and a half and two Hereford steers per acre. Differences between stocking rates, between the grasses, and the effect of conservation were relatively small. Average annual liveweight gains were 419 lb an acre a year for the block on podzolic soils on the hillside and 540 lb on the gleyed soils on the flat.

   Unfortunately there is no ready standard of comparison for these results. Beef cattle are not normally carried on the unimproved blue couch, mat grass, and paspalum pastures at Samford, but it is certain that production would be very low.

4. Beerwah. Beef production on Pangola grass was measured by Evans (1967b) during 1965–67. Nitrogen was applied at 400 lb and 800 lb an acre a year, in the form of calcium-ammonium-nitrate. The stocking rate was three yearling steers an acre from September to April and two yearlings an acre in winter. Average liveweight gains were 1215 lb an acre a year with 800 lb of nitrogen and 1139 lb with 400 lb of nitrogen. This experiment was carried out in Wallum country that normally carries no permanent domestic livestock in its unimproved state.

5. Wollongbar. Work with Kikuyu grass at Wollongbar began in 1965 (R. L. Colman and J. M. Holder, quoted by Holder, 1967) and the experiment is still in progress. The pasture receives 300 lb of nitrogen an acre a year (as sulphate of ammonia) and is grazed year-round at 0.66, 1.00, and 1.33 cows (or heifers) per acre. Results for the 1966–67 lactation are given in Table 3. For comparison, unfertilized Kikuyu, paspalum and mat grass at Wollongbar (2.3 acres per cow) produced 188 lb of butterfat per cow and 82 lb per acre per annum during the period 1960–67.

TABLE 3

Production from nitrogen-fertilized Kikuyu grass at Wollongbar
(After Holder, 1967)

Stocking Rate (Heifers/acre)	Body Weight Gain during lactation (lb/heifer)	Butterfat Production	
		lb/heifer	lb/acre
0.66	203	261	163
1.00	205	244	244
1.33	220	219	292

To sum up: in two of these grazing experiments (Lawes and Rocklea) the use of nitrogen was quite ineffective; two gave satisfactory increases in production (Samford and Wollongbar); and the Pangola grass at Beerwah gave some of the highest liveweight gains ever recorded from pasture. Spectacular rates of beef production (up to 1880 lb of liveweight gain an acre a year; nine steers were turned off per acre per year, in three drafts) were also achieved by the Department of Primary Industries in trials with irrigated, nitrogen-fertilized Pangola grass in North Queensland (Anon., 1967); other details of this work have not yet been published.

These results with Pangola grass are very encouraging. This is actually the first time in Queensland that animal production from a tropical grass has come near to the potential indicated by cutting trials. But even now, nitrogen-fertilized grass can produce about twice as much liveweight gain per acre at Samford and Beerwah as legume-based pastures can.

Profitability

No economic studies of production on nitrogen-fertilized grass have been published to date, so I have tried to fill the gap by adapting Moore's figures for development of grass-legume pastures in the Wallum. Moore (1967) estimates that legume-based pastures on a hypothetical property will carry one beef animal an acre and that the gross return per acre and per animal will be $40.00 a year. From the $40.00 he subtracts the operating costs of buying, caring for and selling beef cattle ($16.40 an acre) and the annual cost of fertilizer ($7.00 an acre), leaving a net return of $16.60, or 12.5% on $132.50, the cost of developing and stocking an acre of legume-based pasture.

Consider a comparable property running the same total number of beef cattle on nitrogen-fertilized grass. How much could be spent on nitrogen fertilizer while still retaining a 12.5% return on costs of development and stock? A hypothetical property based on nitrogen-fertilized Pangola grass could be expected to carry two animals per acre, i.e. to have a total area of 2,000 acres for 4,000 cattle. The cost of development and stocking is estimated to be about $215.00 an acre.* The operating cost is unaltered at $16.40 an animal or $32.80 an acre, and the gross return remains at $40.00 an animal or $80.00 an acre.

A return of 12.5% on $215.00 is $26.88 an acre. Thus, to retain the same profitability, the fertilizer would have to cost $20.32 per acre per annum. The amount of fertilizer required to carry two beasts per acre on Pangola grass in the Wallum is about 300 lb of nitrogen, 4 cwt of superphosphate and 2 cwt of potassium chloride an acre a year (T. R. Evans, personal communication). On Moore's figures, the superphosphate and potash would cost $14.00 an acre, leaving only $6.32 or about 2 cents a pound, to pay for the nitrogen. The present price of nitrogen in the Wallum, with subsidy and allowing for cost of transport, is about 7 cents a pound in aqua ammonia and 9 cents a pound in urea.

Obviously it would be unwise to use this calculation of mine as anything other than a broad indication of the profitability of nitrogen-fertilized grass, since

* This figure was obtained by deducting the cost of lime, half the initial fertilizer cost, and all but $1600 of the seed cost, from the items in Table 4 of Moore's paper (Moore, 1967, p. 34). The total development and stocking cost then reduces to $430,000 ($215 an acre on 2,000 acres).

The other costs in Moore's table were not changed, since it can be argued (1) that the saving on clearing and planting a smaller area would be counterbalanced by the cost of machinery, fuel and labour for spreading nitrogen fertilizer three or four times a year, (2) that smaller paddocks would be used for intensively managed grass, and so the cost of fencing and water reticulation would not be reduced and (3) that the costs of a house, yards, dip, and sheds would not be influenced by the area of the property.

reasons could be advanced for varying many of the items in the calculation and in Moore's paper. For instance, if three animals per acre, instead of two, could be turned off on the Wallum, the use of nitrogen would be much more attractive. Nevertheless, one cannot escape the conclusion that a good deal remains to be done before nitrogen fertilizer will offer as profitable a source of nitrogen for *general* use in Queensland pastures as legumes do.

It can be argued that other systems of livestock production might give better returns than the example I have used. For instance, nitrogen-fertilized grass might be used to fatten cattle in a system similar to fattening on oat crops in the brigalow region. Perhaps the most profitable system will combine legume and fertilizer nitrogen (on separate paddocks) as A.C.F. and Shirleys Fertilizers Ltd have done on Mr. S. W. Caulfield's farm at Gympie.

It is possible that the use of nitrogen on dairy pastures may be more profitable than its use for fattening beef cattle. The cost of land, pasture development and stock in the dairying areas of south-eastern Queensland and north-eastern New South Wales is higher than in the Wallum, but the operating cost per animal may be about the same, provided concentrates are not fed in large amounts (the cost of freight and commission on beef cattle will be offset by a higher labour cost in dairying). It should be possible to produce about 200 lb of butterfat per acre and per cow (Table 3). The gross return from this production, even at the equalization price of 44–45 cents a pound, is $88.00–$90.00 an acre.

There is little doubt that all these possibilities, and others, will be carefully evaluated during the next ten years or so, as the major fertilizer companies in Queensland intensify the search for new and expanded markets. The price of synthetic nitrogen can be expected to fall during this period, as a result of production from large synthetic plants that are being constructed at Brisbane and Newcastle. These plants are large enough to be efficient by world standards (Anon., 1964b; Reynolds, 1965).

Some Other Problems with Nitrogen-Fertilized Grass

The problem of profitability is not the only one awaiting solution. There are a number of practical problems on which we require information, including:

1. The precise requirements of nitrogen-fertilized grass for other nutrients (cf. the large amounts of superphosphate and potash used on Pangola grass at Beerwah).
2. The choice of fertilizer. Urea is usually the cheapest solid form, but sometimes suffers important losses of ammonia to the air.
3. The side effects of nitrogen fertilizers. The acidifying effect of ammonium sulphate is well recognized; urea has a similar effect, but at a much slower rate.
4. The best kind of management to achieve efficient animal production. The grazing experiments carried out so far have given extremely variable results. Obviously it is going to be very important to define the precise conditions required for efficient production in different parts of Queensland.

But the main problem influencing the use of nitrogen on tropical pasture grasses, in the long term, is undoubtedly their low feeding value. Even with good management, on pasture that is *apparently* of high quality, cattle often gain only about one pound a day. The problem is not solved by raising the protein content of these grasses; they still have a relatively low feeding value even when they contain a satisfactory amount of protein. The problem is due to a shortage of digestible energy in the diet, caused by a low intake of material with a relatively low digestibility (Milford and Minson, 1965).

At present, selection of grasses that will give a better intake of digestible energy can only be done reliably in grazing experiments. This is slow, expensive work.

THE FUTURE — LEGUMES OR NITROGEN FERTILIZERS?

This has been a lively topic for debate in temperate climates, and the same question will arise with tropical pastures in Queensland too. The choice is clear-cut while nitrogen remains expensive, but it seems likely in the long term that the price of nitrogen will fall in relation to farm costs and farm returns. If nitrogen becomes relatively very cheap, what then?

The answer is likely to depend on how much progress we make in improving our legumes and grasses. Take the legumes. The main long-term research problem is their relatively low yields. This will not affect the commercial exploitation of legumes by farmers and graziers during the next decade or two, but it will be important when there is more emphasis on production per acre in Queensland. There is little doubt that higher legume yields would result in more total growth by the pasture, a higher rate of nitrogen fixation, a better nitrogen supply to the grasses, better quality feed, and more animal production per acre. However, there may be inherent biochemical or physiological barriers in legumes that will hinder selection for higher yields of dry matter. Some very recent research at the University of Queensland indicates that photosynthesis in the tropical pasture grasses is about twice as efficient per unit of leaf area or unit of chlorophyll as it is in the tropical legumes (Ludlow and Wilson, 1968; M. M. Ludlow, personal communication).

Yield is not a problem with the grasses, but their low feed value is a major disadvantage. Here, too, there may well be genetic barriers that prevent tropical grasses from being as good a feed as ryegrass, or better still, as good as white clover. The productivity of nitrogen-fertilized tropical grasses would be truly spectacular if the problem of feed value could be overcome.

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