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FERTILIZER VS. LEGUME NITROGEN FOR GRASSLANDS

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Of the nutrient elements essential to plant growth, nitrogen is required in greatest amount. Proteins, which constitute a considerable part of most plant tissues, consist of approximately 16 percent nitrogen. In addition, free amino acids, amides, and other organic compounds contain considerable amounts of it. Since herbage of high quality obtained from permanent pastures dressed with fertilizer nitrogen may contain well over 3 percent nitrogen, large amounts of this element must be available for pasture plants to attain optimal growth. Approximately 300 kg. nitrogen must be absorbed for the production of 10,000 kg. dried herbage, a yield that may be easily obtained per ha. annually on permanent pastures in the Netherlands when supplied adequately with nitrogen, phosphate, and potash.

The nodule bacteria of a good crop of clover or alfalfa may fix 300 kg. nitrogen per ha. annually under the moderate climatic conditions of western Europe and on fertile soils. Fixation will be considerably less, however, when the sward consists of 25 percent legumes and 75 percent grasses. In such an association the nodule bacteria fix insufficient nitrogen to supply the grasses with amounts equal to an application of 40 or 60 kg. fertilizer nitrogen per cutting. This is particularly true in early spring when demand for available nitrogen by grasses starts much earlier than legume nitrogen becomes available to them. Since response of grasses to nitrogen in spring is considerably higher than in midsummer, it is of particular importance that the supply in that season be liberal.

From experiments in Connecticut, Brown (1939) and Brown and Munsell (1943) concluded that "it would seem to be better practice to till and seed leguminous mixtures, which will produce larger total and better distributed yields of forage than grasses receiving heavy applications of nitrogen." The amount of fertilizer nitrogen used was as low as 56 lbs. per acre (63 kg. per ha.) for the whole season. This undoubtedly was too low to supply the grasses adequately with nitrogen. If higher amounts had been used, yields of the grass plots certainly would have been as high as or higher than those of the legume-grass mixtures. Robinson and Sprague (1947) using much larger amounts of fertilizer nitrogen, viz., 40 lbs. per acre (45 kg. per ha.) in spring and after each cutting—in total, more than 300 kg. per ha. per season—obtained higher yields of herbage with fertilizer nitrogen than with a high content of white clover in the sward.

A drawback to use of fertilizer nitrogen on pastures is the suppression of legumes by grasses. This is an indirect effect mainly resulting from competition for light, plant nutrients, and water (Robinson and Sprague, 1947). Although under grazing or close clipping this effect may be prevented to a great extent (Frankena 1937), decrease of legumes in a sward amply dressed with fertilizer nitrogen is virtually inevitable. This means that a natural and economical source of nitrogen may be lost. The farmer may partially prevent this with a system of combined grazing and mowing (Frankena 1937).

Qualitative Differences Between Fertilizer and Legume Nitrogen

Fertilizer nitrogen is mostly applied in inorganic form on top of the soil. Ammonium sulphate, ammonium nitrate, calcium nitrate, and sodium nitrate are the most commonly used products. Legume nitrogen, however, is fixed by root nodule bacteria in the soil. Sometimes nodules may be found on aerial roots. Whether excreted by intact nodules (Virtanen 1937, Wilson 1940) or originating from decomposing roots and nodules, the nitrogen initially occurs in the soil in organic form. Although higher plants may absorb amino acids or amides, it is not known to what extent grass growing in association with legumes really absorbs such compounds. It may be assumed, however, that in most soils these organic compounds will be readily decomposed by microorganisms. Part of the nitrogen will be converted to ammonia and subsequently to nitrate, which may be readily absorbed by plant roots, but a further part will be fixed in bacterial protein and thus temporarily made unavailable to plants.

Legume nitrogen reacts more gradually and more evenly than fertilizer nitrogen. This may be an advantage in those regions where long periods of drought may prevail and there is no opportunity for applied fertilizer nitrogen to reach the plant roots. Once added fertilizer nitrogen has been effective in improving production of herbage, its after effect will be small (Table 1).

Table 1. Effect of Fertilizer Nitrogen, Supplied to Grass for First Cutting, on Yield of First and Second Cuttings of Three Permanent Grassland Trials
(Dry matter, kg. per ha.)

Kg. N per ha. supplied to grass of first cutting[1]	Experiment 1272, peaty soil		Experiment 1273, sandy soil		Experiment 1275, sandy soil	
	1st cutting June 7	2nd cutting July 16	1st cutting June 4	2nd cutting July 13	1st cutting June 7	2nd cutting July 23
0	2,570	1,980	1,980	1,030	2,310	1,240
30	3,110	1,960	2,620	1,300	2,940	1,110
60	3,480	2,090	3,730	1,100	3,330	1,330
90	3,910	1,900	3,890	1,270	3,850	1,370
120	4,210	1,840	4,190	1,700	3,960	1,480
150	4,550	1,990	4,850	1,680	3,940	1,580
180	4,310	2,070	4,010	1,780	4,290	1,950

[1] Nitrogen supplied as ammonium nitrate limestone.

In experiment 1272 there was no after effect at all. On the other fields there was a small after effect, starting at a rate of 120 kg. N per ha. Since recovery values for added fertilizer nitrogen seldom are higher than 60 percent (Mulder 1949), and for amounts of fertilizer nitrogen above 100 kg. per ha., often lower than 50 percent, one would have expected a considerable after effect. Similar results as to after effect and recovery of fertilizer nitrogen have been obtained by Munsell and Brown (1939). As contrasted to these results, Blaser and Brady (1950) found the beneficial effect of fertilizer nitrogen on grass extended over as many as four subsequent cuttings. Close examination of the fate of unabsorbed fertilizer nitrogen applied on grassland is certainly worth while.

Since fertilizer treatment of pastures often depresses legumes in an association, application of combined nitrogen to subsequent cuttings should be repeated in order to prevent reduced aftergrowth.

Application of high amounts of fertilizer nitrogen not only improves the nitrogen nutrition of vegetation but affects uptake of other nutrients. This may be due to its effect on soil pH and to a direct relationship between nitrogen uptake and that of other ions. Addition of ammonium sulphate results in a lowering of soil pH owing to preferential absorption of ammonium ions. After a considerable fall owing to the combined effect of preferential absorption of ammonium ions by plants and nitrification, a rise of pH sets in, apparently owing to uptake of NO_3.

Beneficial effects of ammonium sulphate and, to a smaller degree, of ammonium nitrate, as contrasted to calcium and sodium nitrates, on uptake of phosphate is partly due to an indirect pH effect and partly to a direct effect of NH_4 and NO_3 ions. The author has observed this effect in fertilizer experiments with increasing amounts of ammonium nitrate and limestone at different phosphate levels on permanent grassland (Mulder 1949a, b).

On soil poor in available phosphorus, the total yield of herbage from permanent pasture was considerably higher with dressings of ammonium sulfate than with calcium nitrate, and the phosphorus content of the dry material was also enhanced (Mulder, unpublished).

The effect of nitrogen on magnesium uptake is completely different from that on phosphate. Sulphate of ammonia depresses magnesium uptake, whereas nitrates stimulate it. This has been shown by the author in pot and field experiments with cereals only, but undoubtedly similar results may be expected on grassland.

Effect of Legumes and of Fertilizer Nitrogen on Grass Growth in Relation to Soil Conditions and Soil Fertility

Nitrogenous fertilizers may exert either a beneficial or a harmful effect on uptake of other nutrient elements by pasture plants. Legume nitrogen presumably will exert this effect to a much smaller degree, because it comes available more gradually than fertilizer nitrogen. Furthermore it is not present in combination with strong acids or bases.

Fixation of elemental nitrogen by nodule bacteria requires soil conditions different from those required for growth of grasses supplied with combined nitrogen. This is true of pH and of the supply of phosphorus, potassium, boron, molybdenum, and perhaps other nutrient elements. At pH values below pH 5.0, fixation of elemental nitrogen may be poor. Supplied with fertilizer nitrogen, particularly nitrates, relatively normal yields of grasses may be obtained.

Phosphorus

Legumes require for their development a higher phosphorus level in the soil than do cereals and grasses. This was shown by the author in pot experiments with peas and oats. Both crops were grown in a sandy soil, deficient in available phosphorus at pH 5.2. To this soil different amounts of dicalcium phosphate were added (Table 2).

Similar results have been obtained by van der Paauw (personal communication) in plat experiments with a number of grass species and white clover growing separately in phosphorus-deficient soil supplied with different amounts of phosphate. The experiment was con-

Table 2. Yields of Oats and Peas Grown at Different Phosphorus Levels[1] (Dry matter, gm. per pot)

$Ca(H_2PO_4)_2$ (gm. per pot)	Oats		Peas		Peas[2]	
	Grain	Straw	Grain	Straw	Grain	Straw
0.2	4.1	7.0	0.9	3.3	0.9	3.4
0.6	16.8	20.2	0.6	3.2	1.7	4.3
1.0	31.6	33.6	0.9	3.7	2.5	5.7
3.0	—	—	—	—	13.0	13.9
5.0	51.0	50.7	14.2	14.8	17.9	18.8
7.0	—	—	—	—	18.5	19.1
10.0	—	—	—	—	26.8	23.7

[1] Oats as well as peas dressed with 2 gm. NH_4NO_3 per pot; K_2SO_4, $MgSO_4$, $CaSO_4$, and $CuSO_4$ added as basic dressings.
[2] 2 gm. $CaCO_3$ per pot.

tinued 4 years. The P-requirement of each species was determined by calculating the yield of the no-P plats as percentages of the plats with maximal yield. White clover had a higher phosphate requirement than any of the grasses. These results are in accordance with those of Dodd (1941), who points out that adequate phosphate applications are essential in increasing the white-clover content of permanent pastures.

Potassium

The effect of different potassium levels on the development and yield of white clover and of a number of grass species was investigated by van der Paauw (1940) in the same way as described above. White clover was found to have a considerably higher K-requirement than grass. Similar results were obtained by de Vries and Kruyne (1943), who carried out botanical analyses of the sward on a large number of fertilizer trials in the Netherlands. Their conclusion is that the legumes are characterized by high potassium and moderate phosphate requirements.

Important effects of potassium on development of legumes growing in association with grasses were observed by Rich and Odland (1947) and by Blaser and Brady (1950). The latter applied different amounts of potash to mixed pastures and obtained considerable increase in yield of white clover, whereas the grasses virtually did not respond. Fertilizer nitrogen stimulated growth of the grasses. It decreased development of white clover in subsequent harvests because of increased potassium deficiency resulting from an enhanced uptake of potassium by the grasses when treated with fertilizer nitrogen.

Boron and molybdenum

Both these trace elements are required for fixation of elemental nitrogen by root nodules. The author has studied the effect of boron on nitrogen fixation by peas in nutrient solutions and in pot experiments with soil poor in boron. In accordance with the results of Brenchley and Thornton (1925) with *Vicia* beans, it was found that no nodules develop on plants growing in nutrient solutions in the absence of boron. Symptoms of nitrogen deficiency appeared which were absent when very small amounts of boron had been supplied.

In the latter case normal nodulation occurred and the pea plants initially made good growth. After some time, however, symptoms of boron deficiency were seen on the tops of the plants and further growth ceased. With higher quantities of boron added normal plants were obtained. In contrast to the culture-solution experiments, no symptoms of boron deficiency were observed in peas growing in boron-deficient soil. Symptoms of nitrogen deficiency became apparent after the plants had grown nearly 2 months. The plants ripened at an earlier stage than those treated with boron, and their yields were from 30 to 50 percent lower.

Grass-legume associations on boron-deficient soils may suffer from nitrogen deficiency owing to poor development of the legumes. Since the boron requirement of grasses is extremely low, normal yields of grasses may be expected when fertilizer nitrogen is applied on such soils.

Similar results may be obtained on molybdenum-deficient soils. In the absence of adequate amounts of available molybdenum, root nodules of leguminous crops, particularly those of clover and alfalfa, are unable to fix nitrogen. When the sward consists of grasses and clovers, no legume nitrogen is supplied to the grasses and yield of herbage will be very low owing to nitrogen deficiency. When fertilizer nitrogen is supplied to such soils, normal yields will be obtained in the absence of added molybdenum (Table 3) owing to the extremely low molybdenum requirement of grasses. Under such circumstances even legumes may develop, since their molybdenum requirement is likewise much smaller if supplied with combined nitrogen.

In the Netherlands molybdenum deficiency may be found on peaty soils rich in ironstones and on certain acid sandy soils (Mulder 1950). In Australia molybdenum deficiency of legumes may occur in various regions of the country. As a result the nitrogen supply to the pasture grasses which depends on legume nitrogen is very poor (Anderson 1946).

Table 3. Effect of Molybdenum Dressings on Yield of Pure Cultures of White and Red Clover, Alfalfa, and a Mixture of Four Grass Species, viz., *Lolium perenne*, *Lolium multiflorum*, *Phleum pratense*, *Dactylis glomerata*

Na_2MoO_4 (kg. per ha.)	White clover		Red clover		Alfalfa		Grass mixture	
	1st cutting Aug. 13	2nd cutting Oct. 18	1st cutting Aug. 13	2nd cutting Oct. 18	1st cutting Aug. 13	2nd cutting Oct. 18	1st cutting July 26	2nd cutting Aug. 8
0	1,560	2,260	809	2,930	566	522	3,780	1,360
2	2,970	2,910	2,350	3,370	1,540	2,020	3,980	1,300
4	2,640	2,890	2,310	3,360	2,290	1,790	3,230	1,270

Seasonal Distribution of Pasturage Supplied with Fertilizer or Legume Nitrogen

In addition to quantity and quality of herbage, seasonal distribution of its production is of great importance. For grazing purposes a uniform distribution of pasturage throughout the year is most desirable. Owing to climatic variations and to physiological-morphological changes within pasture plants in the course of the growing season, a large variation in seasonal production will be found in many regions. Generally yields will be high when rainfall and temperature are optimal for plant growth and low in dry or cold periods.

In the Netherlands grass growth starts in April and increases rapidly to reach its optimum in May-June. Then a decline sets in, often followed by a second rise in August, after which growth gradually decreases and comes to a standstill in early November (Tables 4 and 5). Similar distribution curves for herbage production are found in the other countries of western Europe (Woodman, *et al.* 1926, Rappe 1951).

Table 4. Effect of Application of Increasing Amounts of Fertilizer Nitrogen on Seasonal Distribution of Herbage Production (Experiment 640, 1941, peaty soil)
(Kg. dry matter per ha. per day)

N applied per cutting (kg. per ha.)	1st cutting May 1 to May 26	2nd cutting May 26 to June 14	3rd cutting June 14 to July 14	4th cutting July 14 to Aug. 7	5th cutting Aug. 7 to Sept. 3	6th cutting Sept. 3 to Oct. 30
0	33.0	76.9	62.4	56.4	58.0	34.6
20	38.9	99.3	77.1	70.8	70.2	39.5
40	55.9	103.9	84.7	78.9	73.4	38.3
60	59.2	130.1	74.6	82.8	73.4	32.5
80	61.4	131.0	80.7	84.8	68.8	27.7
100	73.9	130.5	85.0	80.7	67.4	33.0
120	78.1	141.2	85.1	78.0	68.0	33.8
140	76.5	135.0	79.9	69.4	68.0	30.7
180	93.8	119.0	67.4	76.8	71.5	35.2
240	100.2	172.6	45.3	63.8	62.1	38.8
300	111.0	122.8	32.9	65.9	55.8	28.0
360	129.7	98.0	81.3	43.5	52.6	32.0
420	121.0	115.0	41.9	41.8	53.2	23.7

Table 5. Effect of Application of Increasing Amounts of Fertilizer Nitrogen on Seasonal Distribution of Herbage Production (Experiment 641, 1941, clay soil)
(Kg. dry matter per ha. per day)

N applied per cutting (Kg. per ha.)	1st cutting May 1 to May 27	2nd cutting May 27 to June 16	3rd cutting June 16 to July 29	4th cutting July 29 to Aug. 19	5th cutting Aug. 19 to Sept. 24
0	32.1	39.1	17.0	42.5	25.5
20	45.0	58.2	23.5	65.6	40.1
40	59.4	79.4	28.0	84.6	55.7
60	70.5	84.1	29.7	107.7	60.7
80	75.0	104.1	34.6	104.8	70.1
100	90.0	102.9	35.8	106.0	66.8
120	94.8	111.3	32.0	116.6	68.0
140	109.6	106.5	37.7	106.8	67.3
180	110.8	108.3	38.0	133.1	67.0
240	129.3	88.0	33.6	94.3	69.8
300	128.8	111.2	28.0	91.5	65.4
360	134.8	96.0	26.5	75.3	69.6
420	136.0	81.1	23.7	64.0	65.4

Seasonal distribution (Tables 4 and 5) was due partly to very dry weather conditions during June and much of July. This was particularly true of the very low yields on the clay soil from June 16 to July 29, when the plants suffered severely from lack of water. On the peaty soil the water supply was much better, and there "midsummer depression" was much less pronounced.

Reduced growth occurring in midsummer on the clay soil, as well as lower yields on the peaty soil after June 14, was virtually unaffected by addition of nitrogen. Apparently seasonal variations were independent of nitrogen supply. Besides lack of water, which often is the cause of extremely low yields in midsummer, the growth rhythm of the various pasture plants may affect the amount of herbage produced in various periods of the season ('t Hart 1948, Rappe 1951). There are three main phases in the development of perennial grasses during the season: one before midsummer, providing a preparation for the reproductional phase; one around the summer solstice, the reproductional phase; and one after midsummer, providing a preparation for hibernation. Grasses still pass through these phases when subjected to grazings or cuttings that prevent them from reaching the flowering stage. It is supposed by Rappe (1951) that during the reproductional phase conditions may be less favorable to weight increase of the grass crop than during the period before and after. In pot experiments with various grass species he observed a striking coincidence of the periods during which fertile plants were obtained and those during which plant regrowth after cuttings was depressed.

If it is assumed that seasonal rhythm in herbage production is partly due to growth rhythm of the plants, it may be expected that pastures or leys containing a high amount of legumes will show seasonal distribution in yield different from that of pastures containing mainly grasses. In a ley containing a large amount of clover, 't Hart (1948) found that clover started growth later in the spring than grasses and reached its optimum during the period of reduced grass growth in midsummer. Such a distribution occurs only when moisture is adequate. Under extremely dry conditions clover may suffer even more than grasses (Dodd 1941).

Harmful Root Interactions Between Grasses and Legumes

Harmful root interactions may exist between various species of pasture grasses and legumes. Ahlgren and Aamodt (1939) seldom found white and red clover in dense, closely grazed quackgrass *(Agropyron repens)*, whereas alsike clover *(Trifolium hybridum)* appeared in comparative abundance. They observed a harmful effect of clovers on *Poa pratensis* but not on two strains of *Bromus inermis* and *Phleum pratense*.

Nutritional Value and Nitrogen Source

Considerable nutritional difference may exist between grass supplied with fertilizer nitrogen and a mixture of grass and legumes. Application of high amounts of nitrate under certain circumstances may bring about its accumulation in the herbage that may cause poisoning of cattle.

The protein content of legumes generally is higher than that of grasses supplied with a moderate amount of fertilizer nitrogen. Preliminary investigations employing paper-chromatography carried out in this laboratory have shown that the content of free amino acids of red clover may differ from that of grass dressed with fertilizer nitrogen. No difference was found in amino-acid composition of proteins from red clover and that from grasses. The latter finding is in agreement with the results of Chibnall (1939).

Swift et al. (1948) found considerably higher calcium and magnesium values in white clover than in *Poa pratensis*. Phosphorus and potassium were present in approximately similar concentrations. In contrast Blaser and Brady (1950) found constantly lower concentrations of potassium in white clover than in a mixture of grasses—mainly *Phleum pratense* and *Poa pratensis*. Thomas et al. (1952)

compared the mineral constituents of eight grass species, four legumes, and four herbs and found the legumes to be consistently highest in Ca, Mg, P, and K. Iron and manganese were higher in legumes than in grasses, whereas no differences were found between copper and cobalt contents of these groups of plants. In contrast Beeson and MacDonald (1951) found timothy to be clearly lower in iron, copper, and cobalt than white clover and alfalfa, whereas its manganese content was higher than that of alfalfa but lower than that of white clover.

The molybdenum content of legumes generally is much higher than that of grasses. Lewis (1943), studying molybdenum toxicity of cattle occurring on the "teart pastures" of Somerset, found from 6 to 12 times as much molydenum in white and red clover as in grasses, with the exception of Yorkshire fog *(Holcus lanatus)*, which also was rich in molybdenum.

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DISCUSSION

R. E. Altona, Union of South Africa:

Have you ever had any experience in losing cattle on high-nitrate grass?

E. G. Mulder, Netherlands:

Never have had such a case. Cows may not like high-nitrate grass, however, and move to other areas.

J. R. Neller, United States:

If mixtures of grasses and legumes are fertilized with N do grasses crowd out legumes?

E. G. Mulder, Netherlands:

Yes, some trouble is experienced, but by improved grazing and mowing practices this tendency can be overcome.