NITROGEN FERTILIZATION OF ALFALFA

Donald N. Munns
University of California, Davis

Nitrogen fixation by alfalfa root nodules normally supplies enough nitrogen for the crop. Application of nitrogen fertilizer to alfalfa has large effects only in certain circumstances: (a) when the alfalfa is grown as part of a mixture, e.g. with grass, or (b) when nodulation is slow or nitrogen fixation is impaired by environmental conditions. Lack of effective alfalfa rhizobia in the soil can cause slow establishment of nodulation, especially on new alfalfa land. Heat, drought, or waterlogging can inhibit nodule function, especially on shallow soils. And soil acidity, calcium deficiency, and molybdenum deficiency seriously impair nitrogen fixation on acid soils. Any of these conditions can make alfalfa responsive to N, and such responsiveness is the best evidence of faulty nitrogen fixation.

Little or no N-response is likely on established, normally well-nodulated stands. Little response is to be expected not only because nitrogen fixation is usually very effective in alfalfa, but also because nitrogen fertilization inhibits nitrogen fixation. Where N-fertilization does improve growth of well-nodulated alfalfa, the response tends to be variable, uncertain, and difficult to predict. The uncertainty arises because so many factors influence nitrogen fixation and the inhibitory effect of soil nitrogen.

Nitrogen Fertilizer Trials in the Field

Tables 1, 2, and 3 summarize three recently published sets of trials in Wisconsin Indiana, and Canada. Table 4 summarizes unpublished trials done here in California.

In the Indiana trials (table 1) N was applied at various rates to well established alfalfa producing at a high level (about 8 tons/acre/year). Nitrogen fertilization made the alfalfa look better, but there were no increases in yield or protein content. Nitrogen slightly thinned the stand and slightly increased the incidence of weeds.

In the Canadian trials (table 2) yields were lower than in the Indiana trials. There were small benefits from N in certain cuttings, not in others. Nitrogen substantially (50%) increased the yield of weeds in one year of the trials.

In the Wisconsin trials (table 3), yields were again low. Again there were small benefits from nitrogen at certain times, not at others. The authors reviewed earlier published field trials with N on alfalfa in the U.S., and concluded that there is little economic justification for application of N to well established alfalfa.

The Californian trials (table 4) cover a range of annual production rates ranging from 3 to 8 tons/acre/year. Most of the trials show no benefit from N fertilizer (table 4) The indication "none" in table 4 does not just indicate lack of a statistically significant response; it indicates that the mean yield with N was the same as the mean yield without N. The exceptions, where N gave significant response, are instructive.

In Siskiyou county, N substantially improved yield of a mixture of alfalfa and orchardgrass. This agrees with experience with legume-grass mixtures in England and New Zealand (see ref. 7). The secret appears to be that the grass responds to N, and provides a sink for soil N to minimize its interference with the legume nodules. The same combination of maximum benefit and minimum damage cnnnot be expected in a pure alfalfa stand or a mixed stand where the other plants are weeds.

In the trial at Alturas, the large responses to N were probably also economic. They occurred in a new stand, in which nodulation might have been still establishing, slowly. If so, inoculation of the seed would have given a cheaper fix. There is also, in this trial, the possibility that sulfur deficiency was corrected by the ammonium sulfate used as the source of N.

The Glenn county experience with water-run ammonia is the most clearly economic use of nitrogen yet shown on alfalfa. The figures imply that the addition of 30 lb. N is increasing N-yield in the alfalfa by at least an equal 30 lb., implying either a combination of 100% uptake and zero inhibition of fixation, or more likely, a stimulation of nitrogen fixation by the small addition of N. In reporting these results, Mr. Toenjes stresses the particular set of conditions necessary to obtain these benefits. The responses are observed only on shallow soils, where rooting and nodulation are confined to a foot or so of soil near the surface, subject to alternating drought and waterlogging. The top few inches of the soil overheats during the summer. Significantly, the responses to ammonia are observed only in middle and late summer, not in spring or fall. Heat inhibition of nitrogen fixation is less likely to matter in more favorable soils, where the nodules can develop at greater depths (8).

Exceptionally high rates of N, 400-500 lb/acre, gave a 10% increase in yield in two trials, at Davis and in Tulare county. This is consistent with greenhouse experiments at very high rates of N. With this much N supplied in an already-combined state, nodulation is eliminated, and the 10% yield improvement probably arises from elimination of the inherent inefficiencies present in even the best-tuned combination of plant and nodule-bacteria. In practical terms, these responses would be uneconomic. No 10% yield increase in alfalfa can come anywhere near paying for 400 lb. of fertilizer-N.

The Likelihood of Achieving General Economic Responses to Nitrogen

Some field experiments and greenhouse trials with well-nodulated alfalfa show responses to applied N of the order of 10% increase in yield. For such a yield increase to be economic in the average 6 ton Californian alfalfa field, it would have to be achieved with a good deal less than 100 lb. N.

Part of the problem lies in the inhibitory effect of available soil N on nitrogen fixation. In alfalfa, this is mostly due to inhibition of nodulation. Nitrate is more inhibitory than ammonium. It is inhibitory at very low concentrations, and the degree of inhibition increases with concentration (1, 6). The effect is temporary, in the sense that new nodules form and function once the nitrate is removed or depleted in the soil. The effect of nitrate on nodule formation appears to be local; nodulation is inhibited only in that part of the root system that is exposed to nitrate (1. 7).

These considerations suggest that the form, rate, and placement of N could be adjusted to give a nice balance between maximum benefit to the plant's nitrogen supply and minimum disturbance to nodulation. Some greenhouse experiments suggest this. Hallock (2) grew alfalfa in boxes of sand and perlite, 40 cm deep. Nitrate applied at the surface, above the zone of nodulation, improved growth; but nitrate placed at 25 cm depressed growth, perhaps because it gave maximum interference with nodulation yet was unavailable to most of the absorbing roots (fig. 2). Unfortunately, in the field there is little possibility of controlling the placement of a mobile form of N like nitrate. However, Toenjes might have achieved such control with his small doses of water-run ammonia.

Apart from Toenjes's local experience, there is little basis for predicting rates, methods, and seasonal conditions that would give economic benefits from nitrogen application. Some of the difficulties become clear from a glance at results of greenhouse experiments by Hoglund, in New Zealand (3). In his sand cultures, with one variety of alfalfa, a little ammonium nitrate improved growth (fig. 4a). A little more ammonium nitrate wiped out the benefit, because it eliminated nitrogen fixation (fig. 4b) but did not provide enough nitrogen to compensate. Just how this result might extrapolate to the field is not clear. For one thing, the precise control of N availability in the field is not so simple as in a greenhouse sand culture. For another, Hoglund's data show marked differences in response between different genetic lines of alfalfa (fig. 4c). In California, about 30 alfalfa varieties are important. By some miracle they all seem to combine more or less effectively with the rhizobia present in most of our alfalfa soils. It would be even more a miracle if they responded precisely alike to small additions of N, in all soils and seasons.

Table 1

Effects of N fertilizer on hay yield and protein content of alfalfa in Indiana. (from Rhykerd et.al. (9)).

N applied annually lb/acre	hay yield tons/acre			protein content, %		
	1967	1968	1969	1967	1968	1969
0	6.3	8.4	7.0	19	17	
100	5.5	7.9	6.7	19	18	
200	5.8	7.6	6.7	18	18	
400	5.9	8.1	7.4	18	18	
800	5.9	8.3	7.2	19	19	

Other Effects: N improved plant appearance, increased succulence, slightly reduced stand density and slightly increased weed incidence.

Table 2

Effects of N fertilizer in year of establishment, Prince Edward Is., Canada. (established on acid soil limed to pH 6, with commercial inoculant; from Kunelius (4)).

	dry matter yield			kg/ha	
N applied kg/ha	exp. 1 first cut	exp. 2 first cut	exp. 2 second cut	exp. 3 first cut	exp. 3 second cut
0	156	1530	1490	1560	2170
25	320	1600	1530	1810	2280
50	290	1600	1600	2080	2110
100	370	1540	1620	2210	2140

Other Effects: N reduced number of nodules, increased yield of weeds by 50%
(from H. T. Kunelius, 1974, Agronomy Journal, 66, 806-809.)

Table 3

Effects of fertilizer-N on established stands in Wisconsin.
(from Lee and Smith (5)).

1968. N applied at 0, 56, 112, 224, 448, 896 kg N/ha
applied in Spring: no effect on first cut.
applied after first cut, yield of second cut. tons/acre

no N........................1.4
N rates 56-448..............1.5
N rate 896..................1.2

1969-1970. N applied in single applications of 336 kg/ha or split applications of 168 kg/ha, either in spring or following first or second cuts. All N treatments improved season yield and protein content, equally, as follows:

	1969			
	yield ton/acre	% protein	yield ton/acre	% protein
no N:...............	4.4	1.7	4.2	1.9
N added:............	4.7	1.9	4.9	2.2

Table 4

Some Field Trials with Nitrogen Fertilizer in California.

	Yield Level (no N added) tons/acre/cut	N rate lb/acre	yield increase
Madera Co. 1962. C. Johnson			
1 season 5 cuts*	1.2-2.1	50	none
Monterey Co. 1962-65			
D. Ririe & H. Agamalian	0.5-2	80	none
20 cuts over 4 years		each yr	
Tulare Co. 1965-66. W. Sallee			
June application, several trials.	2	100	none
1 trial on Chino clay, 1 cut	1.9	100	2% ?
		400	10%
Siskiyou Co. R. Benton. 1968.			
first cut, alfalfa + orchard grass	2	400-800	44%
Alturas 1968. J. Robison	1.3	100	20%
new stand, probable S defic.		300	40%
N as ammon. sulfate. 1st cut		600	50%
2nd cut	1.0	100	20%
		300	25%
		600	30%
Imperial Valley Station.			
W. Lehman. winter application	4.5		
6 cuts, 1968	(green)	200	none
first cut, 1969		200	9%
5 later cuts, 1969		200	none
Davis, 1973. D. Munns			
July application, one cut	1.5	500	10%
Glenn Co. 1971-73			
D. Toenjes, water run NH_3			
summer, shallow soils	1.0	30	ca 50%

Except where indicated, these trials were done on established stands

refers to number of cuts on which yields were measured.

References

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8. Munns, D.N., V.W. Fogle, and B.G. Hallock. 1977. Alfalfa root nodule distribution and inhibition of nitrogen fixation by heat. Agron. J. (in press).

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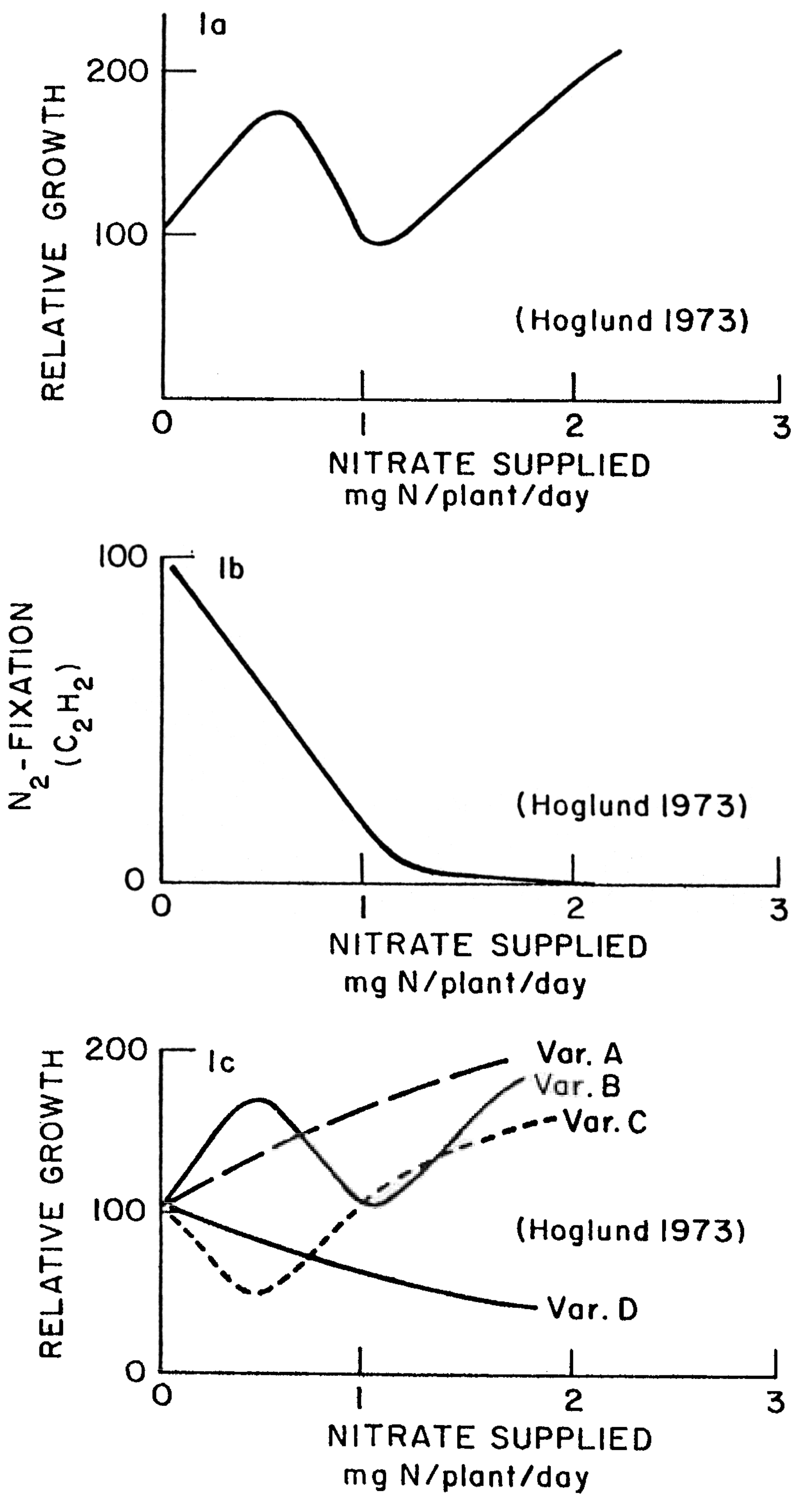
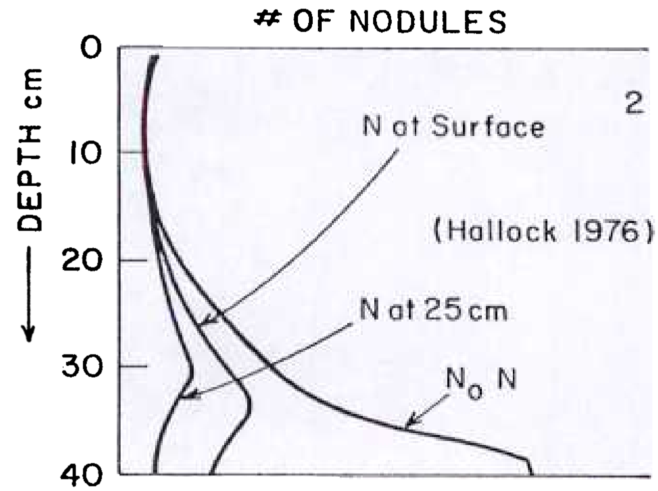
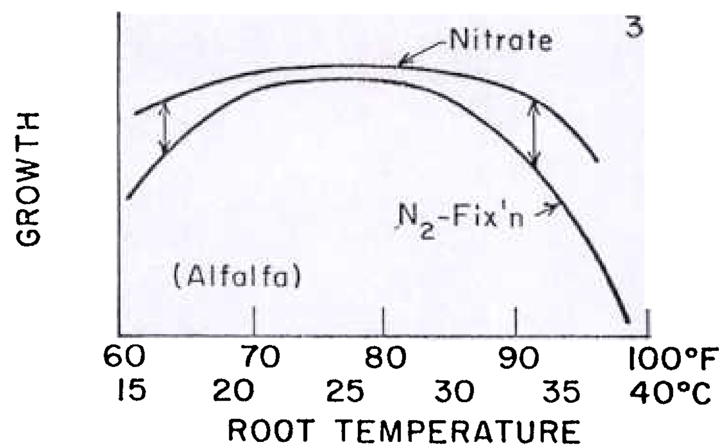
Figures 1a, 1b, 1c



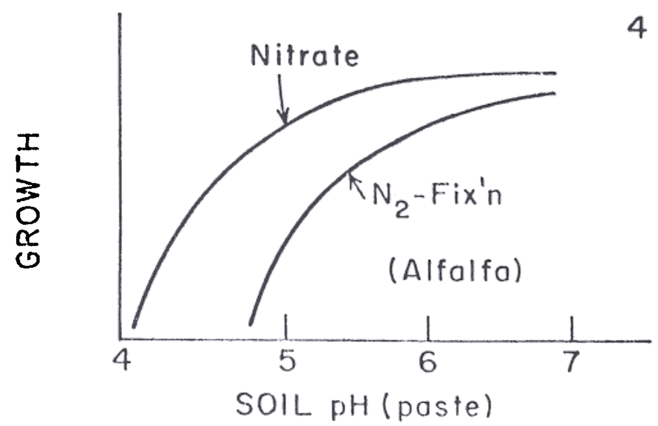
Figures 2, 3, 4



OF NODULES
DEPTH cm
0
10
20
30
40
2
N at Surface
(Hallock 1976)
N at 25cm
N_o N



3
Nitrate
GROWTH
N_2-Fix'n
(Alfalfa)
60
70
80
90
100°F
15
20
25
30
35
40°C
ROOT TEMPERATURE



4
Nitrate
GROWTH
N_2-Fix'n
(Alfalfa)
4
5
6
7
SOIL pH (paste)