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INFLUENCE OF PHOSPHORUS AND LIME ON THE YIELD OF ALFALFA GROWN ON A CHARLTON FINE SANDY LOAM SOIL

D. W. Allinson[1]

Applications of lime are frequently made to acid soils prior to the establishment of many forage species, especially legumes. The changes in the soil environment occurring from such applications have been enumerated frequently (Baker and Brady, 1954; Coleman, Kamprath, and Weed, 1958; White, 1967; Fisher, 1969). While the advantages to be gained from liming acid soils are not in question, the degree of change in the soil reaction necessary for optimum crop growth and the basis to be used for subsequent lime recommendations would appear to be debatable (McLean, 1970; Kamprath, 1970).

Phosphorus (P), too, is usually added to the soil prior to crop establishment and further topdressings applied during the life of most productive forage stands. While alfalfa may respond positively to P additions (Thurlow and Smith, 1960; Parsons and Davis, 1960), it is questionable whether applications should be made frequently with small P levels or rather with one large initial application. Terman, Doll, and Lutz (1960) indicated that while heavy initial P applications, compared to smaller broadcast or topdressed applications, resulted in higher immediate forage yields, yield results in subsequent years were reversed. However, Kamprath (1969) has indicated that, even on soils with a high P fixing capacity, large initial P applications had a marked residual effect on the yield of corn (*Zea mays* L.) for up to 7-9 years.

Initiated in 1959 by the late B. A. Brown, this study evaluated the influence of (a) lime rate and placement and (b) P level—in particular the residual effect of large P applications—on the dry matter (DM) yield and vigor of alfalfa.

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MATERIALS AND METHODS

The experiment was established on a Charlton fine sandy loam soil in an area previously used solely for pasture experiments. The pasture experiments had been terminated some 5 years prior to the initiation of the experiment reported herein. Initial soil analyses indicated pH values at depths of 0-15 and 15-30 centimeters (cm) of 6.1 and 6.0, respectively, and medium P and low potassium (K) levels, using the Morgan soil test procedure (Morgan, 1935).

The 7^2 factorial experiment, replicated four times and set out in randomized complete blocks, was established in the late summer of 1959. Plot size was 6.1 by 2.1 meters (m). Dolomitic limestone and superphosphate (46%) were added to establish the treatment levels tabulated in Table 1. The limestone used analyzed as 30% calcium oxide and 18% magnesium oxide (neutralizing value 98.6) and ground so that 98% passed a 20-mesh sieve and 40% passed a 100-mesh sieve. Following the application of lime and P treatments the entire area was carefully disked, spiketoothed, and cultipacked. 'Vernal' alfalfa (*Medicago sativa* L.) was broadcast at a rate of 16.8 kilograms per hectare (kg/ha) and the area was then cultipacked. All plots received annual applications of approximately 168 kg/ha K. In addition, 45 kg/ha of borax was applied in 1959 and a further 34 kg/ha applied in 1969.

Table 1. Lime and P treatments and their respective designations.

Lime		P	
Treatment designation	Rate and method of application	Treatment designation	Rate and method of application
	m tons/ha*		kg/ha†
L_1	2.24 broadcast	P_1	45 broadcast
L_2	4.48 broadcast	P_2	45 broadcast plus 45/annum, 1960-1969
L_3	8.96 broadcast	P_3	91 broadcast
L_4	17.92 broadcast	P_4	181 broadcast
L_5	35.84 broadcast	P_5	181-50% plowed down, 50% broadcast
L_6	13.44 plowed down	P_6	363 broadcast
L_7	35.84-50% plowed down, 50% broadcast	P_7	363-50% plowed down, 50% broadcast

*To convert m tons/ha to tons/acre, multiply by 0.446.
†To convert kg/ha to lb/acre, multiply by 0.891.

Plots were harvested twice per year, usually when alfalfa reached full bloom, 1960 through 1966. In 1968, two further harvests, the second and third from a three-cutting schedule, were measured. Visual estimates of stand vigor—based on the ground area covered, purity of stand, and the apparent vigor of alfalfa growth—were taken 3 weeks after seeding and again in 1961 and 1968.

In 1969, the original stand was carefully disked to kill the existing

vegetation. Plots were disked seven times and, in addition, one application of paraquat at 18.7 liters per hectare (l/ha) was made. 'Iroquois' alfalfa was seeded at a rate of 13.4 kg/ha on August 1, 1969. Seeding was accomplished using a band-seeder though no fertilizer was drilled. On August 25, 1969, the seedling stand was sprayed with 2,4-DB at a rate of 4.7 l/ha. Seedling establishment was excellent and visual estimates of stand vigor were taken October 7, 1969. In 1970, three harvests were taken, the first at late bud and the remaining two at approximately 6-week intervals.

Soil samples were obtained from all plots at 0-15 cm depths in 1961, 1968, and 1970. The pH of these samples was measured in a 1:1, soil : water suspension. Approximately 4 grams (g) of each of the samples taken in 1968 was extracted in 20 milliliters (ml) of 1.25 normal (*N*) acetic acid + 0.625 *N* ammonium hydroxide (pH 4.8) for 15 minutes (McIntosh, 1969). The soil extracts were analyzed for P colorimetrically using the technique of Dickman and Bray (1940) and for calcium (Ca) using the Technicon Autoanalyzer flame photometer with 10 parts per million (ppm) lithium as the internal standard[2].

Yield data, expressed on a dry matter basis, was subjected to analysis of variance for each individual year during the period 1960-1966 and for 1968 and 1970. Total accumulated yields for the period 1960-1966 were similarly analyzed using the split plots in time design discussed by Steel and Torrie (1960). Estimates of stand vigor, expressed in percentages, were also treated to analysis of variance after being subjected to the angular transformation. Significant differences among treatments were tested with Duncan's multiple range test.

RESULTS

Yields

The lime x P interaction was not significant in any year for which yield data were obtained. Similarly, analysis of variance for the accumulated 1960-1966 data indicated no such interaction. Consequently, the yield data presented will be the respective overall means for P and lime.

There were no significant responses to the various lime treatments, as measured by dry matter yields, in the years 1960-1966 (Table 2). Though not significant, there was a slight trend for yields to be higher on those plots receiving the greater rates of lime from 1963 onwards. Responses to lime treatments were also nonsignificant in the analysis of the combined data. In 1968 significant responses to lime were evident with increased yields being associated with the greatest initial lime levels. It should be noted, however, that 1968 was the ninth harvest year. Significant ($P<0.05$) differences were also evident in the new stand in 1970. As in 1968, the greatest yields were associated with the greatest initial lime applications. In no year was there any significant difference between the L_5 and L_7 treatments, i.e., 35.84 metric tons per hectare

[2]Soil analyses conducted by the University of Connecticut, Soil Testing Laboratory

Table 2. Mean dry matter yields of alfalfa obtained from seven lime treatments in the period 1960-1966, 1968, and 1970.

Lime treatment	Yield m ton/ha									
	1960	1961	1962	1963	1964	1965	1966	1960-1966*	1968	1970
L_1	11.95	9.41	8.47	8.83	7.55	6.11	6.93	8.47	$4.05^{b\dagger}$	6.61^{c}
L_2	11.71	9.18	8.41	9.05	7.55	6.25	6.88	8.43	3.80^{b}	6.71^{bc}
L_3	11.64	9.35	8.30	8.98	7.56	6.27	6.69	8.40	4.12^{ab}	6.78^{bc}
L_4	11.66	9.20	8.38	8.95	7.49	6.25	6.94	8.41	4.06^{b}	6.88^{abc}
L_5	11.67	9.01	8.61	9.03	7.87	6.64	7.22	8.58	4.51^{a}	7.40^{a}
L_6	11.64	9.30	8.64	8.96	7.66	6.28	7.02	8.50	4.21^{ab}	6.56^{c}
L_7	11.83	9.32	8.68	9.37	7.86	6.41	7.12	8.66	4.50^{a}	7.20^{ab}
Mean	11.73	9.25	8.50	9.02	7.65	6.32	6.97	8.49	4.18	6.88

*Accumulated yields for this period.

†Numbers within column followed by the same letter are not significantly different, Duncan's multiple range test ($P<0.05$).

(m tons/ha) of lime broadcast or a like amount applied in split applications, 50% plowed down and the remainder broadcast.

Response to P treatments did not become significant until 1962, though there were trends in both 1960 and 1961 for yields to increase with increasing P level (Table 3). Significant differences were evident on the basis of P treatments from 1962 onwards. In the period 1960-1966, there was no significant difference among the treatments P_2, P_6, and P_7. These treatments were consistently associated with superior alfalfa yields. This was also the situation when the combined data were analyzed. In 1968, the treatments P_2 and P_7 were significantly superior to other P levels. In 1970, however, treatment P_2 produced alfalfa yields significantly ($P<0.05$) greater than other treatment yields and, as in 1968, yields from treatment P_7 were significantly ($P<0.05$) greater than those

Table 3. Mean dry matter yields of alfalfa obtained from seven P treatments in the period 1960-1966, 1968, and 1970.

P treatment	Yield m ton/ha									
	1960	1961	1962	1963	1964	1965	1966	1960-1966*	1968	1970
P_1	11.32	9.12	$8.08^{d\dagger}$	8.17^{c}	6.84^{d}	5.40^{d}	6.18^{d}	7.87^{d}	3.89^{b}	6.14^{e}
P_2	11.58	9.40	8.76^{ab}	9.39^{a}	8.11^{ab}	6.87^{ab}	7.67^{a}	8.82^{a}	4.60^{a}	8.15^{a}
P_3	11.69	9.33	8.31^{cd}	8.91^{ab}	7.28^{cd}	6.22^{bc}	6.54^{cd}	8.33^{c}	4.07^{b}	6.29^{de}
P_4	11.81	9.31	8.43^{bcd}	9.12^{ab}	7.50^{c}	5.82^{cd}	6.68^{cd}	8.38^{bc}	4.02^{b}	6.52^{cde}
P_5	11.77	9.07	8.44^{bcd}	8.72^{b}	7.59^{bc}	6.36^{bc}	6.96^{bc}	8.41^{bc}	3.96^{b}	6.72^{cd}
P_6	11.96	9.15	8.64^{abc}	9.42^{a}	7.85^{abc}	6.50^{ab}	7.40^{ab}	8.70^{ab}	4.15^{b}	6.88^{c}
P_7	11.99	9.38	8.84^{a}	9.43^{a}	8.38^{a}	7.04^{a}	7.38^{ab}	8.92^{a}	4.57^{a}	7.44^{b}
Mean	11.73	9.25	8.50	9.02	7.65	6.32	6.97	8.49	4.18	6.88

*Accumulated yields for this period.

†Numbers within a column followed by the same letter are not significantly different, Duncan's multiple range test ($P<0.05$).

from P_6. However, in comparing treatment P_2 with other P treatments, it should be pointed out that applications of P after 1966 were providing P in excess of the P levels of either treatments P_6 or P_7. Consequently, a comparison of method of application is confounded with rate of P applied. Generally, throughout the experiment, yields of alfalfa increased with increasing levels of P. Yields declined yearly with the exception of 1963 and 1966 when yields increased compared to the previous years.

Stand Vigor

Seedling establishment was good. Visual estimates of seedling growth made 3 weeks after seeding are summarized in Table 4. As with the yield data, neither the lime x P interaction nor the lime main effect differences were significant. However, there was a significant improvement in seedling establishment with increased P level; a similar though nonsignificant response, already mentioned, was observed with yield in 1960.

Table 4. Seedling and stand vigor in 1959, 1961, 1968, 1969, and 1970 as related to P and lime treatments. Data in the original form.

	Year				
Treatment	1959	1961	1968	1969	1970
P_1	58^{c*}	84	55	74^{c}	57^{e}
P_2	60^{c}	85	51	90^{a}	84^{a}
P_3	69^{b}	84	56	75^{c}	62de
P_4	74^{b}	84	59	73^{c}	61de
P_5	71^{b}	84	50	81^{b}	67^{cd}
P_6	81^{a}	81	55	81^{b}	70^{bc}
P_7	81^{a}	85	57	83^{b}	75^{b}
L_1	72	83	52^{b}	78^{b}	61^{c}
L_2	72	82	51^{b}	79^{b}	65^{bc}
L_3	71	84	53^{b}	78^{b}	67^{bc}
L_4	67	84	49^{b}	79^{b}	68^{bc}
L_5	71	86	60^{ab}	85^{a}	78^{a}
L_6	73	85	53^{b}	78^{b}	65^{bc}
L_7	70	85	65^{a}	82^{ab}	73^{ab}

*Numbers within a column, for either P or lime, followed by the same letter are not significantly different, Duncan's multiple range test ($P<0.05$).

In 1961, neither the main effects nor their interactions were significantly different in their effects on stand vigor. Differences in stand vigor, evident in 1959 relative to P level, were no longer apparent. A response to lime treatments was evident in 1968 ($P<0.01$) though not to P level. The L_7 treatment resulted in superior stands compared to other lime treatments with the exception of L_5. The loss of alfalfa vigor and density was accompanied by a gradual encroachment into the plots by orchardgrass (*Dactylis glomerata* L.) and quackgrass (*Agropyron repens* (L.) Beauv).

Significant differences in seedling vigor were evident on the basis of both lime and P in 1969. Estimates were taken 9 weeks after reseeding. Alfalfa grown under the L_5 treatment was superior to that grown under all other treatments except L_7. Alfalfa grown on plots receiving annual applications of P (P_2) was superior to that grown under all other treatments. Seedling establishment was significantly better under the higher P levels. Trends in 1970 were similar to those of 1969.

Soil Analyses

The pH values of soil samples taken in 1961 and 1968 are shown in Table 5. By 1961, the pH values for all treatments had increased over the initial 1959 value. Surprisingly, there was little difference in pH values from applications of 2.24 and 35.84 m tons limestone/ha. The pH values of the L_1, L_2, L_3, and L_6 treatments in 1968 had declined from 1961 values, while the values of the remaining treatments had increased compared to the 1961 values. Values for L_5 and L_7 were identical, as were yields from these treatments, indicating no apparent difference between broadcast lime and broadcast plus incorporated lime.

Table 5. Soil pH in 1961, 1968, and 1970 and available Ca and P levels in 1968 and 1970 as related to lime and P treatments.

Treatment	Year and analysis						
	1961	1968			1970		
	pH	pH	Ca	P	pH	Ca	P
			kg/ha			kg/ha	
L_1	6.4*	6.1	1812	2.1	6.0	2036	2.9
L_2	6.5	6.2	1924	2.2	6.2	2208	2.8
L_3	6.5	6.4	2144	2.0	6.3	2336	2.6
L_4	6.5	6.6	2316	1.9	6.5	2592	2.4
L_5	6.5	6.8	2560	2.0	6.8	2936	2.6
L_6	6.5	6.4	2248	2.1	6.4	2440	2.5
L_7	6.6	6.8	2604	1.8	6.7	2728	2.2
P_1	6.5	6.5	2236	1.5	6.4	2444	1.8
P_2	6.6	6.5	2464	3.1	6.4	2604	4.6
P_3	6.5	6.5	2220	1.7	6.4	2440	2.0
P_4	6.5	6.5	2112	1.6	6.4	2456	2.1
P_5	6.5	6.4	2108	1.8	6.4	2368	2.4
P_6	6.4	6.4	2128	2.0	6.4	2428	2.5
P_7	6.5	6.5	2340	2.3	6.4	2536	2.6

*Values are means of 28 observations.

Available Ca levels followed the trends of the 1968 pH values and, naturally, initial lime application levels. The P_2 treatment had the greatest Ca level compared to other P treatments, a fact which may be attributed to the annual application of superphosphate.

Available P levels were low, certainly in comparison to current Connecticut recommendations which label available soil P levels of 8-13, and 21-34 as being medium and high, respectively. The P_2 and P_7 treatments had the highest P values and these treatments produced significantly higher yields than other P treatments in 1968. Though differences in P values were slight, there were corresponding significant differences in yield. Similarly, these P treatments had the highest available Ca levels in 1968. The simple correlation between pH and DM yield in 1961 was 0.03 (nonsignificant). Similar correlations calculated between 1968 yields and available Ca, P, and pH were 0.54, 0.36, and 0.48, respectively. These three latter values were significant ($P<0.01$).

The pH values in 1970 were generally lower while P and Ca values were slightly higher than in 1969. The unexpected increase in P and Ca values perhaps may be attributed to the disking and decomposition of the original alfalfa stand during the fallow year of 1969.

DISCUSSION

There was no significant response by Vernal alfalfa to varying lime treatments in the period 1960-1966. From these data, it would appear that the smallest lime level applied–2.25 m ton/ha–was sufficient to permit adequate crop growth in the 1960-1966 period when the initial soil pH was 6.1-6.0. In 1961, the pH of the plots receiving the L_1 treatment was 6.4. It is interesting to note that in both 1960 and 1961 the L_1 treatment produced the highest yields compared to the other lime treatments.

In 1968, significant differences in dry matter yield as the result of different lime levels were observed. However, there was no significant difference in yield between the L_3, L_6, L_5, and L_7 treatments. The respective mean pH values of the plots receiving these treatments was 6.4, 6.4, 6.8 and 6.8. These data, along with the yields and soil test data from 1961, would suggest that liming to a pH of 6.4 was adequate for alfalfa growth. The validity of this conclusion may, however, be questioned. In 1968, both the L_5 and L_7 treatments gave significantly greater yields than the L_4 treatment. The mean pH value for plots receiving the L_4 treatment was 6.6. In 1970, there was no significant difference in dry matter yield between treatments L_4, L_5 and L_7. The pH of these plots was 6.5, 6.8, and 6.7, respectively. Significant differences in yield between treatments L_5 and L_7 were not evident. This would suggest that there was no advantage to applying and incorporating lime in both plow-down and broadcast applications. However, since there was no significant response to lime at any rate in the period 1960-1966, it would appear that speed of incorporation of lime was not of importance.

The soil pH beyond which little or no improvement in crop yield occurs is debatable. MacLeod and Bradfield (1963) indicated that liming to a pH of 5.8-6.0 was adequate for alfalfa and orchardgrass grown on a Mardin silt loam. Similarly, Moschler, Jones, and Thomas (1960) showed that, though yields of alfalfa were increased by liming an acid Tatum silt loam soil at rates up to 35.84

m tons/ha, increases in yield beyond the 2.24 m ton/ha rate were not significant. The pH at this latter rate was 5.7. However, though all alfalfa stands were initially vigorous, rates of lime below 2.24 m ton/ha resulted in a rapid loss of productive stands and the 2.24 m ton/ha treatment resulted in an approximate 20% decrease in stand by the third harvest year. Fisher (1969) reported that yields of alfalfa were usually not increased, or increased very little, when the soil pH_S (pH measured in 1:1 soil : 0.01 molar (*M*) $CaCl_2$ suspension) was above 5.8. Yields decreased as pH_S values declined below 5.0.

Woodhouse (1970) suggests that whenever sufficient limestone has been supplied to the soil to raise the pH to 6.0 or above, little exchangeable aluminum (Al) exists. Similarly, White (1967) indicates that effective nodulation will occur provided the soil pH is 6.0 or higher. Consequently, in this experiment, the advantages normally associated with liming acid soils—decreased concentration of Al or manganese, increased nodulation—may not have been apparent since these adverse conditions did not exist at the initiation of the experiment.

Though varying considerably, the P-fixing capacity of some soils may be very large (Toth and Bear, 1947). However, in no year during the period 1960-1966 was there any significant difference between the mean alfalfa yields obtained from P_2, P_6, or P_7 treatments. These data would agree with those of Kamprath (1967) in that large initial applications of P made prior to crop establishment are not lost or irreversibly fixed but are available for plant growth in subsequent years.

The incorporation of P throughout the plow layer by both plow-down and disking appeared to have little value in the period 1960-1966. During this period, there were no significant differences between treatments P_4 and P_5 and between P_6 and P_7. In 1968 and 1970, however, treatment P_7 gave alfalfa yields significantly ($P<0.05$) greater than those from P_6. In these two years, however, there were no significant differences in yields between treatments P_5 and P_4. In both years available P levels were higher in those plots where P had been both disked and plowed down compared to equivalent levels disked in only.

It has been suggested that one of the benefits of liming is to increase the availability of soil phosphate to plants (Longenecker and Merkle, 1952; Coleman et al., 1958). While a significant response to P level was evident from 1962 onwards there was, in this same period, no lime x P interaction.

SUMMARY

'Vernal' alfalfa (*Medicago sativa* L.) was grown under 49 combinations of lime and P treatments. The alfalfa was harvested twice per year in the period 1960-1966 and again in 1968, and DM yields determined. Initial soil pH at the 0-15 cm depth was 6.1, and the soil tested medium in P. In the period 1960-1966 there were no significant ($P<0.05$) differences evident, as reflected by DM yields, among lime levels ranging between 2.24-35.84 m ton/ha. Levels of P ranged from 45-363 kg/ha. Significant yield differences were evident from 1962 onwards as a result of P level. However, there was no significant difference

between small annual P applications and a single heavy P application made prior to alfalfa establishment. In no year was the lime x P interaction significant. Seedling stand vigor was influenced by P level though these differences were not significantly reflected by yield data in the following year.

In 1968, significant yield differences were evident on the basis of both lime and P level. The range in pH in 1968 between varying lime levels was 6.0 to 6.8, the optimum pH range for alfalfa yields being 6.4-6.8.

In 1969, the original stand was removed and the plots reseeded with 'Iroquois' alfalfa. Significant ($P<0.05$) yield response to both lime and P were evident in 1970. Optimum pH range for yields in 1970 was 6.5-6.8.

REFERENCES

1. Baker, A., and N. C. Brady. 1954. Yield and mineral composition of alfalfa and sunflowers as influenced by the degree of reaction of calcium carbonate with two acid soils. Soil Sci. Soc. Amer. Proc. 18:404-408.
2. Coleman, N. T., E. J. Kamprath, and S. B. Weed. 1958. Liming. Advance. Agron. 10:475-522.
3. Dickman, S. R., and R. H. Bray. 1940. Colorimetric determination of phosphate. Ind. Eng. Chem. Anal. Ed. 12:665-668.
4. Fisher, T. R. 1969. Crop yields in relation to soil pH as modified by liming acid soils. Missouri Agr. Exp. Sta. Res. Bull. 947.
5. Kamprath, E. J. 1967. Residual effect of large applications of phosphorus on high phosphorus fixing soils. Agron. J. 59:25-27.
6. Kamprath, E. J. 1970. Exchangeable aluminum as a criterion for liming leached mineral soils. Soil Sci. Soc. Amer. Proc. 34:252-254.
7. McIntosh, J. L. 1969. Bray and Morgan soil extractants modified for testing acid soils from different parent materials. Agron. J. 61:259-265.
8. MacLeod, L. B., and R. Bradfield. 1963. Effect of liming and potassium fertilization on the yield and composition of an alfalfa-orchardgrass association. Agron. J. 55:435-439.
9. McLean, E. O. 1970. Lime requirements of soils—inactive toxic substances or favorable pH range. Soil Sci. Soc. Amer. Proc. 34:363-364.
10. Morgan, M. F. 1935. The universal soil testing system. Conn. Agr. Exp. Sta. Bull. 372.
11. Moschler, W. W., G. D. Jones, and G. W. Thomas. 1960. Lime and soil acidity effects on alfalfa growth in a red-yellow podzolic soil. Soil Sci. Soc. Amer. Proc. 24:507-509.
12. Parsons, J. L., and R. R. Davis. 1960. Forage production of Vernal alfalfa under differential cutting and phosphorus fertilization. Agron. J. 52:441-443.
13. Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co. Inc. 480 p.
14. Terman, G. L., E. C. Doll, and J. A. Lutz, Jr. 1960. Rate, source, time, and method of applying phosphates for alfalfa and legume grass hay and pasture. Agron. J. 52:261-264.
15. Thurlow, D. L., and F. W. Smith. 1960. Rock phosphate and superphosphate as sources of phosphorus and calcium for alfalfa. Agron. J. 52:313-317.
16. Toth, S. J., and F. E. Bear. 1947. Phosphorus-absorbing capacities of some New Jersey soils. Soil Sci. 64:199-211.
17. White, J. G. H. 1967. Establishment of lucerne on acid soils. p 105-113. *In* R. H. M. Langer (ed.) The lucerne crop. A. H. and A. W. Reed, Wellington.
18. Woodhouse, W. W., Jr. 1970. Effect of placement of phosphorus and lime on the growth of a ladino clover-orchardgrass sward. Agron. J. 62:458-461.