MINERAL NUTRITION AND PERSISTENCE OF LUCERNE ON THE GRANITE BELT OF SOUTH-EAST QUEENSLAND

N. M. CLARKSON* AND C. S. ANDREW†

ABSTRACT

The effects of phosphorus, sulphur, copper, boron, molybdenum and various calcium carbonate treatments on the yield and persistence of lucerne were measured at two sites (Ballandean and Dalveen) on the granite belt of south-east Queensland.

Phosphorus and calcium carbonate increased the dry matter yield of lucerne, the effects being additive. When both nutrients were applied, annual lucerne yields increased from 1500 to 5200 kg per hectare at Ballandean and from 3500 to 7700 kg per hectare at Dalveen. Lime at 250 kg per hectare drilled with the seed produced a yield equal to that from 2500 kg per hectare broadcast. Small sporadic yield responses to copper and boron occurred but there was no response to sulphur or molybdenum.

The phosphorus content of plant crops increased linearly with increasing rates of application of phosphorus but the critical levels varied considerably among harvests.

Initial lucerne density was highest in treatments receiving phosphorus, calcium carbonate (lime pelleting or broadcast lime) or boron, but differences in density were small compared to the decline in density over three years. The stands were productive for at least six years.

INTRODUCTION

An area of granite soils, known as the 'granite belt', occupies 11,000 km^2 in south-east Queensland from Warwick to the New South Wales border, and extends into northern New South Wales. Apart from the horticultural area near Stanthorpe, the region supports mostly unproductive, poor quality native pastures suitable only for wool growing. Pastures based on lucerne (*Medicago sativa*) and winter annual legumes (Clarkson 1970) grazed in conjunction with oats permit breeding and fattening of sheep and cattle. Adequate information on the nutrient requirements of improved pastures is needed, particularly as rising fertilizer costs and fluctuating returns have reduced the profitability of wool and beef.

Trials with lucerne revealed widespread yield responses to applied phosphorus and calcium and occasional small responses to added copper, boron and molybdenum (Lee and Cassidy, unpublished data).

The present project began in 1968 with preliminary pot trials on soil from three sites, using lucerne. Yield responses were obtained with phosphorus, sulphur, calcium, copper, boron and molybdenum (Andrew, unpublished data). This paper reports the results of subsequent field experiments on two of the sites used in the pot trials. It examines the effects of the six responsive nutrients on the dry matter production and persistence of lucerne.

MATERIALS AND METHODS

The field sites were at Ballandean and Dalveen. Vegetation was grass-dominant native pasture previously under temperate woodland. The soil at both sites is podzolic consisting of a grey coarse sand (15-20 cm deep) on a sandy mottled yellow clay which overlies granite rock. Chemical characteristics of the surface soil are shown in Table 1.

* Queensland Department of Primary Industries, Warwick, Qld. 4370.
† CSIRO, Division of Tropical Crops and Pastures, Cunningham Laboratory, St. Lucia, Qld. 4067.

TABLE 1

Soil chemical data

(a) *Chemical analysis of surface soil* (0-10 *cm*)

	Ballandean	Dalveen
pH (1:5 water)	6.0	5.9
% Total soluble salts	0.008	0.01
% NaCl	0.006	0.006
% Total N	0.062	0.072
Available P (ppm, method of Kerr & Von Stieglitz, 1938)	18	11
Cation exchange capacity (me%)	4.8	5.1
Exch. Mg (me%)	0.23	0.73
Exch. Ca (me%)	1.5	2.2
Exch. K (me%)	0.19	0.22
Exch. Na (me%)	0.04	0.04
% Saturation	40.9	62.5

(b) *Phosphate-extractable sulphate in soil profile* (*ppm S, method of Barrow* (1967))

Depth	Ballandean	Dalveen
0- 5cm	4.6	<0.1
5-15	0.1	0.2
15-30	<0.1	<0.1
30-45	<0.1	<0.1
45-60	0.1	<0.1
60-75	5.0	6.1
75-90	<0.1	10.5

Three experiments incorporating phosphorus and lime treatments, sulphur and lime, and trace elements and lime were established at each site. Details of the experimental designs and treatments are given in Table 2. All trials were sown at 11 kg ha^{-1} with seed of *M. sativa* cv. Hunter River inoculated with commercial *Rhizobium* inoculum. Plots were 19.3 m^2 with a sample area of 2.8 m^2. Samples were cut at a height of 3 cm with an autoscythe and the surplus growth was removed by heavy grazing after each harvest. Samples from the first harvest at Ballandean were hand-sorted to remove weeds. All other samples contained negligible weeds.

Experiment 1—Rates of phosphorus and lime

Five phosphorus rates with and without lime were broadcast on the soil surface in May 1969 and the lucerne was established in July 1969. Yields were measured whenever reasonably good growth had occurred. The Ballandean site was harvested in November 1969, February, October and December 1970, January, March and October 1971 and February 1972. The Dalveen site was harvested in February and November 1970, March and September 1971, and January and February 1972. Sub-samples were taken from the cut material for chemical analysis. Lucerne plant density was measured at 8 months, 2 years and 3 years after planting. Phosphorus was re-applied at one quarter of the original rate in August 1970 and October 1971. All plots received sulphur at 34 and 11 kg ha^{-1} in 1970 and 1971 respectively, and boron at 5.6 kg ha^{-1} in both years. Molybdenum and copper were not re-applied.

Experiment 2—Rates of sulphur and lime

Five rates of sulphur with and without lime were applied in May 1969, and both the planting day and the harvest dates were the same as for Experiment 1. The last

TABLE 2

Details of experiments on each site

Experiment	Design	Variable Tested	Chemical Applied	Rates of Variable ($kg\ ha^{-1}$)	Basal Elements
1	5 x 2 complete factorial, 4 replicates	P Ca	Mono-calcium orthophosphate Agricultural lime	0, 12, 24, 48, 96 of P 0, 2500 of lime	K as KCl at 125 $kg\ ha^{-1}$ S as magnesium sulphate at 258 $kg\ ha^{-1}$ Mo as sodium molybdate at 1.1 $kg\ ha^{-1}$ Cu as copper carbonate at 3.3 $kg\ ha^{-1}$ B as borax at 11.2 $kg\ ha^{-1}$
2	5 x 2 complete factorial, 4 replicates	S Ca	Flowers of sulphur Agricultural lime	0, 11.2, 22.4, 33.6, 67.2 0, 2500 of lime	K, Cu, B, Mo as above P as mono-calcium orthophosphate at 183 $kg\ ha^{-1}$
3	5 main lime treatments, each split to contain a 2^3 factorial of trace elements, 2 replicates	Lime pelleting Drilled lime Broadcast lime Cu B Mo	Plasterer's lime Agricultural lime Agricultural lime Copper carbonate Borax Sodium molybdate	Absent or present 0, 250 0, 2500 0, 3.3 of compound 0, 11.2 of compound 0, 1.1 of compound	K as above P, S as superphosphate at 500 $kg\ ha^{-1}$

two harvests at Ballandean contained missing plots due to death of lucerne from water-logging. Sulphur treatments were re-applied in August 1970 at one third of the original rate, while in 1970 and 1971 the trial received basal phosphorus at 12 kg ha^{-1} and boron at half the original rate.

Experiment 3—Rates of lime and trace elements

Five lime treatments were applied, each split with a factorial combination of copper, boron and molybdenum. The lime treatments included a control, lime pelleting, untreated seed with drilled lime at 250 kg ha^{-1}, lime pelleting with drilled lime at 250 kg ha^{-1}, and untreated seed with broadcast lime at 2500 kg ha^{-1}. The trial failed to establish in May 1969 due to deep planting in a loose seed-bed but was successfully replanted in July after fertilizer treatments had been applied. The drilled lime was re-applied but the broadcast lime and trace elements were not. Yields were measured at the same times as Experiment 1 with an extra harvest at Ballandean in December 1971. The only treatment to be re-applied was boron, at half the original rate in 1970 and 1971. In both years all plots received superphosphate at 125 kg ha^{-1}.

RESULTS

At Ballandean (mean annual rainfall 761 mm) the three summers were slightly wetter and the winters drier than average, the driest being in 1970 (25% below). At Dalveen (mean annual rainfall 702 mm) both summer and winter rainfall were below average with the 1969-70 summer and the 1970 winter being 27% and 29% below average respectively.

Experiment 1—Rates of phosphorus and lime

The yield of lucerne was substantially increased by phosphorus and lime (Table 3) with only one small interaction. At Ballandean unfertilized lucerne produced a mean annual yield of 1516 kg ha^{-1} for the two years 1970 and 1971. Application of lime alone produced 2948 kg ha^{-1}, optium phosphorus produced 4453 kg ha^{-1}, while phosphorus and lime together produced 5248 kg ha^{-1}. The corresponding yields for one year at Dalveen were 3539 (unfertilized), 3761 (lime alone), 7018 (phosphorus alone) and 7668 kg ha^{-1} (lime and phosphorus together).

TABLE 3

The effect of phosphorus and lime on the dry matter yield of lucerne (kg ha^{-1}, main effects only). Values followed by the same letter are not significantly different at $P < 0.05$.

Harvest Date	Initial phosphorus application (kg $ha^{-1}yr^{-1}$) 0	12	24	48	96	Initial lime application 0	2500
(a) Ballandean							
18/11/69	216a	783b	777b	1133b	998b	664f	899g
7/2/70	602a	876b	987bc	1296c	1314c	886f	1145g
27/10/70	695a	1215b	1310bc	1505bc	1652c	962f	1588g
20/12/70	622a	876ab	1186bc	1542cd	1578d	1078f	1244g
26/1/71	862a	1308b	1330bc	1713c	1659bc	1097f	1652g
8/3/71	1053a	1398b	1384ab	1651b	1475b	1143f	1641g
3/10/71	630a	1124ab	1348bc	1840cd	2024d	1127f	1659g
6/2/72	1322a	1766b	1901bc	2227c	2178bc	1575f	2183g
TOTAL	6003a	9350b	10226bc	12911c	12880c	8534f	12013g
(b) Dalveen							
10/2/70	996a	1120a	1363a	1261a	1602a	1256f	1281f
3/11/70	1331a	1560a	1891b	2061bc	2333c	1790f	1881f
10/3/71	1305a	1549ab	1852bc	1756bc	2021c	1528f	1865g
27/9/71	1004a	1261ab	1607b	2343c	2987d	1700f	1980g
5/1/72	1186a	1276ab	1502bc	1585cd	1753d	1417f	1504g
25/2/72	1796a	1939a	2308b	2364b	2718c	1909f	2540g
TOTAL	7619a	8706a	10526b	11371b	13417c	9603f	11053g

Nitrogen and phosphorus content were measured whenever significant treatment effects occurred. To test the use of critical levels for diagnosis of phosphorus deficiency, the relationship between yield and phosphorus content was examined for each harvest and the critical level was estimated where the yield was 90% of the maximum (Table 4). The values obtained ranged from 0.18% to 0.31%. The increase in phosphorus content with increasing rates of application of phosphorus was approximately linear, the average increase over the full fertilizer range being 0.09% at both sites. Application of lime caused a small additional increase of 0.01%. Similarly phosphorus fertilizer alone raised the nitrogen content by 0.2% at Ballandean and 0.1% at Dalveen. Application of lime increased levels by a further 0.3% at Ballandean only.

TABLE 4

Relationship between dry matter yield (kg ha^{-1}) and phosphorus content (%) of lucerne (without additional lime) and estimated critical levels of phosphorus concentration at 90% of maximum yield.

Harvest Date		Initial phosphorus rate (kg ha^{-1}) 0	12	24	48	96	Critical level of P (%)
(a) Ballandean							
18/11/69	Yield	58	661	786	875	940	
	% P	.22	.23	.26	.29	.37	.28
7/2/70	Yield	426	729	770	1213	1291	
	% P	.17	.18	.18	.19	.22	.18
27/10/70	Yield	288	979	987	1179	1378	
	% P	.21	.22	.22	.24	.29	.26
20/12/70	Yield	461	701	1108	1458	1661	
	% P	.19	.21	.27	.26	.30	.27
26/1/71	Yield	599	1097	983	1335	1469	
	% P	.25	.29	.29	.31	.32	.31
8/3/71	Yield	830	1232	1105	1229	1321	
	% P	.17	.24	.24	.22	.24	.23
3/10/71	Yield	428	791	972	1660	1786	
	% P	.23	.24	.23	.28	.31	.28
6/2/72	Yield	1205	1424	1546	1807	1893	
	% P	.15	.18	.19	.22	.25	.21
(b) Dalveen							
3/11/70	Yield	1351	1385	1784	2119	2312	
	% P	.17	.19	.21	.23	.26	.23
10/3/71	Yield	1193	1299	1712	1603	1836	
	% P	.16	.17	.20	.23	.25	.20
27/9/71	Yield	995	1234	1201	2200	2870	
	% P	.24	.25	.23	.28	.33	.30
5/1/72	Yield	1194	1180	1384	1668	1656	
	% P	.17	.18	.19	.22	.23	.20
25/2/72	Yield	1668	1654	1935	2047	2244	
	% P	.17	.19	.20	.22	.26	.21

The calcium content of lucerne which was checked on one occasion was increased by application of lime from 0.69% to 0.82% at Dalveen and from 0.91% to 1.13% at Ballandean. Manganese and aluminium levels were normal.

Application of phosphorus at all but the highest rate significantly increased lucerne density at establishment from 77 to 98 plants m^{-2} at Ballandean. Lime increased the density from 83 to 99 plants m^{-2}. There were no significant effects of either fertilizer at Dalveen. Plant density was halved in three years at both sites, with the rate of decline being unaffected by treatments.

Experiment 2—Rates of sulphur and lime

Statistical differences between sulphur treatments were obtained in two harvests from each site but the results were not clear. There was no convincing evidence of sulphur deficiency. Responses to lime were obtained four times at Ballandean (yield increases of 20 to 25%) and once at Dalveen (10% increase).

Sulphur fertilizer increased the sulphur content of lucerne. In the one harvest which was analysed, values ranged from 0.17% to 0.28% at Ballandean and from 0.27% to 0.36% at Dalveen. Nitrogen content was also increased by 0.5% and 0.4%, respectively.

Fertilizer treatments had no effect on establishment or persistence of lucerne.

Experiment 3—Rates of lime and trace elements

Differences between lime treatments were not significant at Ballandean, and were significant in only one harvest at Dalveen when yields were increased by application of lime either drilled or broadcast from 1800 to 2200 kg ha^{-1}. These trends were also evident in the total yields over all harvests but differences failed to reach significance.

Application of copper significantly increased yields at Ballandean on three occasions by 9 to 14% and increased average copper levels in plant tops from 5.6 to 6.6 ppm. Application of boron increased yields once at Dalveen by 12% and increased the boron levels from 19.4 to 33.1 ppm. Neither site responded to molybdenum.

Miscellaneous interactions between lime treatments and trace elements also occurred. There was a strong tendency for copper to increase yields in unlimed plots and a slight tendency to depress yields in plots where lime was drilled at 250 kg ha^{-1} in the presence or absence of pelleting. The only sizeable yield increases with boron occurred in unlimed or lime-pelleted plots. Molybdenum tended to depress yields when applied with drilled lime or with copper.

Lucerne density at establishment was significantly increased at Ballandean from 75 plants m^{-2} in unlimed plots to 105 plants m^{-2} in lime pelleted plots with or without drilled lime at 250 kg ha^{-1}, and to 91 plants m^{-2} in plots receiving broadcast lime at 2500 kg ha^{-1}. These trends continued on both sites over three years but were not otherwise statistically significant. On both sites boron significantly increased lucerne density in two years by 5 to 12%, the effect being almost significant in the other year.

DISCUSSION

Liming and the correction of phosphorus deficiency enabled the yield of lucerne to be trebled at Ballandean and doubled at Dalveen (Experiment 1). It is probable that the lime requirement could be supplied with drilled lime at 250 kg ha^{-1} (Experiment 3) although inadequate replication prevented differences from reaching statistical significance. The Dalveen site was more productive than the Ballandean site.

The marginal responses to copper at Ballandean and boron at Dalveen were greatest in the absence of added lime and are unlikely to be of major importance.

Sulphur deficiency in top soil (0-10 cm) used in the preliminary pot trials (Andrew, unpublished data) was not confirmed in the field experiments. Soil sulphur levels were very low (Barrow 1967) but showed modest increases below 60 cm Table 1). This suggests that either lucerne was exploiting subsoil sulphur with its deep root system or that fluctuations in soil sulphur occurred over time. Lack of response to sulphur on other soils in the region with low sulphate levels has been recorded previously (Jones 1970).

The critical levels of phosphorus in Experiment 1 were too variable to be used in the diagnosis of deficiency. The variability was not readily attributable to such factors as the yield of lucerne, time of year, or stage of growth which was late vegetative to early flower initiation. However the average critical levels of 0.25% at Ballandean and 0.23% at Dalveen agreed generally with values of 0.23% reported by Andrew and Robins (1969) from pot experiments. They were higher than the 0.21% of Jones (1973) recorded in field plots at Nanango.

The calcium response was probably due to overcoming calcium deficiency in the plant or to beneficial effects on nodulation and symbiosis, rather than to indirect effects of lime on increased soil phosphorus or molybdenum availability or reduced manganese or aluminium levels. The soils were low in calcium (Table 1) and no interaction occurred with phosphorus. Moreover molybdenum deficiency was eliminated by fertilizing, while manganese and aluminium levels in the plant were normal. Lime application increased the nitrogen content of plants at Ballandean by 0.3% and the calcium content by 0.13% at Dalveen and 0.22% at Ballandean (Experiment 1). These results confirm the restricted ability of lucerne to extract soil calcium (Andrew and Norris 1961).

The copper content of plants was above the critical level of 5 ppm found by Andrew and Thorne (1962) although yield responses occurred at Ballandean. The 11% yield increase obtained at a copper level of 5.6 ppm is consistent with earlier data in which yield increases of 28% occurred at a copper level of 4.6 ppm (Clarkson, unpublished).

Lucerne density declined steadily with time, the effect of fertilizer being mainly on initial population density. Plant density was initially increased by phosphorus and lime at Ballandean, the lime effect being still significant after three years in Experiment 1. Lime pelleting with or without drilled lime was as effective as the heavy broadcast application. Boron also increased lucerne density slightly on both sides but was unimportant in relation to the overall decline in population. These results support the view that fertilizer is only a minor factor influencing the useful lifespan of lucerne stands (Jones 1973) which in these experiments was six or seven years.

It is concluded that for optimum production lucerne seed should be lime pelleted and sown with drilled lime at approximately 250 kg per hectare. Superphosphate should be applied at 250 kg per hectare in the first year and 125 kg per hectare annually thereafter. Molybdenized superphosphate is preferred in the first year as a cheap precaution against molybdenum deficiency. Because of high cost, copper and boron are not recommended unless deficiencies are severe.

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