# Effects of topdressed lime, superphosphate, sewage ash and stocking rate on subterranean clover production of a Southern Tablelands pasture

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**Abstract:** *High levels of phosphorus (P) led to peak subterranean clover production for the first 4 years in a treatment with no lime and a low stocking rate although productivity subsequently declined to low levels, on soils with high levels of* $Al^{3+}$*, low* $pH_{Ca}$ *and under the increasingly dry seasons of the mid-term Millennium Drought. Conversely where high P levels were combined with lime, productivity was high and remained stable over the longer term under the same seasonal conditions. This was associated with reduced soil* $Al^{3+}$ *levels and higher* $pH_{Ca}$ *after liming. At the low P rates (125 kg/ha superphosphate every 2–3 years, 5 t/ha sewage ash) legume productivity was constrained.*

**Key words:** Acid soil amelioration, surface application, drought persistence

## Introduction

On many fragile, non-arable soils grazing animal production from permanent pastures is a relatively sustainable form of agriculture. Legume productivity is pivotal to many of these extensive grazing systems as nitrogen (N) fixation is the primary source of N as well as providing high quality forage. Adequate phosphorus (P) is crucial to maintaining legume production (Richardson 1924) although questions regarding P use efficiency and methods of determining appropriate P levels remain. In addition the build-up of organic matter associated with these systems can acidify soils (Williams 1980), as can the removal of alkalinity due to agricultural production. Soil acidity constrains pasture productivity limiting production from grazing animals. It is estimated that there are 50 M ha throughout Australia with a $pH_{Ca}$ <5.5 and associated increase in soil aluminium ($Al^{3+}$). Many of these areas produce meat and wool, but many Australian farmers are uncertain of the benefits of liming. Research has concentrated on the effects of lime incorporated into the 0–10 cm soil profile. However, incorporation is only an option where land is arable. On the NSW Southern Tablelands, there are large areas of non-arable soils, acidic to depth where the only option to ameliorate acidity is to surface apply lime. Given these knowledge deficiencies in Australia a detailed study is justified of the effects on subterranean clover production of different levels of lime, superphosphate, sewage ash and stocking rate over a time period long enough to ensure that the effects of lime will be acting to ameliorate the acid soil.

## Materials and Methods

A replicated experiment continuously grazed by sheep was conducted (35.12° S, 149.27° E) near Sutton, NSW, Australia. The soils, predominately Chromosols with Leptic Rudosols (Isbell 1996) in higher areas, are mainly shallow (<0.20 to >1.5 m) and stony with texture contrast having brown loam topsoils overlying reddish to reddish brown light clays and clay loams. The climate of the area is warm temperate, with average annual rainfall of 660 mm. In autumn 1998, prior to lime application an initial spray to remove annual grasses and broadleaved weeds whilst retaining the established native perennial grasses was performed. Sowing occurred in May 1998 using a direct drill seeder at a row spacing of 30 cm so as to only minimally disturb the established native perennial grasses, whilst giving a reasonable density of introduced pasture species. The sown mix comprised *Trifolium subterraneum* (subterranean clover) cvv. Goulburn and Seaton Park LF, *Dactylis glomerata* (cocksfoot) cv. Kara, *Phalaris aquatica* (phalaris) cvv. Australian and Holdfast and *Lolium perenne* (perennial ryegrass) cv. Roper at 5.4, 2.6, 1.75, 1.75, 1.75 and 1.75 kg/ha respectively. All legume seed was inoculated and lime pelleted, with an additional treatment of molybdenum trioxide at approximately 100 g/ha applied to the seed.

The soil was strongly acidic to depth with a $pH_{Ca}$ ranging from 4.1 at the surface to 4.7 at 55 cm. In the 0–10 and 10–20 cm profiles $Al^{3+}$ saturation was very high ranging from 30 to 48% of the effective cation exchange complex (ECEC). ECEC levels were low (4.6 cmol+/kg) as were extractable P (9.7 mg/kg, Colwell) and total carbon (3%).

There were three treatment factors, *P*, lime and stocking rate, with different levels, replicated twice. All treatments received a *P* source either as superphosphate (0–9–0–11, N, *P*, potassium, sulphur), at a typical local application rate, P1, 125 kg/ha every 2 to 3 years, at a high, non-limiting rate, P2 (250 kg/ha/yr) or as sewage ash (P3). Four rates of lime were applied at experiment commencement: nil (L0); sufficient lime to increase $pH_{Ca}$ in the 0–10 cm profile to 5.0 (L1); lime to increase $pH_{Ca}$ in the 0–10 cm profile to 5.5 (L2) and sewage ash at 5 t/ha (L3). All lime applied was F70 superfine (70% <75 μm, neutralising value = 97 %). The single rate of 5 t/ha sewage ash (P3L3) contained 14% $CaCO_3$ by weight, 24% CaO and 4.5% MgO, calculated to have a neutralising value of 64%. This ash also contained 23% $Ca_3(PO_4)_2$.

The experiment was set stocked with wethers at two stocking rates, with the lower stocking rate (SR1) being 67% of the higher rate (SR2). The low P treatment was only stocked at SR1 whereas the high P treatment was stocked at both SR1 and SR2. Thus the treatments were combinations of three rates of P, four rates of lime and two stocking rates as follows: P1L0SR1, P1L1SR1, P2L0SR2, P2L0SR2, P2L1SR1, P2L1SR2, P2L2SR2, P2L2SR and P3L3SR2. Stocking rates were modified by seasonal conditions and consequent pasture growth rates. There were extremely dry periods, when pasture growth rates were so low that plots had to be destocked. Plot sizes for SR1 and SR2 were 1 and 0.67 ha respectively.

Herbage mass and botanical composition (as a percentage of herbage mass) were measured in each plot every six weeks, except after April 2002 when measurements were more sporadic due to drought and funding constraints, using BOTANAL procedures (Tothill *et al.* 1992). In each plot, the pasture measurements were taken in 30 quadrats at 1 m intervals along two permanent transects chosen to sample the environmental variation. Sheep camping sites were avoided. Herbage mass was estimated directly as kg DM/ha. Statistical analyses using both splines for continuous data (1999–2002, 2005–2008) and a linear mixed model for discrete data (2003, 2004) were fitted using ASReml 3.0 (Gilmour *et al.* 2009).

## Results and Discussion

While results here from 1999 to 2006 are presented, seasonal conditions close to average were only experienced during the first three years. From 2002, the area entered a period of below-average rainfall, with altered seasonal patterns during a climatic event which has come to be known as the Millennium Drought. Consequently, animals at times were fed with supplements, paddocks were de-stocked, and some measurements suspended with the effect that these changes altered stocking rate over the duration of the experiment.

The high P, nil lime, low stocking rate treatment, P2L0SR1, in the period between September 1999 and May 2003 was the most productive on 16 occasions and at the other three harvests was either second or third most productive (Table 1). However, from July 2004 its productivity fell so that at that time it was equal sixth, and at the two harvests after, December 2005 and February 2006, it was the least productive treatment. The subterranean clover in this treatment initially responded positively to the high P levels and low stocking rates. The subsequent decline is unlikely to be due to excessive competition from other pasture components because its corresponding high stocking rate treatment (P2L0SR2) also had relatively low productivity from July 2004 till experiment termination in 2008 (Dear *et al.* 2000). By contrast, the two high P, high lime treatments (P2L2SR1, P2L2SR2) as well as the high P, low lime, low stocking rate treatment (P2L1SR1) were highly productive with these treatments being in the most productive group at nine, 12 and seven occasions respectively of the 23 harvests for which there were significant results between September 1999 and February 2006 (Table 1). Unlike P2L0SR1, these treatments did not decline in relative productivity over time. The level of soil $Al^{3+}$ declined markedly and the soil $pH_{Ca}$ increased after lime application in these treatments in contrast to the nil lime treatments (Norton *et al.* 2018). It is likely that the reduction in levels of toxic $Al^{3+}$ is a key reason why the clover was more persistent and productive than under the nil lime treatments presumably because the clover roots were able to exploit more soil volume, a major advantage during drought. In contrast the low P treatments, P1L0SR1, P3L3SR2 and P1L1SR1, were in the most productive groups on only four, four and one occasion respectively out of the 23 harvests with most occurring within the first two years after experiment commencement (Table 1). It is clear that P and lime were major drivers of legume productivity and persistence, and that within the P1 and sewage ash treatments, the low P levels reduced legume growth.

## Conclusions

- The standard Southern Tablelands superphosphate rate, 125 kg/ha applied every two to three years is inadequate leading to subterranean clover pastures highly responsive to extra *P*.

**Table 1. Harvest occasions when yields of subterranean clover biomass showed significant differences under nine treatment combinations of superphosphate (P1, P2), lime (L0, L1, L2), sewage ash (P3, L3) and stocking rate (SR1, SR2) from September 1999 to February 2006 at Sutton, NSW. Z scores (*P* = 0.05) show significant differences between data modelled with splines. (*l.s.d., *P* = 0.05 was used between discrete points.)**

| Harvest month | Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P1L0 SR1 | P1L1 SR1 | P2L0 SR1 | P2L0 SR2 | P2L1 SR1 | P2L1 SR2 | P2L2 SR1 | P2L2 SR2 | P3L3 SR2 | Z score |
| Sep 99 | 130 | 138 | 336 | 114 | 316 | 183 | 201 | 326 | 270 | 188 |
| Oct 99 | 706 | 687 | 1011 | 622 | 968 | 689 | 838 | 870 | 835 | 226 |
| Dec 99 | 359 | 344 | 762 | 292 | 709 | 392 | 528 | 626 | 793 | 321 |
| Jun 00 | 241 | 30 | 299 | 137 | 59 | 126 | 160 | 192 | 240 | 211 |
| Jul 00 | 325 | 61 | 387 | 197 | 96 | 192 | 215 | 272 | 314 | 210 |
| Sep 00 | 415 | 50 | 481 | 255 | 89 | 265 | 249 | 377 | 286 | 234 |
| Oct 00 | 1857 | 1321 | 1931 | 1562 | 1470 | 1560 | 1657 | 1696 | 1403 | 261 |
| Dec 00 | 888 | 300 | 972 | 569 | 408 | 580 | 630 | 742 | 546 | 344 |
| Jan 01 | 330 | 218 | 547 | 328 | 245 | 367 | 464 | 494 | 347 | 187 |
| Mar 01 | 128 | 45 | 327 | 103 | 61 | 147 | 253 | 236 | 210 | 172 |
| Apr 01 | 92 | 22 | 267 | 88 | 32 | 146 | 208 | 215 | 149 | 167 |
| Jun 01 | 113 | 58 | 270 | 127 | 79 | 197 | 225 | 226 | 205 | 163 |
| Jul 01 | 43 | 0 | 169 | 49 | 3 | 128 | 133 | 137 | 80 | 163 |
| Sep 01 | 87 | 53 | 227 | 176 | 113 | 275 | 216 | 248 | 144 | 167 |
| Oct 01 | 281 | 252 | 550 | 408 | 444 | 499 | 541 | 461 | 328 | 172 |
| Jan 02 | 52 | 17 | 207 | 47 | 19 | 60 | 75 | 40 | 70 | 119 |
| Mar 02 | 241 | 205 | 381 | 228 | 235 | 238 | 283 | 213 | 141 | 106 |
| Apr 02 | 69 | 46 | 162 | 59 | 49 | 79 | 90 | 51 | 58 | 102 |
| May 03 | 150 | 69 | 153 | 61 | 116 | 79 | 170 | 73 | 86 | 90* |
| Jun 04 | 24 | 46 | 88 | 150 | 189 | 70 | 83 | 71 | 81 | 131* |
| Jul 04 | 93 | 131 | 87 | 87 | 161 | 78 | 184 | 33 | 86 | 131* |
| Dec 05 | 169 | 313 | 34 | 343 | 432 | 593 | 398 | 266 | 315 | 370 |
| Feb 06 | 49 | 248 | 15 | 181 | 224 | 207 | 135 | 125 | 261 | 153 |

- On acidic soils with high levels of exchangeable $Al^{3+}$ the addition of lime in the presence of sufficient P improves subterranean clover production and persistence even under drought conditions.
- The addition of adequate P alone is not enough to maintain clover production on acidic soils with high exchangeable $Al^{3+}$.

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