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Ameliorating soil acidity improves the resilience of pasture production under extended drought

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Abstract. In an experiment beginning in 1999 and ending in 2008 conducted on soil with low pH and high levels of Al^{3+}, high levels of applied phosphorus (P, 250 kg superphosphate ha^{-1} yr^{-1}) in a treatment with no lime and a low sheep stocking rate led to high subterranean clover production for the first four years (1999 to 2002). However, clover productivity in this treatment subsequently declined to low levels and did not recover, during increasingly dry seasons of the drought that afflicted south-eastern Australia in the first decade of this Century. Conversely where high P levels were combined with lime, clover content and sward total productivity was higher and remained more stable over the longer term (up to experiment termination in 2008) under the same seasonal conditions. This was associated with lower soil Al^{3+} levels and higher pH_{Ca} after liming. At the low P application rates (125 kg superphosphate ha^{-1} every 2-3 years) subterranean clover productivity was constrained although the addition of lime had helped to improve total sward production by the end of the trial.

Keywords. Subterranean clover – Grazing pressure – Legume nutrition – Soil amelioration – Acid soils.

Une meilleure acidité du sol augmente la résilience de production des pâturages soumis à une sécheresse prolongée

Résumé. *Une expérimentation débutée en 1999 et terminée en 2008 a été conduite sur des sols à pH bas avec des teneurs élevées en Al^{3+}. De fortes concentrations en phosphore ont été appliquées (P, 250 kg de superphosphate $ha^{-1}.an^{-1}$) dans un traitement sans chaux et avec un faible taux de chargement en moutons. Ainsi une forte production de trèfle souterrain a été constatée pendant les quatre premières années (1999 à 2002). Cependant, la productivité du trèfle dans ce traitement a par la suite diminué à de faibles niveaux et ne s'est pas rétablie au cours des saisons qui étaient de plus en plus sèches, notamment avec la sécheresse qui a frappé le sud-est de l'Australie durant la première décennie de ce siècle. A l'inverse, lorsque des teneurs élevées en P étaient combinées à de la chaux, la quantité de trèfle et la productivité totale des pâturages étaient plus élevées et restaient plus stables à long terme (jusqu'à la fin des expériences en 2008) dans ces mêmes conditions saisonnières. Ceci a été associé à des niveaux plus faibles en Al^{3+} dans le sol et à un pH_{Ca} plus élevé après le chaulage. A de faibles doses d'application de P (125 kg de superphosphate ha^{-1} tous les 2-3 ans), la productivité du trèfle souterrain a été limitée, bien que l'ajout de chaux ait contribué à améliorer la production totale des pâturages à la fin de l'essai.*

Mots-clés. *Trèfle souterrain – Pression pastorale – Nutrition des légumineuses – Amélioration des sols – Sols acides.*

I – Introduction

Animal production from grazed permanent pastures is a reasonably sustainable form of agriculture on many fragile, non-arable soils. Legume productivity is crucial to most of these pastures as nitrogen (N) fixation is their primary source of N as well as providing high quality forage. Sufficient phosphorus

(P) is pivotal to maintaining legume productivity although issues of P use efficiency and methods of determining appropriate P levels remain. Moreover, the build-up of organic matter in these pastures can acidify soils, as can the removal of alkalinity with agricultural production. Soil acidity constrains pasture productivity limiting production from grazing animals. Throughout Australia it is estimated that there are 50 M ha with a soil 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, although incorporation is only possible where land is arable. On the New South Wales (NSW) Southern Tablelands, large areas of non-arable soils are acidic to depth and the only option to ameliorate acidity is to surface apply lime. Therefore, an experiment was undertaken to study the effects on pasture production of different rates of lime, P and stocking rate over a time period long enough to ensure that the effects of lime would be acting to ameliorate the acid soil.

II – Materials and methods

A replicated experiment continuously stocked by sheep was conducted near Sutton, NSW, Australia (35.12° S, 149.27° E) between January 1999 and October 2008. The soils, predominately Chromosols with Leptic Rudosols in higher areas, were 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, Sprayseed 250® (Paraquat, Diquat) was applied to remove annual grasses and broadleaved weeds, whilst retaining the established native perennial grasses. Sowing occurred in May 1998 using a direct drill seeder at a row spacing of 30 cm so as to minimise disturbance of the established native perennial grasses, whilst ensuring 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 subterranean clover seed was inoculated and lime pelleted, with an additional application 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), suggesting that Al^{3+} toxicity may constrain plant growth. ECEC levels were low (4.6 cmol+/kg) as were extractable P (9.7 mg/kg, and total carbon (3%).

There were three treatment factors, P, lime and stocking rate, replicated twice. All treatments received the P as superphosphate (0-9-0-11, N, P, K, S), either at a typical local application rate, P1, 125 kg/ha every 2 to 3 years, or at a high rate, P2 (250 kg/ha/yr) which reached and surpassed the critical P level (25 mg P/kg soil) across these treatments from 2002 (unpublished data). Three 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). All lime applied was F70 superfine (70% < 75 µm, neutralising value = 97 %).

The experiment was continuously stocked with wethers at two 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 two rates of P, three rates of lime and two stocking rates as follows: P1L0SR1, P1L1SR1, P2L0SR1, P2L0SR2, P2L1SR1, P2L1SR2, P2L2SR1 and P2L2SR2. A treatment P1L2SR1 was not included, it being considered unlikely to be used in practise. It was necessary to modify stocking rates due to seasonal conditions and their effects on pasture growth rates. There were extremely dry periods, when pasture growth rates were so low that plots had to be destocked for short periods. Plot sizes for SR1 and SR2 were 1 and 0.67 ha respectively.

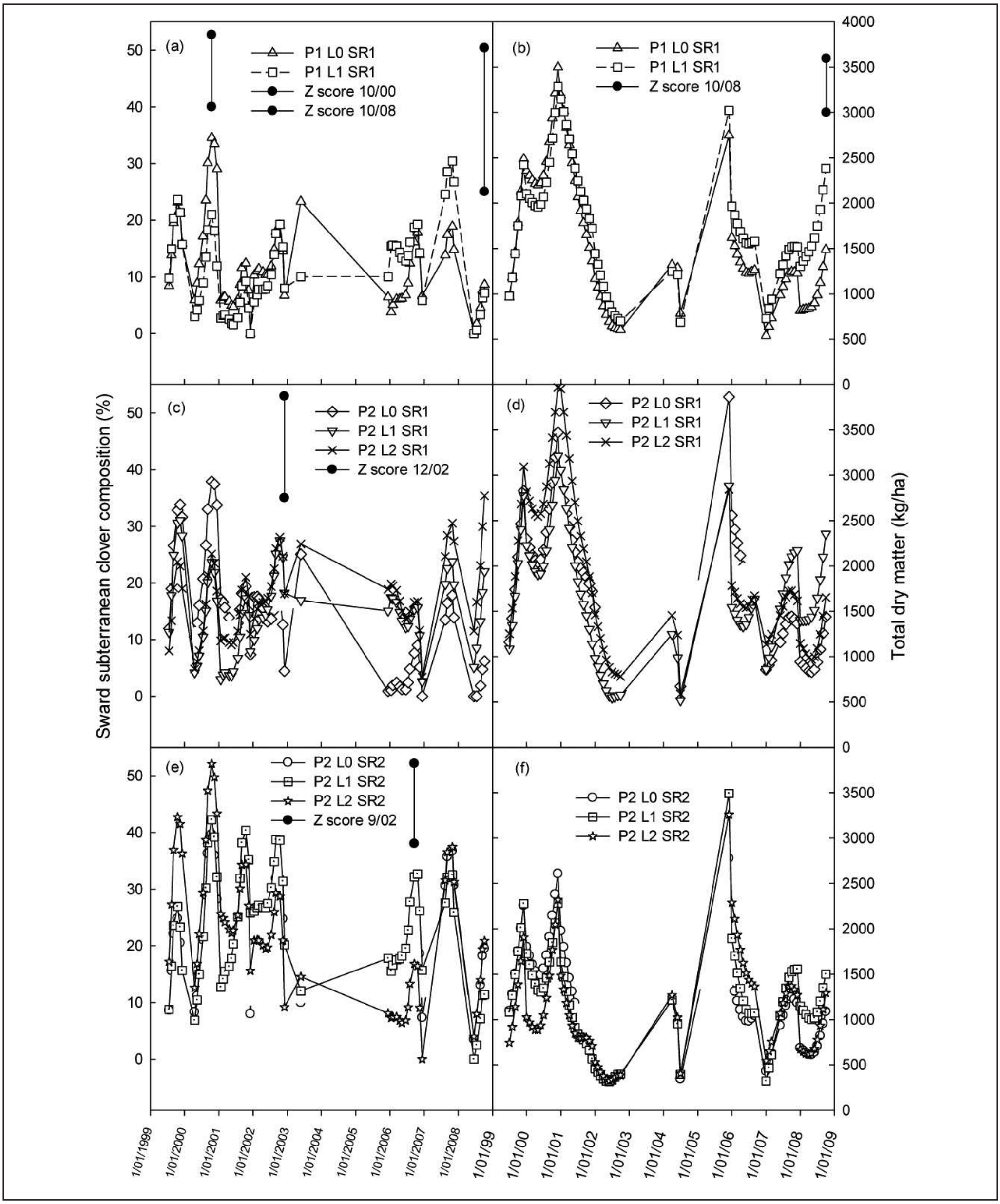

Fig. 1. The time course between 1999 and 2008 of sward subterranean clover content (%, Figs 1a, 1c, 1e) and total sward dry matter production (Figs 1b, 1d, 1f) as affected by differing levels of surface applied lime (L0, L1, L2), superphosphate (P1, P2) and two stocking rates (SR1, SR2), in the treatments P1L0SR1 (∆), P1L1SR1 (□), P2L0SR2 (○), P2L0SR1 (◊), P2L1SR2 (⊡), P2L1SR1 (∇), P2L2SR2 (⋆) and P2L2SR1 (×) at Sutton, NSW, Australia. Vertical bars represent significant differences at specific measurement times between all the eight treatments for the specific parameter of the result presented in the text. Bars are only placed in one of the three graphs to minimise congestion and positioned in the frame of the major treatment comparison but apply equally to the other two graphs.

Herbage mass and botanical composition (as a percentage of herbage mass) were measured in each plot every six weeks between March 1999 and October 2008, using BOTANAL procedures except from January 2003 to November 2005 when measurements were more sporadic due to drought and funding constraints. 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 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; Norton *et al.*, 2018).

III – Results and discussion

Rainfall close to average was experienced only during the first three years of the trial from 1999 to 2001 and in 2005. From 2002, the area entered a period of below-average rainfall with altered seasonal patterns during a climatic event which has become known in Australia as the Millennium Drought. As a result substantial year to year variation was exhibited both in total pasture dry matter production and in the subterranean clover composition of the pasture (Fig. 1) with production and composition peaks associated with the high rainfall years occurring in 2000/2001 and 2005, while major declines especially in production occurred in the very dry years of 2002 and 2006.

Under the different P treatments it became clear by 2000/2001 that subterranean clover sward composition was constrained under the low P treatment (P1, Fig. 1a) as composition was higher under high P (P2, Figs 1c, 1e). Under P1 sward subterranean clover composition rarely exceeded 30% and by trial termination none of the P1 treatments had more than 9% subterranean clover. Conversely under the P2 treatments, swards with more than 30% subterranean clover were relatively common particularly under the higher stocking rate (Fig. 1e). Until June 2002 the high P, nil lime, low stocking rate treatment (P2L0SR1) was within the top producing treatment group on 23 out of the 33 occasions from the beginning of the trial up to this time. However, from that time till trial termination the subterranean clover composition of this treatment collapsed so that from August 2003, except for one occasion, P2L0SR1 was in the treatment group with the least legume. Possible reasons for this decline include an inability of the subterranean clover to access water deeper in the soil profile due to toxic levels of aluminium in the subsoil, and the possibility that taller growing and more acid soil tolerant companion species may have outcompeted the clover for water and nutrients particularly in spring when clover seedset occurs. In this context it is noteworthy that P2L0SR2, differing from P2L0SR1 only in stocking rate, had a substantially higher subterranean clover composition at trial termination (ca. 20%) and was not different from either of its comparator lime treatments, P2L1SR2 and P2L2SR2. The maintenance of a higher stocking rate may have ensured adequate seedset and thus composition, by limiting companion species competition in these three treatments (Fig.1e). However, the excellent subterranean clover sward content present in October 2008 in P2L1SR1 and P2L2SR1 (Fig. 1c) suggests that a lighter stocking rate together with a reduction of high Al levels in the subsoil, brought about by the liming, was more important for improving subterranean clover content under drought than reducing inter-species competition (Norton, *et al.*, 2018).

The role that lime application played in increasing total sward production must also be noted, particularly in P1L1SR1 and P2L1SR1. These production increases happened toward the end of the trial so that although the ongoing drought was still severe in 2008, the reduction in Al at depth which had occurred in these soils due to the lime treatments, allowed significantly greater sward production on these soils, presumably because plant roots were able to exploit a greater volume of soil for water.

IV – Conclusions

High levels of P led initially to high subterranean clover production for the first four years (1999 to 2002) in a treatment with no lime and a low sheep stocking rate. This productivity subsequently fell to low levels and did not recover on those soils which also had low pH and high levels of Al^{3+}. Superimposed over these results was an extended drought period becoming more intense as the trial progressed. Where high P levels were combined with lime, clover content and sward total productivity was higher and remained more stable over the longer term (up to experiment termination in 2008) under the same dry seasonal conditions. This was associated with lower soil Al^{3+} levels and higher pH_{Ca} after liming. At low P rates subterranean clover productivity was constrained although the addition of lime helped to improve total sward production by the end of the trial.

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