Effect of soil physical condition, and phosphorus and nitrogen availability on pasture persistence

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Abstract

Soils are the substrate at the base of any grazing or cropping system providing plants with nutrients, water and physical support, a habitat for beneficial organisms and a physical base on which animals stand. A change or a loss of any one of these soil services has the potential to impact on plant growth and persistence. The findings of two ongoing field-based studies are presented and discussed as they relate to the current debate on pasture persistence. One study is investigating the influence of the physical condition of the soil on a ryegrass-based pasture response to added phosphorus (P). The second study is investigating the P requirements of high producing perennial ryegrass and tall fescue-based pastures, where the constraints to pasture growth and associated P uptake imposed by low nitrogen availability and low soil moisture over summer-autumn have been removed. The critical Olsen P value for maximum pasture production appears to increase as the constraints to pasture growth are removed. This challenges the continued use of a single relative yield Olsen P function and one critical Olsen P value for near maximum yield regardless of the absolute pasture yield. Loss of soil pore function also appears to increase the critical Olsen P value necessary for optimum pasture growth. Additional P can compensate for a lack of pore function to a degree, but there appears to be an upper limit to this effect. Given that the physical condition of many of our pasture soils in intensive lowland situations is below optimum, nutrient stress may be more of a factor in poor pasture-persistence, than previously thought. Inclusion of a measure of soil physical condition would appear to warrant further study in defining the conditions for optimum plant growth and persistence.

Keywords: fertiliser nitrogen, *Festuca arundinacea*, *Lolium perenne*, Olsen P, pasture persistence, soil pore function, soil services

Introduction

Soils are the substrate at the base of any grazing or cropping system providing plants with nutrients, water and physical support. That physical support extends to a physical base on which animals stand (Dominati *et al*. 2010). Soils also provide a range of regulating and cultural services including pest and disease regulation that impact directly on plants. A change or a loss of any of these soil services has the potential to impact on the growth and on persistence of the desired plant species by affecting their ability to resist and rebound from environmental and management pressures.

The single biggest factor influencing pasture composition, growth and quality is nutrient supply, a perception held also by producers (Daly *et al.* 1999). For example, the legume content of pasture is dependent on the phosphorus (P) and sulphur (S) status of a soil (During 1972). Long-term studies investigating the influence of annual P fertiliser inputs or conversely the withholding of P inputs, show the close relationship between soil P status and legume content (Lambert *et al.* 1990). Soil acidity (pH) influences the solubility of aluminium and manganese, both of which are toxic to plants, and molybdenum which is an essential trace element for clover root nodule function (During 1972).

Where nitrogen (N) from legume is the only source of N, the contribution of legumes through biological N fixation to soil N in a mixed pasture has a major influence on species balance, including the proportions of high and low fertility demanding grass species (Lambert *et al.* 1986). Application of N fertiliser can have a major influence on pasture composition and species persistence. Lambert & Clark (1986) found a small (<50 kg N/ha) autumn application of fertiliser N reduced legume content in a hill pasture. Harris & Clark (1996) found high rates (up to 400 kg/ha) of N fertiliser in intensive lowland pasture reduced white clover (*Trifolium repens*) plant density, stolon-biomass and N fixation activity. In the same study (Harris *et al.* 1996) reported that perennial ryegrass (*Lolium perenne*) tiller number and production increased with N fertiliser inputs and cow stocking rate, prompting the authors to suggest fertiliser N may offer a tool for improving the persistence of perennial ryegrass in intensively grazed dairy pastures. Thom *et al*. (1986) investigated ryegrass persistence in the Waikato and found that while N fertiliser increased plant production in spring, this did not translate into increased persistence, as other factors influencing survival were more important. There is some literature to show that high N inputs can reduce ryegrass tiller survival in summer. Stewart (1987) found that N fertiliser inputs reduced the survival of endophyte-free Italian (*Lolium multiflorum*) ryegrass plants in summer-dry conditions, highlighting the many potential interactions that could be governing persistence. Earlier, Gaynor & Hunt (1983) showed that Argentine stem weevil (*Sitona lepidus*) damage to endophyte-free perennial ryegrass was greater under high N inputs, but in endophyte-infected plants this effect appeared to be overridden.

Prolonged periods of water deficit or at the other extreme water-logging, will impact plant growth and survival. Gillingham *et al*. (1998) reported that the contrasting moisture regimes on north and south facing aspects within dryland soils resulted in differing amounts of clover persisting in the pasture, suggesting that nutrient requirements, especially P may also vary. Moist soils are more susceptible to compaction and when above their plastic limit, deform when trodden. Soil pore function is disrupted and this affects pasture growth and survival by compromising root function. Drewry *et al.* (2002) found a linear relationship between spring pasture growth and macroporosity with spring growth improving by 1.5% per unit of macroporosity increase between 5-15%. Soils differ markedly in their vulnerability to treading damage, due to differences in mineralogy, texture and structure.

Pasture species also differ markedly in their sensitivity to livestock treading. Lambert *et al*. (1986) found an interaction between soil P status and sheep and cattle grazing, with the cattle grazed pasture containing a higher percentage of white clover and ryegrass than the equivalent pasture grazed by sheep. The resilience of ryegrass and white clover to treading has been used in "pasture development" for some time to sustain the desired pasture species mix.

The role soils play in the regulation of plant pests can be quantified. For example, the difference in the *Wiseana* spp. (porina) population in the first year after sowing a new pasture, compared with the numbers in an established pasture (Kalmakoff *et al*. 1993) is a measure, in part, of the soils ability to regulate this pasture pest. Augmenting the soil with a bio-control agent at sowing in recognition of the reduced regulatory service offered by the soil after disturbance, is now used by some farmers as a bio-protection strategy for preventative action against pasture pests (Jackson *et al*. 2002)

The key soil attributes underpinning the provision of nutrients, water and support for plants and the physical base for animal support are soil structure, nutrient status, organic matter content and biota. With the ongoing industry pressure to continue to lift primary production, these soil attributes are coming under increasing demand. Evidence is mounting to show that all these three soil attributes, physical condition (Sparling & Schipper 2004), organic matter levels (Schipper *et al*. 2010) and abundance and diversity of soil biota (Schon *et al*. 2010a) are in decline in our intensive pasture systems. Also, many soils in NZ have physical limitations to intensive land use.

In this paper the findings of two ongoing field-based studies are presented and discussed as they relate to the current debate on pasture persistence. One study investigates the influence soil pore function has on ryegrass-based pasture response to added P. The second assesses the P requirements of high producing perennial ryegrass and tall fescue (*Festuca arundinacea*)-based pastures, where the constraints to pasture growth and associated P uptake imposed by low N availability and low soil moisture over summer-autumn have been removed.

Materials and Methods

Field locations and experimental design of soil compaction study

Two soil compaction studies, one in the Manawatu and one in Southland were sown in the autumn with a modern ryegrass cultivar: 'Bronsyn' and 'Meridian' with a standard endophyte in the Manawatu and 'Impact' and 'Sterling' with nil endophyte in Southland, before the start of the study in 2007 and 2008, respectively. Soils were derived from sedimentary material. A split-plot design was used at both sites with four soil P levels within each of three compaction levels in Southland and four compaction levels in the Manawatu. There were four replicates of each treatment. More detailed information on the compaction method and management of the trials were given by Mackay *et al.* (2010). Four Olsen P levels of 10-15, 20-25, 30-40, and >60 µgP/ml were generated by the appropriate capital P applications of triple-super fertiliser applied in a split application at the beginning of the experiment. Further applications of P are made annually to adjust and maintain the target Olsen P levels. Pasture production is measured at about monthly intervals using a rising plate meter. Pastures are not grazed but cut. A standard calibration curve is used to convert height measurements to DM yield. Soil cores are taken each spring to measure bulk density.

Field locations and experimental design of the P response study

Three field sites were selected in the Waikato; one under irrigation was established in 2005; and in 2008, one further rain-fed and one irrigated site were established. In 2009-2010 the site established in 2008 to be irrigated, was not irrigated. In the Manawatu, two trial sites were selected; one under irrigation was established in 2005, and in 2007, a rain-fed site was established. Canterbury has one irrigated site established in 2008 but irrigation was suspended in March 2010. One irrigated site was established in Southland in 2005. Except for the two Waikato sites where tall fescue ('Advance' MaxP) was sown, all other sites were sown with a perennial ryegrass 12 months before establishing the P response study. Details on cultivars used in each study were reported by Mackay *et al.* (2010). At the three Waikato sites, soils are derived from volcanic material. At the other sites, soils were derived from sedimentary material.

Field trial design was the same at all sites - a five (P treatments) x two (N treatments) factorial with four replicates. Five Olsen P levels of 10-15, 20-25, 30-35, 40-45 and >60 µgP/ml were generated by appropriate capital P applications of triple-super applied in a split application at the start of each study. Two rates of N fertiliser, 0 and 400 kg N/ha/yr as urea were applied. Applications of the latter treatment were equally split with about 40 kg N/ha applied at about monthly intervals, following each pasture measurement. Further applications of P are made annually to adjust and maintain the target Olsen P levels. Additional information on the field study was reported by Mackay *et al.* (2010). Pasture production was measured at about monthly intervals using a rising plate meter. Pastures are not grazed but cut. A standard calibration curve is used to convert height measurements to DM yield. Botanical composition is assessed by weight, following cutting and hand sorting. Soil samples were collected from each plot (0-75 mm) before the start of the trials and in late November-early December of each year.

Analysis

All data (DM yield, botanical composition, Olsen P x soil compaction) were analysed to determine treatment effects using ANOVA within Genstat (v 10). P response curves, derived after annual yield data for the individual N treatments, were first fitted by means of Mitscherlich response curves against the Olsen P values from the November soil sample of that year. There were 38 data sets (5 sites x 1- 5 years x 2 N rates).

Results and Discussion

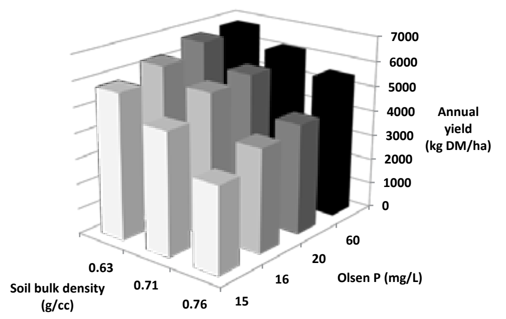
Soil pore function, Olsen P and pasture growth

At the Southland field site, increased soil compaction, measured by bulk density (Fig. 1a), reduced pasture yield ($P<0.01$); increased Olsen P level increased yield ($P<0.001$). However, only the influence of Olsen P was significant ($P<0.01$) in the Manawatu in 2009-2010 (Fig.1b). Significant ($P<0.05$) interactions were found between soil compaction, Olsen P and pasture yield at individual cuts but this did not extended to annual pasture yield at either site. The critical Olsen P value for maximum pasture production appeared to increase as the soil was compacted at the Southland site, but there would also appear to be an upper limit to the extent to which additional P can compensate for a lack of pore function (Fig. 1a). Loss of pore function impacted on pasture growth through the effect of reduced aeration and drainage, and lower soil temperatures on root function and growth. Assuming the optimum physical conditions for maximum pasture growth align with the optimum conditions for plant persistence, physical conditions that limit growth are also likely to influence persistence by increasing the susceptibility of plants to other stresses. Sparling & Schipper (2004) found in a survey of lowland soils that half the dairy sites, predominantly on the more resilient soils, had a macroporosity value of <10%. Inclusion of a measure of the soil physical condition as part of a farm's routine monitoring would appear to have some merit in assessing likely barriers to pasture persistence. The current study would also suggest inclusion of a measure of soil physical condition in either the derivation of relative P response curves or in the interpretation of the Olsen P test value, given the increasing cost of this nutrient, and the potential impact that soil with limited pore function could have on nutrient supply and on the wider environment.

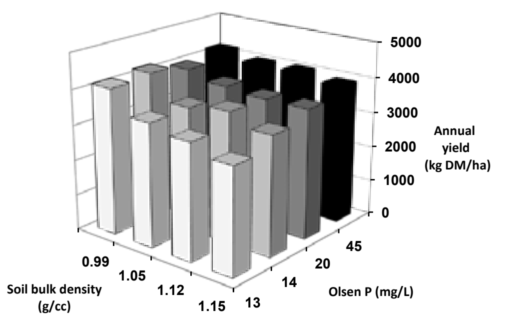
Importantly, soils with reduced pore function are more susceptible to livestock treading damage by virtue of the fact that the period when the soils are wet and above field capacity will be prolonged. Establishing sown species in a soil with limited pore function is problematic, as seedling establishment and early growth are particularly sensitive to water and oxygen supply. Newly established pasture in a cultivated soil is also more susceptible to treading damage, as is the underlying soil resource, until soil strength, plant number and ground cover provide physical protection to the soil from hoof damage. Loss of plant number can occur through burial or detachment as a consequence of a livestock treading events during the late winter and early spring. In late spring some treading pressure has the potential to remove some of the less desirable, low fertility grass species, which compete with sown

Figure 1 Relationship between soil bulk density, Olsen P and pasture yield (kg DM/ha) at the (a) Southland site in 2010/11 (LSD $_{0.05}$ for comparing means within the same Olsen P is 526 and within the same soil bulk density is 601) and (b) Manawatu site in 2010/11 (LSD $_{0.05}$ for comparing means within the same Olsen P is 722 and within the same soil bulk density is 593).

(a)



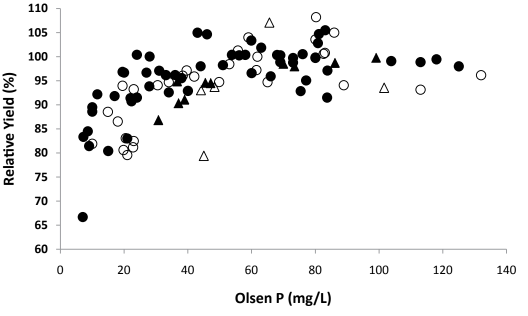
(b)



or high fertility grasses species (Pande *et al.* 2000). Bare ground created as a consequence of a treading event, creates opportunities for less desirable species to establish and compete with sown species for water, nutrients, space and light.

There are a range of management practices that can be taken to limit the losses of sown species from treading damage (Betteridge *et al*. 2003). Evidence emerging from some recent studies (Schon *et al.* 2010b) suggest that surface feeding, deep burrowing anecic earthworms can substitute for, and support the important functions, including sustaining the soil pores formed by the surface feeding (and dwelling) epigeic earthworm species in intensively managed dairy-grazed pastures. Vulnerable to treading, epigeic earthworms are often found in low abundance in intensive pasture systems (Schon *et al*. 2010a), limiting the soil's ability to construct and maintain effective pore space. Most New Zealand pastures, however, do not have anecic earthworms as their introduction has been largely accidental, and as a consequence, their distribution is patchy (Springett 1992). Extending soil monitoring to include an assessment of the soils invertebrate community warrants further investigation.

Figure 2 Relationship between relative yield and Olsen P for all sites where an asymptote could be established. ○= Ryegrass pasture without added N; ● = ryegrass pasture with added N; △ = Tall fescue pasture without added N; ▲= Tall fescue pasture with added N.



Nutrient supply

Phosphorus requirements of ryegrass-based pastures

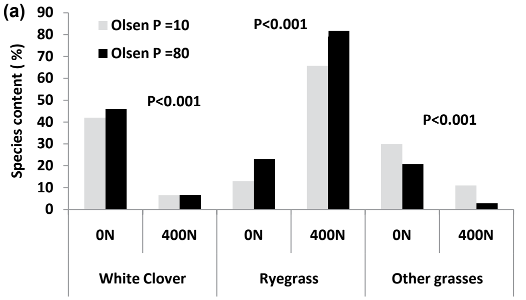
The relationship between relative pasture yield (RY) and Olsen P for annual data sets (20 out of 38 data sets) from all sites over all years in the current study assessing the P requirements of high producing perennial ryegrass and tall fescue-based pastures could be described by a Mitscherlich response curve (Fig. 2).

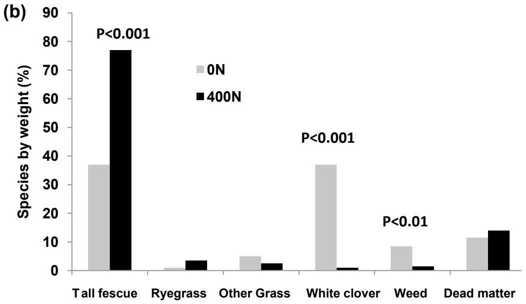
$$RY\ (\%) = 99.87 - 27.24 \times 0.9534^{\text{olsen P}} \quad (1)$$

All annual data $r^2 = 0.52$

Using equation (1), near maximum pasture production, defined as the relative yield at 97% of maximum production, was achieved at an Olsen P level of 47 µgP/ml. This value is much higher than the current values of 20 and 22 µgP/ml for near maximum (97%) pasture production for a sedimentary and volcanic ash soil, respectively (Roberts & Morton 2009). Assuming that near maximum pasture production equates to near optimal conditions for nutrient supply, plant survival and growth, then ensuring the soil P status is in the optimal range is a critical factor in ensuring pasture persistence. Importantly, a curve fitting model different from that of Roberts & Morton (2009) was used to describe the relationship between Olsen P and relative yield in the current study. The values reported in the current study are also higher than those reported by Gillingham *et al.* (2007) for sheep and beef pastures located on the East Coast of both Islands; their field sites were characterised by old, grass-dominant pastures, where frequent seasonal moisture and overall levels of production were low due to the combination of limited soil moisture, low N availability and poor legume growth. This contrasts sharply with the characteristics of the field sites in the current study and

Figure 3 (a) The influence of fertiliser N and Olsen P on the botanical composition calculated on a dry weight basis for the ryegrass-based pasture at the Manawatu site in 2009/2010 (probabilities refer to the effect of 400 kg N/ha) and (b) influence of fertiliser N on the botanical composition calculated on a dry weight basis for the tall fescue-based pasture at the Waikato site in December 2010.





supports the suggestion that as constraints are removed and production increases, so does the critical Olsen P value. The current study challenges the continued use of a single relative yield Olsen P function and one critical Olsen P value for near maximum yield regardless of the absolute pasture yield. Current recommendations do recognise that in high production systems, to limit the risk of under-fertilising pastures for sites that may fall below the single Olsen P relative yield curve currently used, two additional target ranges have been added (Roberts & Morton 2009). Incidentally, it would be interesting to establish if the critical Olsen P value for 97% maximum pasture yield, aligns with the near maximum ryegrass and tall fescue tiller number and size.

An examination of samples from dairy pastures on volcanic and sedimentary soils submitted for analysis from 2005-2008 (data supplied by Dr A.H.C. Roberts, Ravensdown Fertiliser Company) found on average 10 and 20%, respectively, of samples had Olsen P values <20 µgP/ml, and 30 and 50%, respectively, had Olsen P values <30 µgP/ml. These data indicate that on sedimentary soils, sub-optimal soil P levels may be a factor in pasture persistence. These values take on greater significance if coupled with the knowledge that the physical condition of many of our pasture soils in intensive lowland situations is below optimum (Sparling & Schipper 2004). Nutrient stress, may be of greater significance in pasture persistence in intensive lowland pastures, more often associated with sheep and beef pasture soils where soil fertility is lower (Wheeler 2004).

Impact of fertiliser N

In the current study legume persistence was reduced by N fertiliser inputs (Fig. 3). This aligns with the findings of Harris & Clark (1996) and many other studies investigating the influence of N fertiliser on legume persistence. At the Manawatu site application of 400 kg N/ha reduced (P<0.001) legume content in February 2011 to <7%, compared with approximately 40% in the ryegrass pasture without added N fertiliser (Fig. 3a). Similarly in the tall fescue-based pasture in the Waikato, application of 400 kg N/ha reduced the legume content of the sward in December 2010 to only 1% of total DM (Fig. 3b). Use of N fertiliser is often part of the initial pasture establishment process during pasture renewal and likely exacerbates the difficulty of sustaining sown legumes in a mix with most grass species.

In comparison to the negative impact of applied N fertiliser inputs on legume persistence, fertiliser N had a large positive (P<0.001) influence on ryegrass persistence, as indicated by the increased proportion of total DM assessed by botanical analysis in February 2011 (Fig. 3a). Tall fescue showed a similar response in December 2010 (Fig. 3b). Both the ryegrass-based pasture and the fescue-based pasture also responded to increasing Olsen P (Fig. 2), suggesting the persistence of both these grass species is highly dependent on nutrient supply, particularly N supply. Currently, no allowance is made in pasture nutrient recommendations for species differences.

Conclusions

Inclusion of a measure of soil physical condition, along with plant nutrient levels as part of a structured programme of soil monitoring and pasture management will reduce the risk of poor pasture establishment and increase the likelihood of persistence of desired species.

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