Long term effect of superphosphate fertilisers on pasture persistence

T. J. FRASER[1], S. DENNIS[1], R. A. MOSS[1], K. N. TOZER[2], N.R. STOCKER[1], A.L. TAYLOR[1], M. J. FAVILLE[3] and C. SMITH[4] .
[1]*AgResearch Lincoln, Private Bag 4749, Christchurch*
[2]*AgResearch Ruakura Research Centre, Private Bag 3123, Hamilton*
[3]*AgResearch Grasslands, Private Bag 1108, Palmerston North*
[4]*AgResearch Woodlands, RD 1 Invercargill*
tom.fraser@agresearch.co.nz

Abstract

Core samples were taken from 60-year-old pastures on a long-term fertiliser trial at the Winchmore research station, in Canterbury, New Zealand. Plots had been treated with 0, 188 or 376 kg/ha of superphosphate annually, grazed by sheep, and pasture yields were recorded. Ryegrass persisted in all treatments, but was only dominant in the superphosphate treatments, unsown grasses dominated in the no superphosphate treatments. White clover was more common with superphosphate, and both cocksfoot and timothy required adequate superphosphate in order to persist. Over 60 years of measurements, yields were 9-15 t DM/ha with superphosphate, and did not reduce over time. Given adequate fertiliser, a ryegrass-based irrigated pasture can continue to produce high yields 60 years following sowing.

Keywords: ryegrass, cocksfoot, timothy, white clover, phosphate, pasture persistence

Introduction

Pasture persistence is an important issue for New Zealand pastoral farmers. Lack of persistence is a major cost to farmers due to reduced quality and quantity of feed produced and/or the high cost of pasture renewal. A knowledge of the factors that increase pasture persistence while at least maintaining production is therefore important to maintain the economic viability of pastoral farms. For example, naturally occurring wild-type endophytes can improve ryegrass persistence by protecting the plant from insect pests, however these also produce alkaloids that can be detrimental to livestock health (Fletcher *et al.* 1999).

Previous work has shown that withholding maintenance fertiliser P and S can result in a reduction in ryegrass and white clover production (McBride *et al.* 1990) while increasing browntop (Ledgard & Brier 1993) content. A soil Olsen P level of 20 is required to achieve optimum pasture production on Canterbury's sedimentary soils (Morton *et al*. 1994).

This study investigated the sward species composition, ryegrass endophyte status and yield of pastures that are over 60 years of age, and considered the effect of soil fertility on these factors.

Method

Pasture establishment

The trial has been previously described by Rickard (1968) and Rickard & McBride (1987). It is located on the Winchmore Research Station, in Mid Canterbury and was established following a browntop (*Agrostis* spp.) pasture. This pasture was ploughed in the winter of 1948 and left fallow over summer, during which time border dyke irrigation was established. It was sown to greenfeed in the autumn of 1949, ploughed and summer fallowed again, and sown to pasture in February 1950. The area received fertiliser at sowing, lime at 2.5 t/ha and superphosphate at 126 kg/ha with the greenfeed, and 2.5 t/ha lime plus 251 kg/ha superphosphate with the pasture. The pasture mix sown was the standard mixture used at Winchmore at the time (Walker 1955), and is outlined in Table 1. The seed was broadcast with the superphosphate.

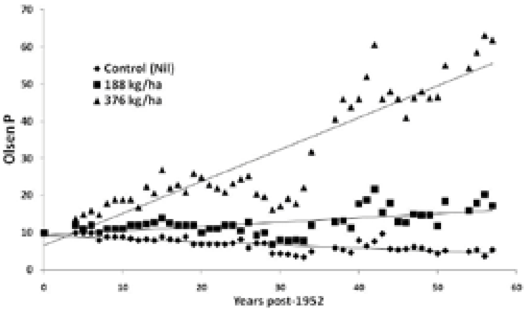
Experimental treatments

The experiment commenced in 1952, when the pasture was 2 years old. At that stage the pasture was perennial ryegrass/white clover dominant, with crested dogstail prominent in spring and cocksfoot and red clover in autumn. Five superphosphate treatments were laid down, of which three have been maintained until the present, these being: no fertiliser (Treatment 1), superphosphate at 188 kg/ha (2) and 376 kg/ha (3), initially applied in autumn, but in later years (from and including 1985) applied in late winter. Following sowing, lime was only applied in a single application of 4 t/ha in 1972. No other fertilisers were applied at any stage.

Trial design

A randomised complete block design was used, with four replicates. Each plot consisted of a separately fenced irrigated border of approximately 0.1 ha. Each treatment was grazed by a separate flock of hoggets,

Figure 1 Soil Olsen P level assessed immediately prior to the annual superphosphate treatment application.



which rotated around the same treatments on the four replicates only. Herbage was controlled by adjusting hogget numbers. To avoid fertility transfer onto the trial, all stock were fasted for 30 hours prior to entering the trial.

Fertiliser application and soil fertility

Predictably, Olsen P levels declined over the 60 year period in the absence of artificial supply (Figure 1). Levels have tended to increase slightly when 188 kg/ha of superphosphate was applied annually, while levels increased dramatically, particularly during the last 25 years, with the application of 376 kg/ha. The dip and subsequent rise in Olsen P around 30 years post 1952 was due to decreases in the availability of P in the superphosphate applied, as described by Quin (1982). The values in Figure 1 represent Olsen P levels when at their annual lowest, immediately prior to annual treatment application. When averaged from four dates uniformly spread over 12 months the Olsen P values for 1952 were 10.0 for all treatments, and in 2009 were 5.7, 20.0 and 66.4 for treatments 1, 2 and 3 respectively.

Sulphate sulphur levels were not reported in 1952 but the assumption is that they were similar across treatments. Sulphate sulphur values for treatments in 2009 were 3.25, 5.0 and 4.75 respectively.

Soil pH levels averaged 6.2 on all treatment areas during 1952, gradually declining over time apart from an increase upon liming in 1972 (Figure 2). There has been no significant difference between treatments in any year in soil pH levels, and the average pH in 2009 was 5.78.

Irrigation

Border-strip irrigation was applied at a soil moisture content of 15% w/w until the winter of 1996, and at 20% following that date. Soil samples were taken each year during July, October, January and April to a depth of 75 mm, with 14 cores per plot taken along a diagonal transect through the centre of the strip and analysed for pH, Olsen phosphorus, potassium, calcium and magnesium (ammonium acetate extraction) and sulphate sulphur (mono-calcium phosphate extraction).

Table 1 Pasture mixture sown at Winchmore in 1950.

	kg per hectare
Perennial ryegrass *(Lolium perenne)*	17
Short rotation ryegrass *(Lolium multiflorum)*	17
Cocksfoot *(Dactylis glomerata)*	6
Timothy *(Phleum pratense)*	6
Crested dogstail *(Cynosurns cristatus)*	1
White clover *(Trifolium repens)*	2
Subterranean clover *(Trifolium subterraneum)*	2
Red clover *(Trifolium pratense)*	2

Pasture production

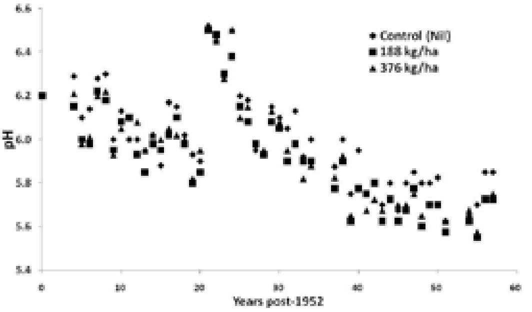
Pasture production was measured using exclusion cages (2.75 x 0.61 m), with two cages per plot. These areas were pre-trimmed to 25 mm above ground level, and left for a standard grazing interval for that time of year, before a 0.40 m wide strip in the middle of each enclosure was harvested to 25 mm above ground level using a lawnmower. The total wet weight was determined and a subsample taken to determine dry matter content. A sample within the harvested area was first cut with hand shears to 25 mm above ground level, and manually dissected into grass, clover and weeds, with the weight included in the total herbage wet weight. A new area was pre-trimmed on each occasion. All surplus mown herbage was returned to the plot.

Species analysis

In October 2010, pasture species presence was assessed by taking 50 soil cores (50 mm diameter and 50 mm deep) from each plot. Cores were maintained in trays in a glasshouse at ambient temperature for 3 weeks prior to identifying the species. In each core, grass, legume and herbaceous species were identified and their presence recorded. The abundance of each species (cores in which a species was present/total number of cores) was calculated for each plot and expressed as a percentage. Percentages were analysed using Generalised Linear Models in Minitab 15.

The presence of endophyte was determined using the method described by Hahn *et al.* (2003). Total genomic (plant + endophyte) DNA was isolated, using the FastDNA kit plant protocol (MP Biomedicals LLC, Solon, Ohio, USA), from tiller bases or nodes of 45 individual ryegrass plants sampled randomly from both pasture and 'Grasslands Ruanui' populations (the latter sourced from the Margot Forde Germplasm Centre, AgResearch, Palmerston North). Each individual was then assayed with endophyte simple sequence repeat (SSR) markers B10 and B11 (Moon *et al.* 1999) and

Figure 2 Soil pH level assessed immediately prior to the annual superphosphate treatment application.



ryegrass SSR markers using previously-described protocols (Faville *et al*. 2004).

Genetic distance-based clustering of the dataset was computed using the software package PowerMarker 3.25 (Liu and Muse 2005). Assignment of individuals to populations was completed using an assignment calculator (http://www.biology.ualberta.ca/jbrzusto/Doh.php). This calculator takes multi-locus genotypes of individuals from several populations and determines from which population each individual is most likely to have come, by using the assignment index, the highest probability of an individual's genotype in any of the populations (Paetkau *et al*. 1995).

Results and Discussion

Fertiliser application and soil fertility

Predictably, Olsen P levels declined over the 60-year period in the absence of artificial supply (Fig. 1). Levels have tended to increase slightly when 188 kg/ha of superphosphate was applied annually, while levels increased dramatically, particularly during the last 25 years, with the application of 376 kg/ha. The dip and subsequent rise in Olsen P around 30 years post 1952 was due to decreases in the availability of P in the superphosphate applied, as described by Quin (1982). The values in Fig. 1 represent Olsen P levels when at their annual lowest, immediately prior to annual treatment application. When averaged from four dates uniformly spread over 12 months, the Olsen P values for 1952 were 10.0 for all treatments, and in 2009 were 5.7, 20.0 and 66.4 for Treatments 1, 2 and 3 respectively**.**

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Table 2 Presence of individual pasture species identified in pasture cores during late spring 2010 (proportion of cores with individual species present %). Means within rows with superscript letters in common are not significantly different P<0.01.

Species	Control	188 kg/ha	376 kg/ha
Ryegrass	54.8 ^{B}	89.9 ^{A}	96.0 ^{A}
Cocksfoot	7.6 ^{C}	35.7 ^{A}	24.0 ^{B}
Timothy	0.0 ^{B}	18.1 ^{A}	13.5 ^{A}
Crested dogstail	4.1 ^{A}	5.0 ^{A}	2.0 ^{A}
White clover	47.2 ^{B}	66.3 ^{A}	64.0 ^{A}
Unsown annual grasses	79.2 ^{A}	50.3 ^{B}	59.5 ^{B}
Unsown perennial grasses	83.2 ^{A}	45.7 ^{B}	43.0 ^{B}
Suckling clover	22.3 ^{A}	0.0 ^{B}	0.0 ^{B}
Unsown herbs	61.9 ^{A}	39.2 ^{B}	34.5 ^{B}
Moss	67.5 ^{A}	15.6 ^{B}	14.0 ^{B}
Summary:			
Sown species	76.1 ^{B}	98.0 ^{A}	99.5 ^{A}
Unsown species	98.0 ^{A}	85.9 ^{B}	86.0 ^{B}

Definition of persistence

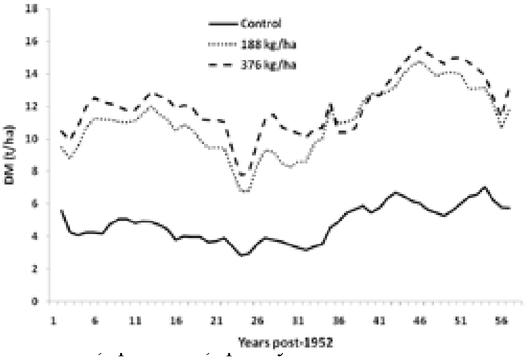
Two aspects of persistence are considered here - whether the sown species have survived in the sward, and whether the pasture as a whole has maintained production.

Pasture species persistence

Table 2 presents the proportion of soil cores that contained different species in October 2010. No red clover and minimal subterranean clover were present, so these species are not presented. The only unsown clover present was suckling clover (*Trifolium dubium*).

The species distribution on the Control treatment differed in many respects from the two fertiliser treatments. All sown grasses (except for dogstail) and white clover were less abundant on the control treatment. On the control, the main unsown annual grass was hair grass (*Vulpia bromoides*, present in 63.5% of cores), and the main unsown perennial grass was browntop (*Agrostis capillaris,* 57.4%), each of these grasses having a higher abundance than ryegrass. Sweet vernal (*Anthoxanthum odoratum,* 50.3%) and Yorkshire fog (*Holcus lanatus*, 24.4%) were the other unsown perennials present, while goose grass (*Bromus mollis*, 23.9%), poa (*Poa annua* and *trivialis*, 17.3%) and barley grass (*Hordeum murinum*, 8.6%) were the other annuals. Key herbs in the Control treatment were plantain (40.6%), yarrow (20.8%), dandelion (11.2%) and sedge (8.6%), with traces (<5%) of chickweed,

Figure 3 Annual pasture production from trial establishment at three annual rates of superphosphate application.



The pasture species distribution in the two fertilised treatments was very similar. Applying a higher fertiliser rate did not alter the overall persistence of sown species versus unsown, however of the sown species, ryegrass was slightly more common (P<0.05) and cocksfoot less common (P<0.01) than in the low fertiliser treatment.

Ryegrass was the dominant grass species in the fertilised treatments, with both cocksfoot and timothy also abundant. However unsown grasses were still common, although less than in the control. Browntop (42.7 and 39.5%, Treatments 2 and 3 respectively), goose grass (24.1 and 45.0%) and Poa (32.7 and 28.0%) were the primary species present in the low and high fertility treatments respectively, with only low levels of the other unsown grasses. Fewer herbs were present, primarily yarrow (18.1 and 10.0%), dandelion (7.5 and 11.0%), chickweed (9.0 and 8.5%), speedwell (4.0 and 7.0%) and plantain (5.5 and 0.5%) with traces of daisy, sedge and subterranean clover.

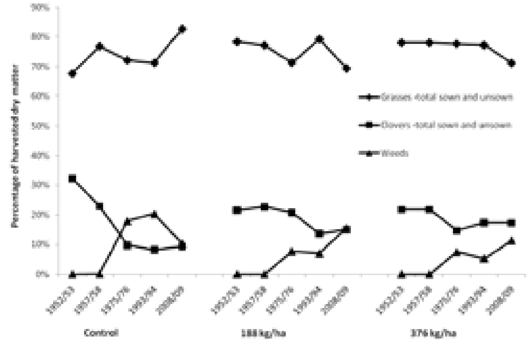
Endophyte

Analysis of genomic DNA extracted from perennial ryegrass tillers, using B10 and B11 endophyte SSR markers (Moon *et al*. 1999), revealed allele sizes of 176 bp (for B10) and 177 bp (for B11) in 91% of sampled tillers. This profile is consistent with the presence of NZ common toxic *Neotyphodium lolii* endophyte (Latch 2000). The remaining four tiller samples yielded a null result, indicative of nil endophyte status or low endophyte mycelial biomass in those samples. Genetic analysis of the ryegrass plants, based on multi-locus ryegrass SSR fingerprints, was consistent with the pasture being of, or related to, the cultivar 'Grasslands Ruanui'.

Productivity of the pasture

Pasture production reached the lowest levels around 25 years following trial establishment (Fig. 4), corresponding to the decline in fertility resulting from poor superphosphate quality illustrated in Fig. 1. Both fertiliser treatments have otherwise maintained high levels of pasture production throughout the trial's history, yielding 9-13 t/ha in the initial decade, and 11-15 t/ha in the latest decade. A contributing factor may be the higher levels of white clover in these swards than in the control. Production differences between the control and fertiliser treatments were immediately apparent, and the control treatment has produced around 4-6 tonnes of dry matter in most years.

Figure 4 Percentage of grasses, clovers and weeds in harvested herbage, and annual averages for 5 years over the trial period. Note that there were some changes in how the dissections were carried out over time. In 1952-58, both dead matter and weeds were included in the weed category. In 2008/09 dissections were not carried out in all harvests but at four times during the year.



Overall, production has gradually increased over the 60 years of the trial. This is most likely due to gradual improvements in soil conditions, particularly water holding capacity, as the soil adapted to irrigation. An adjacent trial on the same property showed a greater depth of soils to stones (due to earthworm activity) on irrigated soil than dryland, resulting in improved soil moisture retention under irrigation (Metherell *et al.* 2002).

The proportion of clover in the sward was high following establishment, and few weeds were present (Fig. 4). Clover levels declined in all treatments over time, however they remained at >13% in the fertiliser treatments, while they declined to <8% in the control. Weeds comprised around 20% of herbage mass in the control in later years. Grass has remained the dominant herbage component in all treatments, however the proportion of unsown grasses were elevated in the control.

In the fertilised treatments, the pasture has maintained high levels of production, with reasonable white clover content.

Conclusions

Ryegrass, cocksfoot and white clover can persist for 60 years in a pasture. However in order for them to be the dominant species in the sward, adequate fertiliser inputs are essential. High phosphorus and sulphur input has little impact on the persistence of these species.

White clover is more common with adequate superphosphate fertiliser, resulting in increased N fixation and higher yields than without superphosphate. In both high and low fertility soils ryegrass will persist, but it will only dominate with adequate fertility. Cocksfoot and timothy also require adequate fertility to persist in a pasture.

While the grass component remained high in all treatments, unsown grasses dominated in the control while ryegrass dominated in the fertilised treatments.

Given adequate fertiliser, a ryegrass and white clover-based pasture can continue to produce high annual yields with a reasonable legume content 60 years following sowing. The indication is that an old pasture can produce comparable yields to new pastures under similar management.

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