PHOSPHORUS REQUIREMENTS OF HIGH PRODUCING DAIRY PASTURES

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Abstract

Features of today's high producing dairy farms include the increasing use of new plant germplasm, the greater use of nitrogen (N) fertilizer and the expansion of irrigation, including effluent application. Alongside that, the industry is consistently moving towards higher than recommended soil P levels, as a potential safeguard against the risk of under-fertilizing pastures. This paper briefly summarises current knowledge on the nutrient requirements of legume based pastures and on critical and target soil P test ranges for dairy pastures, before reporting on some interim findings of a series of field studies, with locations in the Waikato, Manawatu, Canterbury and Southland exploring whether current recommended critical Olsen P levels apply to today's high performance dairy pastures. The implications of the findings to the interpretation of current soil test information for dairy farms are also discussed.

Interim findings indicate that the critical Olsen P level for a high performance dairy pasture align with those reported and recommended by Roberts & Morton (1999) for those situations where current milk solids production/ha is in the top 25% for the supply area or it is intended to increase to that level. The initial findings also indicate that the source of added N (e.g. legume N versus Fertiliser N) influences the relationship between Olsen P and relative yield. It is important to note that the results were obtained in situations where regular irrigation was applied through late spring-autumn to avoid any moisture stress on plants.

Introduction

Features of today's high producing dairy farms include the increasing use of new plant germplasm, the greater use of nitrogen (N) fertilizer and the expansion of irrigation, including effluent application. Alongside that the industry continues to consistently move towards higher than recommended soil P levels, as a potential safeguard against the risk of under-fertilizing pastures. This is no better illustrated than from an examination of recent soil test data from the Waikato, where a significant proportion can be regarded as high or extreme (Anonymous, 2008). It is possible that farmers are seeing a significant benefit from using P at high levels especially if N and irrigation is also regularly used.

Soil P levels recommended by science are below those becoming common practice. This is in the absence of research based information to either justify the practice and to evaluate the economic benefits, or alternatively to show where such rates are not required. The deficiency in research information relating to the economics of dairy production at high P levels places researchers in a difficult position to not only defend current recommendations, but also to evaluate the real trade-offs between production losses and environmental benefits. Application of fertiliser P above the target range, without justification, increases the environmental risk, particularly on soils with low anion storage capacity (McDowell et al., 2005). The risk of high P losses is not just from the higher soil P levels, associated with over use of P fertiliser, but from the associated higher variance in these levels.

In the past, fertiliser expenditure was limited primarily to phosphorus (P) based fertilisers. In the last 19 years nitrogen (N) fertiliser use has increased dramatically, to lift on-farm pasture production beyond the ceilings determined by a legume based pasture system. For example in the Waikato there has been a seven-fold increase in the application of N fertilisers on dairy farms since 1990, with an average 166kgN/ha applied in 2007 (Anonymous, 2008). Under irrigation those rates often exceed >200 kgN/ha/yr. Associated with the increased pasture growth from added N on dairy farms, has been additional maintenance inputs of P. With the recent dramatic lift in fertiliser prices, the optimum use of these two nutrients takes on added importance.

This paper briefly summarises current knowledge on the nutrient requirements of legume based pastures and on critical and target soil P test ranges for dairy pastures, before presenting some interim findings from a series of field studies, located in the Waikato, Manawatu, Canterbury and Southland. The field studies are examining modern pasture cultivar response to P fertilizer under conditions where growth limitations such as moisture stress and N availability have been removed. The implications of the findings to the interpretation of current soil P test recommendations for dairy pastures are also discussed.

Current knowledge

(a) Nutrient requirements

New Zealand soils have pH <6.0 and are naturally deficient in nitrogen (N) and phosphorus (P), with sulphur (S) deficiency widespread and potassium (K) deficient under intensive livestock (i.e. dairying) and or where silage or hay is regularly harvested. Low available soil N is the primary nutrient limiting pasture production on dairy farms. The main source of N in New Zealand pastures comes from biological N_2 fixation by legumes, with N fertilisers used in the past to augment biological N supply during periods when legume growth and N_2 fixation are low. Increasingly N fertiliser is being used to lift production beyond the ceiling determined by a legume based pasture. A legume-based pasture system is a self-regulating biological system with an upper limit on the amount of N that can be fixed and made available for plant growth, setting a limit on production. Nutrient (P, S, K), trace elements and lime recommendations for pastures target the legume component of the sward, to ensure maximum biological N_2 fixation and N supply to the grass component of the sward. While the legume is an important feed source and in maintaining pasture quality, its primary role is in N supply to the grass component of the sward. Legumes are less competitive than grasses for soil P (Jackman and Mouat 1965), and as a result soil P levels for optimum pasture production are defined by the legumes requirement for this nutrient, rather than the grass component.

(b) Critical and target soil P test ranges.

The relationship between Olsen P and pasture production differs with soil group. For the sedimentary, volcanic ash, and pumice soils near maximum pasture production (97% of relative pasture production) is achieved at a critical Olsen P of 20, 22 and 38 µg/ml, respectively (Roberts and Morton 1999). Because of the variability in the calibration curves between Olsen P and relative pasture production and in soil test results, there is no precise soil P level that will guarantee, in all situations, a particular level of pasture production. As a consequence a target range is also included for each soil group. For both the sedimentary and volcanic ash soils the target Olsen P range is 20-30 µg/ml and for the pumice soils 35-45 µg/ml. Similarly because of variability in the measurement of pasture production and Olsen P between trial sites, at any Olsen P level there is a range of relative pasture production that could be achieved. As a consequence in some situations below the upper range, further increases in pasture production could be gained at Olsen P beyond these target ranges. Roberts and Morton (1999) indicate that for both the sedimentary and volcanic ash soils the upper target Olsen P range is 30-40 µg/ml and the pumice soils 45-55 µg/ml. This recommendation is qualified on the basis that the increased pasture production from the higher Olsen P values can be utilised and covert to extra milk. Conversely at other sites about the upper range, near maximum pasture production would be achieved at Olsen P levels lower than the target range.

The vast majority of the data sets that contribute to the relationship between Olsen P and relative yield came from field studies with long-established permanent pastures and where little if any fertiliser N was applied. Further, very few would have been irrigated. This situation has changed in the last decade with increasing use of N fertiliser, new plant germplasm and irrigation. The overall nutrient status of dairy pasture soils has continued to improve (Wheeler, 2004), as has per hectare pasture milk solids.

Phosphorus requirements of high producing dairy pastures

(a) Locations and field study design

There are two field sites in the Waikato, both under irrigation, two sites in the Manawatu one rain fed (unirrigated) and one under irrigation, one site in Canterbury under irrigation and one site in Southland under irrigation. Except for one of the Waikato sites sown with tall fescue (*Festuca arundinacea)*, all other sites were sown with a modern ryegrass (*Lolium perenne*) cultivar in the year prior to the establishment of the response study. Modern white clover (*Trifolium repens*) cultivars were also sown at all sites. Except for the Waikato site where the soil was derived from volcanic material, at all the other sites the soils where derived from sedimentary material.

Field trial design is a 5P by 2N factorial with 4 replicates at each site. Five Olsen P levels of 15-20, 20-25, 30-35, 40-45 and >60 were generated by appropriate capital P applications applied in a split application at the start of each study, three of which started in 2005, one in 2007 and two in 2008. Two rates of N fertiliser 0 and 400 kg N/ha/yr were applied in applications of 40 kg N/ha at approximately monthly intervals from August to June. Further applications of P were made annually to adjust and maintain the target Olsen P levels. Basal applications of trace elements were applied at the trial start and annually. Potassium fertiliser at a rate of 50 kg K/ha/application was applied 4 times per year, with S fertiliser applied at a rate of 50 kg S/ha every 6 months. Trials were fenced to exclude stock and trimmed to leave a residue of 1600-1800 kg DM/ha following each measurement. All clippings were removed. Pasture production was measured by means of a rising plate meter at approx. monthly intervals. Soil samples were collected from each plot (0-75mm) prior to the commencement of the trials and in late November-early December each year.

All data were analysed statistically to determine treatment effects by means of ANOVA within Genstat (v10). The P response curves for the two N treatments (0 and 400 kgN/ha) were compared via a SSPLINE function for the annual totals. To examine the annual P response curves from the analysed annual data, initially the data for the individual N treatments of each year were fitted by means of Mitscherlich response curves against the Olsen P from the November soil sample of that year. For individual N application rates there were 24 data sets (4 sites x 1- 4 years x 2 N rates).

(b) Interim findings

(i) Pasture dry matter response to nitrogen, irrigation and phosphorus.

The upper limit to pasture production to the modern ryegrass cultivars, where N and moisture were non-limiting, ranged from 15,180 to 17,250 kg DM/ha in the Waikato (2005-2008), 18,450 to 23,890 kg DM/ha in the Manawatu (2005-09) and 15,540 to 23,890 kg DM/ha in Southland (2005-08). These swards were grass dominant, with legume contents often <5%. In comparison swards irrigated, but receiving no N fertiliser, were legume dominant (20-40%) for long periods of the year. The irrigated pasture yields without added N ranged from 12,250 to 13,570 kgDM/ha at Waikato (2005-2008), 12,530 to 18,484 kgDM/ha at Manawatu (2005-09), and 9,570 to 17,200 kgDM/ha at Southland (2005-08).

At all sites irrigated pastures responded to fertiliser N (400 kgN/ha) in all years, with total production increased on average by 40% (Range = 12 to 67%). The inclusion of an irrigation comparison at the Manawatu site allowed a comparison to be made of the contribution of water, N and P to pasture growth (Table 1). Using the 2008/09 year data to date, the pasture response to irrigation was 30%. The pasture response to applied N on the unirrigated plots was 50%, compared with 30% on the irrigated pasture. Under irrigation the legume based pasture was able to supply sufficient N for the pasture to produce the same quantity of dry matter as the unirrigated pasture receiving N fertiliser. The pasture response to added P was higher on the irrigated (23%) than unirrigated (13%) pasture, but much smaller than that from either water or N, when the comparison was limited to a single years production.

Table 1. Effect of irrigation, applied N and P on pasture response in 2008/09 year data to date at the Manawatu site

	Treatment	Pasture production (kgDM/ha)
Rain fed (unirrigated)		
	N 0	12,013
	N 400	18,183 (50%) ***
	Nil P	14,142
	Plus P	16,022 (13%) †
Irrigated		
	N 0	18,484
	N 400	23,890 (30%) ***
	Nil P	17,532
	Plus P	21,600 (23%) **

†, **, *** Significant at the P<0.10, <0.01, <0.001, respectively.

(ii) Relationship between Olsen P and relative yield of high producing pastures

The Mitscherlich relationship between relative yield (RY) and Olsen P for the annual data from the Waikato, Manawatu, Canterbury and Southland locations for the 0N and 400N application rates separately were

0N: (4 of the 12 data sets) $RY (\%) = 101.06 – 34.0 \times 0.9535^{Olsen\ P}$

400N (8 of the 12 data sets): $RY (\%) = 99.26 – 40.32 \times 0.9174^{Olsen\ P}$

The relationships accounted for 62% and 66% of the variation in RY for the 0N and 400N data sets, respectively, that could be described by a Mitscherlich response curve (Fig.1). It is interesting to speculate on possible reasons for the limited success in fitting a Mitscherlich response curve to the 0N data sets, given only 4 of the 12 data sets met the criteria. Much of the 0N data could in fact be explained by a linear function. Defining the asymptote within acceptable tolerance levels (the SE of the asymptote had to be <10% of the asymptote) was also a factor contributing to the poor fit. This might reflect the inability of the legume component of the sward to supply sufficient N for maximum pasture growth, or simply reflect the fact that there were other factors limiting clover growth and N_2 fixation and as a consequence expression of P response. Removing N as a limiting nutrient by the addition of 400 kgN/ha allowed maximum expression of pasture growth to added P and the establishment of the upper limit or asymptote.

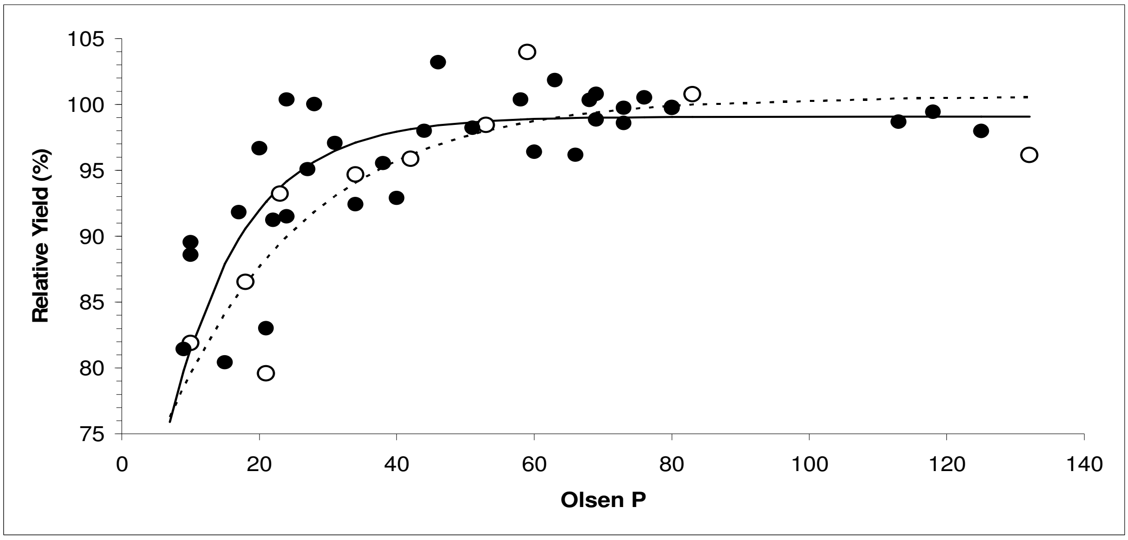

Figure 1 Relationship between relative yield and Olsen P for the annual data from the Waikato, Manawatu, Canterbury and Southland locations for the 0N (○ dotted line) and 400N (● solid line) treatments.

Maximum pasture production (97% RY) was achieved at an Olsen P level of 43.7 µg/ml and 33.5 µg/ml for the 0N and 400N application rates, respectively (Fig. 1). Although this difference was not significant the data suggests that by removing N as a limiting factor, a lower Olsen P for near maximum pasture growth is required. This is not to be confused by the P requirements for sustaining pasture production. The lower target Olsen P value of a pasture supplied with fertiliser N for 97% of maximum pasture production, rather than N supplied by legumes, might reflect the fact grasses are more competitive in foraging for P in soil than clover (Jackman and Mouat 1972) and require a lower soil P level for optimum growth.

The critical Olsen P for 97% maximum pasture production in this study are well above the critical values of 20 and 22 µg/ml for a sedimentary and volcanic ash soil, respectively, reported by Roberts & Morton (1999). They are also above the target range (20-30 µg/ml.) but align with the range of 30-40 µg/ml reported and recommended by the two authors for those situations where current milk solids production/ha is in the top 25% for the supply area or it is intended to increase to that level.

It is interesting to compare the critical Olsen P values found in the present study, with those of Gillingham et al., (2007). They found near maximum pasture production at a critical Olsen P value close to 20µg/ml for sheep and beef pastures located on the East Coast of both Islands. The field sites in Gillingham et al., (2007) study were characterised by seasonal moisture deficits and low to moderate pasture production.

Alongside the current findings this suggests that as constraints are removed and production increases, so does the critical Olsen P value.

To the present series of field studies, scheduled to continue until 2011, an additional study has been added to examine the influence of the physical condition of the soil on the pasture response to added P, as evidence is accumulating to show that the soil pore size distribution and function are declining on our intensively farmed soils, due in a large part to the heavier liveweight loadings (Mackay 2008). Findings from cropping studies suggest that a loss in soil pore function results in losses of production and efficiencies of use of inputs (Shepherd 1992).

(iii) Summary of interim results

The initial findings indicate that the critical Olsen P level for a high performance dairy pasture is higher than the recommended soil test value that gives near maximum pasture production, which for a sedimentary and volcanic soil are 20 and 22 µg/ml, respectively. They are also higher than the target Olsen P range, which is 20-30 µg/ml for both the sedimentary and volcanic soils. They do align with the range of 30-40 µg/ml reported and recommended by Roberts & Morton (1999) for those situations where current milk solids production/ha is in the top 25% for the supply area or it is intended to increase to that level.

The initial findings also indicate that the source of added N (e.g. legume N versus Fertiliser N) influences the relationship between Olsen P and relative yield. Where 400N is used and N supply is largely corrected then the pasture respond to soil P was more predictable providing support for the hypothesis that the correction of N supply is important in defining P requirements. Where farmers adopt a practice of regular N fertiliser application the optimum level of soil P required is less than where no N fertiliser is used. The limited success in fitting a Mitscherlich response curve to the 0N data sets, suggests that the soil P level is not the major factor defining pasture production and so the likely response to P is largely uncertain. It is important to note that the results were obtained in situations where regular irrigation was applied through late spring- autumn to avoid moisture stress on plants. This is the time of year when legumes usually grow best and provide maximum N fixation.

Acknowledgments

The authors wish to acknowledge the support of FRST/Pastoral sustainable forage productivity gains (C10X0604).

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