

## Implications of long-term superphosphate applications on the accumulation and plant availability of soil phosphorus under irrigated pastures

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### Abstract

Changes in soil phosphorus (P) associated with the establishment and maintenance of improved ryegrass-clover pasture under different superphosphate fertiliser treatments were examined over a 20-year period (1957-77). Results showed that soil organic P increased with increasing applications of P fertiliser. This represents a dynamic balance between rates of organic P addition and breakdown in the soil. This balance is reached slowly and may be significantly altered only by drastic changes in land use. In annually fertilised soils, amounts of inorganic P increased with time. However, the potential utilisation of this residual inorganic P is limited by its apparent stability in the soil.

Keywords grazed pasture, irrigation, fertiliser P, soil inorganic P, soil organic P, soil P fractionation

### Introduction

The low native phosphorus (P) status and high P retention characteristics of many New Zealand soils necessitate regular applications of P fertiliser to establish and maintain improved grass-clover pasture. On an annual basis, the amount of P removed from soil under pasture in off-farm produce and by stock transfer is equivalent to only 10-50% of the P applied in fertiliser (Parfitt 1980). As a direct result of continued applications of P fertiliser, considerable accumulations of P have been observed in established grassland soils in New Zealand (Jackman 1964; Condon & Goh 1989). In recent years, P fertiliser application to pastures in New Zealand has declined dramatically in response to lower product returns and the removal of direct subsidies. Under these circumstances, residual P accumulated in the soil from previous fertiliser additions may play an important role in plant P nutrition (Mackay & Wewala 1990).

The main objective of this paper is to describe aspects of recent research on P accumulation in

fertilised pasture soils and highlight some important limitations of the potential utilisation of residual P by pasture plants.

### Methods

Soils were obtained from the long-term superphosphate (SSP) trial situated at the Winchmore Irrigation Station in Mid-Canterbury (Condon & Goh 1989; Nguyen *et al.* 1989). This particular trial is the longest running experiment of its kind in New Zealand. The present study was concerned with changes in soil P which occurred between 1958 and 1977 in the following treatments: control (420 kg SSP/ha 1948-51, none 1952-77) 188PA (420 kg SSP/ha 1948-51, 188 kg SSP/ha/yr 1952-77) 376RES (420 kg SSP/ha 1948-51, 376 kg SSP/ha/yr 1952-57, none 1958-77)

Soil samples (0-75 mm) collected from these treatments in 1958, 1968 and 1977 were subjected to soil P analysis which involved sequential extractions to (i) determine total inorganic-P-(Pi)-and-organic P (Po), and (ii) separate and identify different forms of inorganic and organic P (Condon & Goh 1989). For the purpose of this study the different P fractions were assigned the following relative plant availabilities:

- available Pi (NaHCO<sub>3</sub> and NaOHI extractable Pi)
- stable Pi (HCl and NaOHII extractable Pi)
- labile Po (NaHCO<sub>3</sub> extractable Po)
- stable Po (NaOHI and NaOHII extractable Po).

### Results and discussion

Amounts of total soil Pi increased in the 188PA treatment between 1958 and 1977 and decreased in the control and 376RES treatments between 1958 and 1968 (Table 1). On the other hand, total soil Po increased in all 3 treatments between 1958 and 1968, substantially more so in the fertilised treatments (188PA, 376RES) than in the control (Table 1).

#### Organic P

Accumulations of Po in soil with time under pasture (Table 1) reflect increases in overall biomass production and microbial activity in the soil which

Table 1 Amounts (mg P/kg) of total inorganic P (Pi) and organic (Po) in soils from the control, 188PA and 376RES treatments sampled in 1958, 1968 and 1977.

	1958		1968		1977	
	Pi	Po	Pi	Po	Pi	Po
control	238	348	225	373	224	360
188PA	266	371	291	443	319	439
376RES	308	371	253	421	261	401

result from improved soil moisture (from irrigation) and nutrient availability (especially P and N) (Jackman 1964; Condon & Goh 1989). Nonetheless, soil Po increased in the 376RES treatment after 1958 in the absence of continued P fertiliser inputs despite a dramatic decline in pasture production (Figure 1). This suggests that despite decreased plant P uptake and consequent returns of P in organic residues in the 376RES treatment, the effective rate of Pi immobilisation exceeded the corresponding rate of Po mineralisation over the 1958 to 1968 period. This finding demonstrates the dynamic nature of P transformations in recently improved pasture soils and the time required to reach the appropriate equilibrium or steady-state condition. The influence of greater inputs of soluble P fertiliser on the final equilibrium level of soil organic P is evident in the 188PA soil sampled in 1977 (i.e. >376RES) (Table 1).

The elevated organic P content of the fertilised soils effectively represents a dynamic balance between the respective rates of Pi immobilisation and Po mineralisation, and as a result organic P has limited value as an "exploitable" P resource.

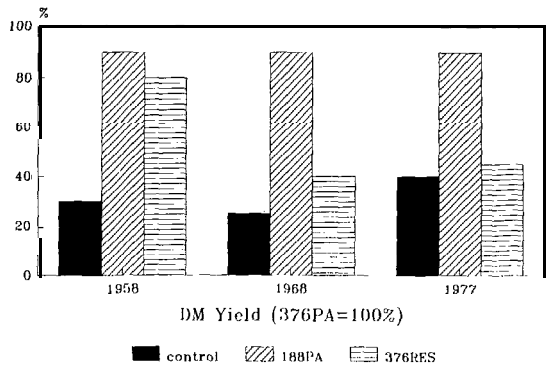


Figure 1 Relative dry matter yields for the control, 188PA and 376RES treatments in 1958, 1968 and 1977 (376PA = 100%).

Table 2 Amounts (mg P/kg) of available Pi (AVPi), stable Pi (SPi), labile Po (LPo) and stable Po (SPo) in soils from the control, 188PA and 376RES treatments sampled in 1958, 1968 and 1977.

	1958				1968				1977			
	AVPi	SPi	LPo	SPo	AVPi	SPi	LPo	SPo	AVPi	SPi	LPo	SPo
control	128	110	42	306	116	109	44	329	109	115	41	319
188PA	148	118	48	323	159	132	59	384	154	165	59	380
376RES	168	140	51	320	135	118	50	371	128	133	51	350

Nonetheless, soil management practices can disturb this balance. For example, the addition of lime to regularly fertilised pasture soils can result in some net mineralisation of Po, although the overall effect is often very small and, short-lived as soil pH and exchangeable bases decline again with time (Oniani et al. 1973; Condon & Goh 1989; Perrott & Manse 1989). The Winchmore trial was limed in 1972 which may partly account for the small net decreases in organic P evident in the control and 376RES treatments between 1968 and 1977 (Table 1). On the other hand, more drastic changes in land use such as the long-term cultivation of grassland soils dramatically alters Po cycling and often results in a marked decline in soil Po (Stewart & Tiessen 1987).

The recent origin of most of the organic matter in the Winchmore soils is reflected in the distribution of soil Po. Thus proportionate increases in soil Po caused by fertiliser addition were greater in the labile pool than in more stable forms of Po. For example, in soils sampled in 1968 the increases in labile Po and stable Po in the 188PA treatment compared with the control were 34% and 17% respectively (Table 2).

### Inorganic P

The decline in soil Pi which occurred in the 376RES treatment after 1958 (Table 1 and 2) may be attributed to the utilisation of residual P from previous P fertiliser applications (1948-1957). The concomitant increase in soil Po which occurred in this treatment (Table 1) suggests that a significant proportion of the residual Pi was converted to organic P forms in the soil.

Despite the fact that in 1977 amounts of available and stable Pi were greater in the 376RES soil than in the control (Table 2), the respective pasture yields for that year were very similar (Figure 1). This clearly illustrates the limited plant availability of residual Pi in soil which may be partly due to the increased stability of fertiliser P-soil colloid reaction products with time (Devine et al. 1968). This was confirmed in glasshouse and field experiments carried out on the Winchmore long-term trial by Goh & Condon (1989) and Condon & Goh (1990).

### Conclusions

Fertiliser P applied during the early stages of improved pasture development contributes to the accumulation of organic P in the soil. Data from the Winchmore long-term trial show that at the optimum P application rate (i.e. 188PA treatment), the

accumulation of residual Pi in soil becomes significant only once the equilibrium level of soil Po has been reached (i.e. once continued net accumulation of Po in soil has effectively ceased after around 20 years). However, constraints on the long-term availability of residual Pi in soil (ref. 376RS) mean that while it may be possible to reduce P fertiliser application rates in established grassland, continued additions of P fertiliser will be required to maintain a consistent level of pasture production.

#### ACKNOWLEDGEMENTS

This study was supported by the New Zealand Ministry of Agriculture and Fisheries and the Lincoln College Research Committee. Thanks are also due to Mr D.S. Rickard for providing the soil samples and pasture production data.

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