T

PASTURE RESPONSES TO LIME
AND PHOSPHORUS ON ACID SOILS
IN NATAL

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NEIL MILES.

A thesis submitted in partial fulfilment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY

NT Thesis (Ph.D.; Soil Science + Agrometeorology) - University of Natal, Pietermaritzburg 1986.

in the

Department of Soil Science and Agrometeorology

Faculty of Agriculture

P University of Natal,

Pietermaritzburg:

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1986.

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ABSTRACT

Animal production in Natal may be greatly improved by the replacement of low quality, natural grassland with introduced pasture. However, soil chemical constraints, in particular excessive acidity and low phosphorus (P) status, together with a dearth of information relating to pasture fertility requirements, pose major obstacles to the introduction of improved pastures. In 1979, a research programme aimed at evaluating the macronutrient and lime requirements of pasture species of importance in Natal was commenced. In this thesis, pasture responses to lime and P on acid, well drained soils in the Natal Midlands and Mistbelt are dealt with. Eleven factorial field trials were conducted over a seven year period, with dry matter production, herbage nutrient levels and chemical properties of topsoils (0-100mm) being monitored. Species included were kikuyu (Pennisetum clandestinum), weeping lovegrass (Eragrostis curvula), white clover (Trifolium repens), Italian ryegrass (Lolium multiflorum) and tall fescue (Festuca arundinacea).

Dry matter production data were frequently characterized by significant lime-P interactions. Positive lime-P interactions, noted in yields of white clover and Italian ryegrass soon after establishment, as well as in the spring/early summer growth of kikuyu, appeared to be restricted to conditions of severe P deficiency. Negative lime-P interactions, suggested to be of considerable practical significance, occurred at more favourable levels of P supply. Herbage P concentrations increased with increases in soil pH, with this effect attaining significance in the case of kikuyu early in its growing season.

Species differed widely in their responses to lime. The yields of the temperates, white clover and Italian ryegrass, increased sharply with lime additions commensurate with the elimination of the bulk of exchangeable Al (pH 5,0). Further increases in pH resulted in yield depressions, which could be overcome by high rates of P fertilizer. Relationships between yield and soil acid saturation for these temperate species indicated that acid saturations in excess of 15% have an adverse effect on their dry matter production. The tropical species, kikuyu and weeping lovegrass, in contrast, were little affected by liming; data reported here indicate that near-maximum yields of these grasses may be realized at soil acid saturations of 50% or more.

With the soils on which these studies were undertaken having low native P reserves and high P immobilization capacites (P sorbed at an equilibrium P conc. of 0,2 mg L^{-1} ranged from 450 to 900 mg P kg^{-1}), large responses to applied P were measured. The P requirement for maximum yield varied widely over the soils and also with the species propagated. Maximum requirement was indicated on the high clay content (500 to 600g kg^{-1} clay in the topsoil) Mistbelt soils, where up to 430 kg P ha^{-1} was required for maximum growth of white clover. Phosphorus interacted positively with applied N in its effects on kikuyu yields on the virgin Mistbelt soils. Responses to applied P were consistently at a maximum during pasture establishment and, in the case of kikuyu, in the early part of the growing season. Yield response to P was closely related to P extractable from the soil with a solution consisting of 0,25$\underline{M}$ NH_4HCO_3 + 0,01$\underline{M}$ EDTA + 0,01$\underline{M}$ NH_4F, adjusted to pH 8,0. In contrast, sorption isotherms failed to reflect meaningful (in terms of dry matter yield) differences between soils with respect to their P status. Internal (plant) P requirement for maximum yield varied between species, with that of weeping lovegrass being lowest at 1,5 g kg^{-1}. Plant P content failed, in certain instances, to reflect significant effects of applied P on yield; furthermore, measured critical P content varied with pasture age and time of the season. These findings emphasize the need for caution in the use of plant analyses for predictive purposes.

DECLARATION

I hereby declare that the whole of this thesis, except where otherwise indicated in the text, is my own original work. I also declare that the results contained in this thesis have not been previously submitted by me in respect of a degree at any university.

Neil Miles

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to the following persons and institutions:

The Department of Agriculture and Water Supply for the opportunity to undertake this research, and for permission to publish the results in the form of a thesis.

Professor John de Villiers, Head of the Department of Soil Science and Agrometeorology and Dean of the Faculty of Agriculture, for supervising this project. The author is particularly appreciative of the fact that Prof. de Villiers so willingly gave of his time in the midst of his many duties as Dean.

Dr Mart Farina, Assistant Director of the Grain Crops Research Institute, and co-supervisor of this project. The author gratefully acknowledges his many hours of discussion with Dr Farina, and considers it a singular privilege to have been able to avail himself of the guidance and encouragement of this research leader.

Dr Peter Bartholomew, Assistant Director, Pasture Research, Natal Region. The guidance and constant encouragement and enthusiasm of Dr Bartholomew are most gratefully acknowledged.

The late Dr Peter Edwards, for initiating this programme and for much sound advice and encouragement.

Mrs Marie Smith, Department of Datametrics, Cedara, for guidance in designing experiments and for many statistical analyses.

Messers Ian Macdonald and John Cunningham for invaluable field work.

Mr Richard Eckard for assistance in the laboratory and field.

Mr Tony Naicker for conducting many thousands of laboratory analyses and for assistance in the preparation of diagrams for this thesis.

Mesdames S. Schroeder, M. Lishman, R. Punwasi, M. Whitwell and A. Heath,

and Messers P. Grace, T. Ndlovu and L. Mbanjwa for assistance with various aspects of this investigation.

The Pasture Research labour forces at Cedara and Tabamhlope for much hard field work under often adverse weather conditions.

Mrs Irene van Wyk, secretary of Pasture Research at Cedara, for much assistance over the past seven years and for her excellent typing of this thesis.

My wife, Bev, for being the blessing she is.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

The potential for animal production off natural grassland in Natal is only a fraction of that attainable from introduced pastures. This is best illustrated by data for the Ngongoni Mistbelt area, where natural grassland is dominated by the highly unpalatable pioneer grass, *Aristida junciformis*. Jones *et al*. (1967) established that the potential production off *A. junciformis* grassland was of the order of 22 kg beef per ha per annum. In contrast, Bartholomew (1985), in long-term grazing trials on introduced pastures in the Mistbelt, found that 1080 kg beef per ha could be produced over a 180 day period on kikuyu (*Pennisetum clandestinum*), and up to 1400 kg beef per ha over a 210 day period on irrigated Italian ryegrass (*Lolium multiflorum*). Not surprisingly, in the light of these data, a survey completed in 1981 revealed that in Natal, a twofold increase in the area under pastures had taken place in the previous decade (Anon., 1981). Significantly, the 123 000 ha under pasture at that time constitutes only six percent of the area potentially available for pasturage. A formidable obstacle in pasture introduction programmes is the correction of soil chemical constraints, in particular excessive acidity and low phosphorus (P) status.

Soil fertility research in Natal, and in Southern Africa as a whole, has over the years centred on the fertility requirements of cash crops, with maize, sugar cane and wheat in particular enjoying priority. The limited pasture work undertaken has generally been in the form of glasshouse investigations or field fertilizer response experiments conducted in the absence of meaningful soil or plant analyses. The latter, aptly termed "spread and measure" by Sumner and Farina (1986), have contributed little to our knowledge of the fertility requirements of pastures.

A relatively wide range of species is included in introduced pastures in

Natal, with the considerable climatic variation within the province being the principal reason for species diversification. The tropical grass, kikuyu, and the temperates, Italian ryegrass, tall fescue (Festuca arundinacea) and cocksfoot (Dactylis glomerata) are favoured in the Midlands and Mistbelt where dairy farming is of major importance. Legumes, principally white (Trifolium repens) and red (Trifolium pratense) clover are frequently included with the temperate grasses. The release of the locally-bred Italian ryegrass cultivar, Midmar, together with favourable economic data emerging from animal trials on heavily-fertilized, irrigated ryegrass, has led to a particularly rapid increase in the area under this species. In extensive beef operations where natural grassland forms the principal summer food source, the hay which is necessary for sustaining animals over the harsh winters, is made mainly from cultivated pastures of the tropical species, weeping lovegrass (Eragrostis curvula). Furthermore, in the drier northern areas, smuts fingergrass (Digitaria eriantha), together with several Cynodon spp., assume importance in beef enterprises. Little is known of the fertilizer and lime requirements of these various species, although practical experience has indicated wide variations in their responses to soil chemical factors. Differing fertility requirements, together with variations in management and utilization (e.g. N application rates, cutting vs grazing), create major difficulties in extending fertilizer advice and present a worthwhile challenge to the pasture research effort.

In 1979, a research programme aimed at evaluating the macronutrient and lime requirements of pasture species of importance in Natal was commenced. Field cutting trials were initiated on a number of sites at the Tabamhlope and Cedara research stations in the Midlands and Mistbelt, respectively. The soils on which these trials were located were typical of the soils in these regions, being well drained and having excellent physical properties, though in an advanced stage of weathering, highly acidic and with an impoverished nutrient status. These soils are representitive of the majority of upland, well drained soils in bioclimatic groups 3 and 4, and also to some extent of the soils in bioclimates 2, 6 and 8 (Fig. 1). Species chosen for detailed study were weeping lovegrass, Italian ryegrass, kikuyu and white clover. In this thesis consideration is given to the responses of these species to lime and P. In the first two papers, lime-P interactions are discussed, with a view to elucidating interrelationships between these amendments in their effects on plant growth. These first papers are viewed as a necessary foundation for subsequent papers, where individual effects of lime and P on the various pasture species are considered, and relationships developed for the prediction of responses to lime and P.

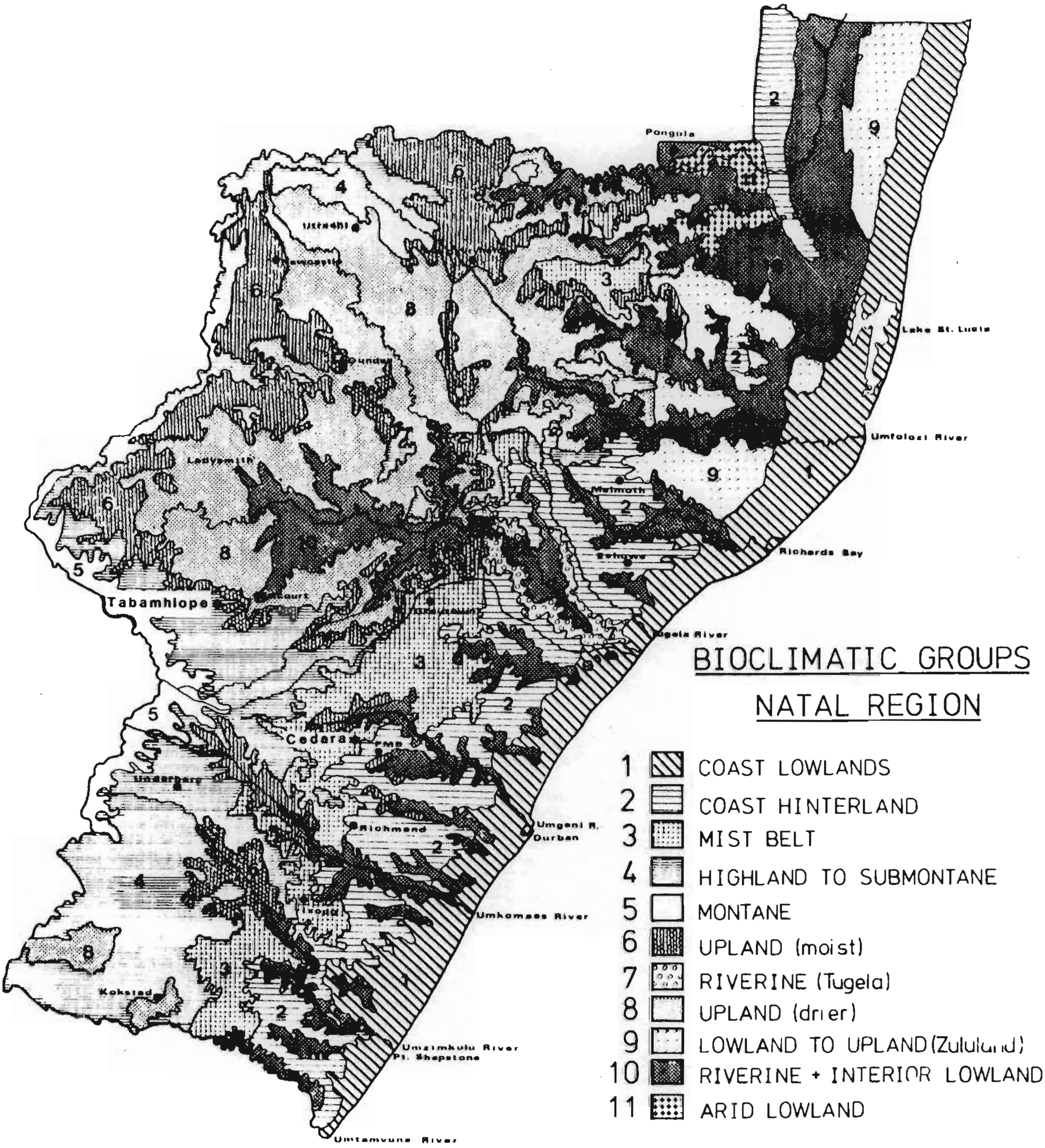


Fig. 1. Bioclimatic groups of Natal

PAPER 1

LIME-PHOSPHORUS INTERACTIONS IN THE GROWTH OF WHITE CLOVER, TALL FESCUE AND ITALIAN RYEGRASS ON ACID SOILS

INTRODUCTION

Correction of chemical constraints, in particular the elimination of soluble Al and the creation of a favourable P status, present major obstacles in agricultural development on acid, highly weathered soils. Plant responses to lime and P on such soils have, particularly under glasshouse conditions, received much attention (Shoop _et al_., 1961; Munns, 1965; Sumner, 1979; Farina _et al_., 1981), with interactions between these amendents being frequently noted. However, despite emphasis in recent years on the importance of interactions in future advances in farm profitability (Cooke, 1982; Wagner, 1981, 1983), little attempt has been made to verify the existence of such interactions under field conditions. In this paper field-measured lime-P interactions in the growth of temperate pasture species on highly weathered soils are considered.

MATERIALS AND METHODS

The data discussed here were obtained from four field experiments on two highly weathered soils. Two of the experiments were located on a Cleveland soil series in the Natal Midlands (altitude 1450m, mean annual rainfall 1166mm and pan evaporation 1436mm) and the remaining two on a Farmhill soil in the Natal Mistbelt (altitude 1067m, rainfall 885mm and pan evaporation 1478mm). Selected properties of these soils are presented in Table 1.1.

Table 1.1 Selected properties of the soils on which the field experiments were carried out.

		Exchangeable cations							pH			Particle size		
Soil	Depth	Ca	Mg	K	Al+H	Mn	P	P†req	KCl	H_2O	Org. C	Clay	Silt	Sand
	mm	--- cmol(+)L^{-1} ----				mgL^{-1}		mg kg^{-1}			----- g kg^{-1} ------			
Farmhill	0-150	0,76	0,57	0,35	3,40	9,9	4	475	3,96	4,90	49	590	220	190
	150-350	0,31	0,67	0,14	1,83	1,0	3	-	4,10	5,05	34	670	190	140
Cleveland	0-150	0,62	0,25	0,07	2,85	6,1	6	370	4,04	4,47	28	330	120	560
	150-350	0,30	0,17	0,05	1,52	6,0	1	-	4,24	4,84	12	370	120	510

† P sorbed at a solution concentration of 0,1 mgL^{-1} by the method of Fox and Kamprath (1970)

The Cleveland soil was under a permanent low producing (mown) Eragrostis curvula sward while the Farmhill soil was in the virgin state.

On the Cleveland soil, the effects of P and lime on the growth of a pure white clover (Trifolium repens cv Ladino) sward were studied. The design used was a 4^3 unreplicated fully confounded factorial with blocks of 16 plots. The factors varied were P, K and lime. Potassium treatments and responses to K are not of concern to this discussion, and P and lime effects are examined at non-limiting levels of K. Lime, as calcium hyroxide, was incorporated into moist soil at rates of 0, 2000, 4000 and 12000 kg ha^{-1}. One week after liming, P, as double superphosphate (19.6%P) was applied at rates of 0, 100, 200 and 300 kg ha^{-1}. Both the P and lime were incorporated by means of a rotovator to a depth of approximately 200mm. Included with P treatments was a basal dressing of Mg, S, Zn, Cu, B and Mo at rates of 150, 100, 20, 7, 5 and 0.5 kg ha^{-1}, respectively. Plot size was 10m X 3.5m with a net plot of 7.6m X 1.2m. Clover was planted in March 1983 using inoculated seed at a seeding rate of 3 kg ha^{-1}. The experiment was harvested (cutting height 70mm) at intervals of six weeks for the duration of the following season after which lack of persistence and weed invasion on zero lime and P plots precluded statistical evaluation of the responses.

On the Farmhill soil, the effects of lime and P on the dry matter production of white clover and white clover/tall fescue (Festuca arundinacea cv K31) swards were examined using twice replicated 5^2 factorial designs. Individual plot sizes were 9m X 3m (net plot 7.6m X 1.4m). Dolomitic lime was applied at rates of 0, 3400, 6800, 13600 and 20400 kg ha^{-1}. Phosphorus, as double superphosphate was applied at rates of 40, 80, 120, 160 and 200 kg P ha^{-1}. The lime and P, together with 4 kg Cu ha^{-1}, 3.5 kg Zn ha^{-1} and 2 kg B ha^{-1}, were incorporated by rotovator to a depth of 200mm prior to planting. Clover seed was inoculated, pelleted with lime and treated with Mo. The clover seeding rate in both the clover alone and clover/fescue trials was 3 kg ha⁻¹ and the fescue seeding rate 29 kg ha⁻¹. Planting was in February 1979. Three weeks after seedling emergence, N, as ammonium sulphate, was applied at 60 kg ha⁻¹. In the case of white clover alone, P topdressings were applied at the end of the 1979/80 season, resulting in final P rates of 86, 164, 242, 306 and 373 kg ha⁻¹. The swards were harvested (70mm cutting height) at intervals of six weeks throughout the growing seasons. Annual rainfall in both 1979/80 and 1980/81 season (541mm and 625mm, respectively) was only sixty to seventy percent of the long-term average for the area; as a result productivity of these swards was generally poor. In the case of the fescue/clover, invasion by native grasses and weeds restricted experimentation to a single season. The pure clover trial, which was hand-weeded, was continued for three seasons.

Also studied on the Cleveland soil were P and lime effects on the performance of the annual, Italian ryegrass (Lolium multiflorum cv Midmar). Experimental design, factors and nutrient incorporation were as in the adjacent white clover trial. Once again, K levels and their effects are not discussed here. In the first year (1985), levels of P were 0, 50, 100 and 150 kg ha⁻¹, with double superphosphate as source. Lime (calcium hydroxide) was applied at rates of 0, 1500, 3000 and 4500 kg ha⁻¹. Also applied was a basal dressing consisting of N, Mg, S, B, Cu, Zn and Mo at rates of 75, 200, 100, 4, 6, 15 and 0,3 kg ha⁻¹, respectively. Plot size was 10m X 4m (net plot 7,6m X 1,2m) with individual plots being separated in the direction of tractor movement by a 2m wide border. Planting was in late February, with the seeding rate being 25 kg ha⁻¹. Rainfall was supplemented by irrigation so as to ensure an application of 25mm of water per week. Harvesting was at intervals of four weeks (70mm cutting height) from late April through to December. The experiment as a whole received 75 kg N ha⁻¹ (as urea) after each harvest. The site was ploughed in late December and ryegrass re-established in early March 1986. Prior to re-establishment, lime and P were re-applied, with rates being 0, 2000, 4000 and 6000 kg lime ha^{-1} and 20, 40, 60 and 80 kg P ha^{-1} (sources as in the first season). In addition, basal dressings of Mg and S were applied at rates of 100 and 66 kg ha^{-1}, respectively. Irrigation and harvesting were as in the previous season; however, N rate was reduced, with 42 kg N ha^{-1} being applied at establishment and after each harvest.

In all experiments, grab samples (c. 0.5 kg) from individual plots were taken at harvesting. These samples were used for dry matter determination, and in the case of selected harvests, for chemical analysis. Here, the plant material was milled (1mm screen), dry ashed and analysed for K, Ca, Mg and Zn by means of atomic absorption, P by colorimetric methods. A modified Kjeldahl technique was used for N determination (AOAC, 1980).

Soil samples from individual plots (25 cores per plot; depth 100mm) were taken once a year in the case of clover trials, and three times a year in the case of Italian ryegrass. Exchangeable Ca and Mg in soil samples was determined by atomic absorption after extraction in 1$\underline{M}$ KCl using a soil solution ratio of 1:10 (V/V) and a stirring time (400 r.p.m.) of 10 min. Exchangeable acidity was determined in the same extract by titration with 0.1$\underline{M}$ NaOH P and K were extracted in 0.25$\underline{M}$ NH_4HCO_3 + 0.01$\underline{M}$ NH_4F + 0.01$\underline{M}$ EDTA at pH 8.0 (1:10 soil:solution ratio; 10 min stirring time), with K being determined by flame emission and P colorimetrically. Soil pH was determined in 1$\underline{M}$ KCl at a soil:solution ratio of 1:2,5.

RESULTS

White clover and tall fescue

Yield responses of white clover on the Cleveland soil over the first half of the 1983/84 season (first production season) were characterized by a lime-P interaction (Fig. 1.1). Isolation of interactive effects in the second half of the season was precluded by the existence of highly significant interactions between both lime and P and the remaining factor studied, K. Data presented in Fig.1.1 reflect a significant, though variable response to lime over all levels of applied P. In the absence of lime (pH 4,0), a continuous response to applied P up to the highest P level was suggested. Where soil was limed to pH 4,4 and 5,0, a maximum in yield occurred with the addition of 100 kg P ha^{-1}; at higher P rates, a levelling-off in response, or possibly even a yield depression was suggested. Relative to the two intermediate lime rates, liming to pH 6,8 tended, at lower levels of applied P, to depress yields. In addition, at pH 6,8, a levelling-off in response to applied P was, as in the case of the unlimed soil, not apparent.

Effects of applied P and soil pH on P and Zn contents of clover at one of the harvests contributing to the yield data shown in Fig. 1.1 are presented in Figures 1.2 and 1.3. Highly significant increases in P content accompanied P fertilizer additions. Liming to pH 4,4 and 5,0 resulted in small (non-significant) increases in P content relative to that on unlimed soil. Liming to pH 6,8 significantly depressed P content at the 100 kg ha^{-1} P level, relative to the other lime levels. Clover Zn content decreased continuously with increasing soil pH, with this effect being at a maximum over the pH range 4,0 to 4,4. At pH 4,0, P treatments had significant though variable effects on Zn content, while at higher pH

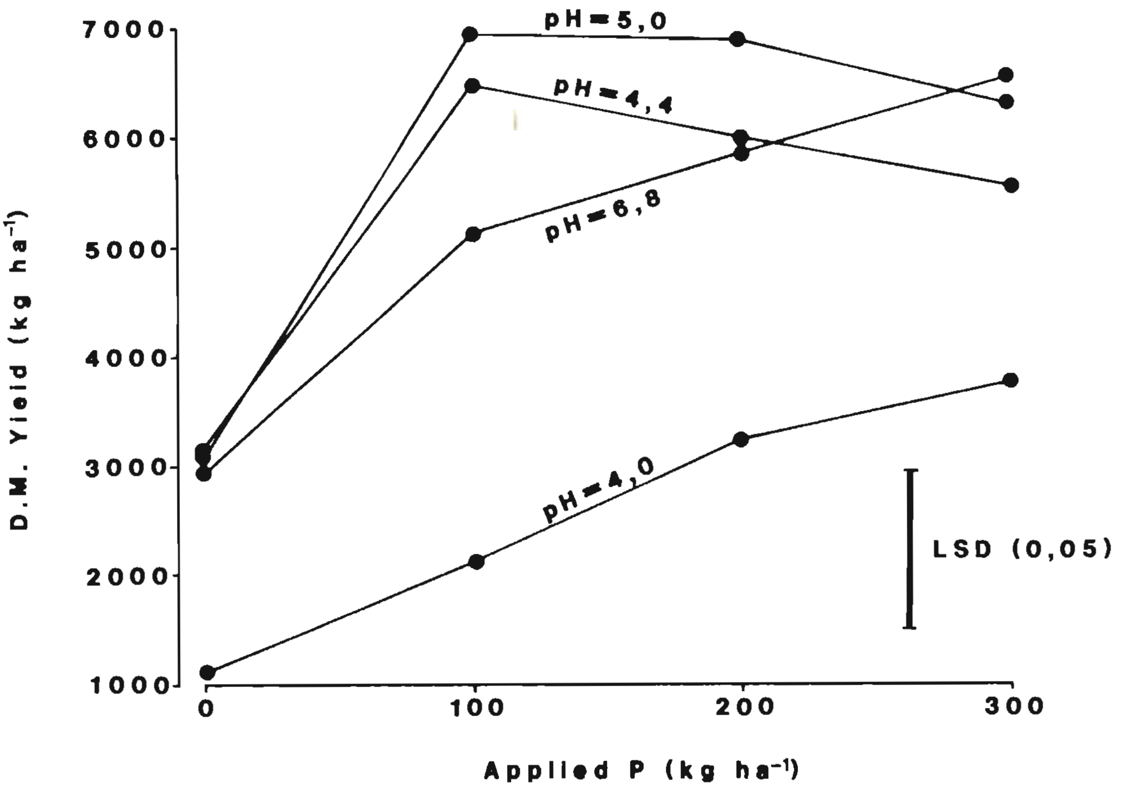


Fig. 1.1 Effects of applied P and soil pH on white clover dry matter production in the first half of the 1983/84 season on the Cleveland soil.

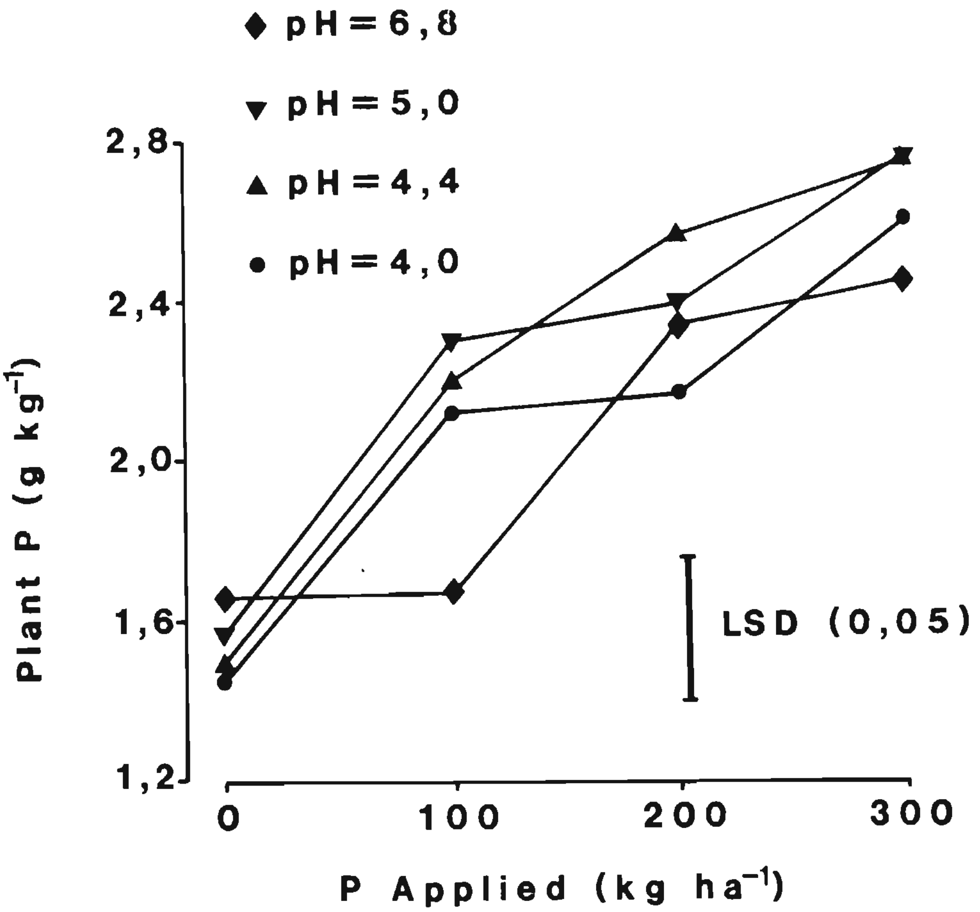


Fig. 1.2 Effects of applied P and soil pH (KCl) on white clover P content in November 1983 on the Cleveland soil.

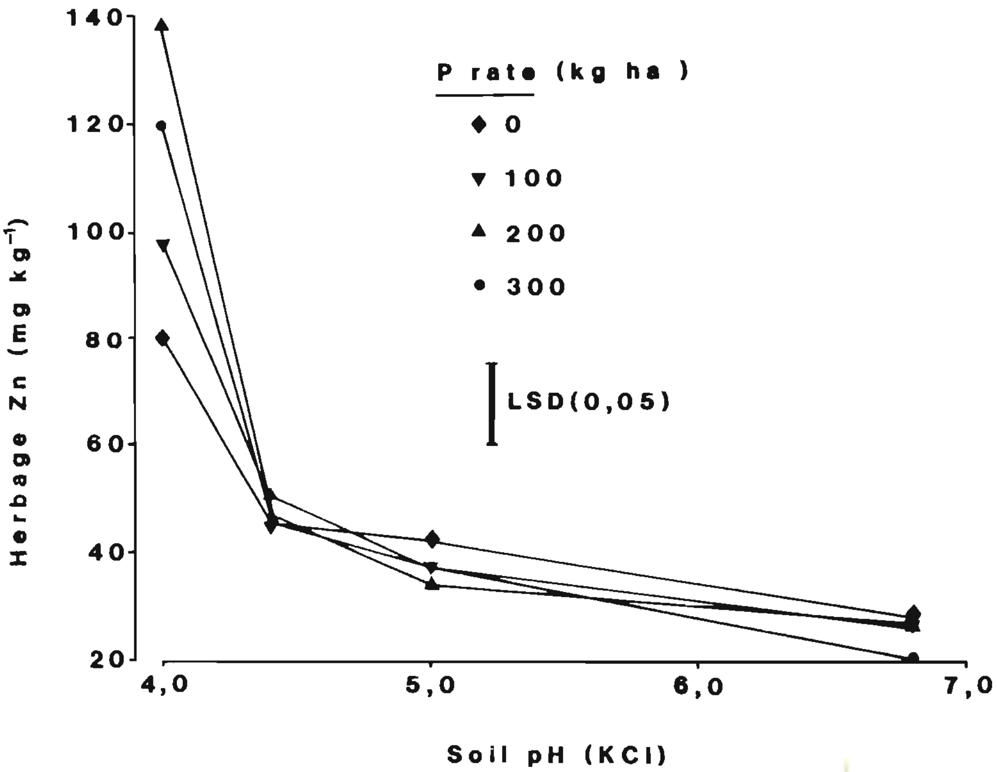


Fig. 1.3 Soil pH and phosphorus fertilizer effects on white clover zinc content in November 1983 on the Cleveland soil.

values, P had no effect on Zn.

On the Farmhill soil, evidence of a lime-P interaction in the clover yield data was not apparent. Yield data for clover-only swards for the first two seasons of experimentation are presented in Table 1.2. The relatively low dry matter production was no doubt largely ascribable to the severe drought in the seasons in which the study was in progress. Clover yield responses in the clover/fescue experiment displayed essentially similar trends to those in the pure clover study and are not reported here. The response of fescue to P appeared to be appreciably modified by liming (Fig. 1.4). At pH 3,9 (zero lime), a linear response to P was indicated. However, with small increments in pH, a levelling-off in response to applied P was apparent. It is noteworthy that there was little difference in maximum yield between the three pH levels.

Italian Ryegrass

Effects of applied P and soil pH on total dry matter production of Italian ryegrass in the 1985 season on the Cleveland soil are shown in Fig. 1.5. No evidence of a lime-P interaction is apparent in these data. The major trend, quite clearly, is an enormous P response with relatively uniform though appreciable increases in yield accompanying pH increases at each P application level.

In Figures 1.6 and 1.7, lime-P effects on ryegrass yields are examined over the March to June and July to December periods of 1985, respectively. Although overall P-lime interactions did not attain statistical significance, a suggestion of interaction is contained in both sets of data. Response to P in the March to June period (which included the establishment phase) was more marked than in the July to December period. In this former period (Fig. 1.6), negligible dry matter was obtained in the absence of applied P; furthermore, no measurable response to lime occurred at zero P. At higher P rates a response to lime was evident, with herbage analysis

Table 1.2 Variations in white clover dry matter production with soil pH and applied P on a Farmhill soil in the 1979/80 and 1980/81 seasons.

Total P applied	Soil pH (KCl)				
	3,93	4,08	4,42	4,99	5,53
kg ha^{-1}	kg D.M. ha^{-1}				
			1979/80		
40	752	503	1041	1589	1153
80	1203	1761	2656	2227	2630
120	1215	1910	1712	2358	2633
160	1684	2010	3270	3324	3070
200	1825	2850	3834	2771	4270
LSD (0,05)	678				
			1980/81		
86	861	851	897	1229	1234
164	1389	1098	1552	1480	2218
242	1581	1623	1524	2006	2037
306	1880	2014	2005	2394	2192
373	2028	2300	2182	2016	2466
LSD (0,05)	708				

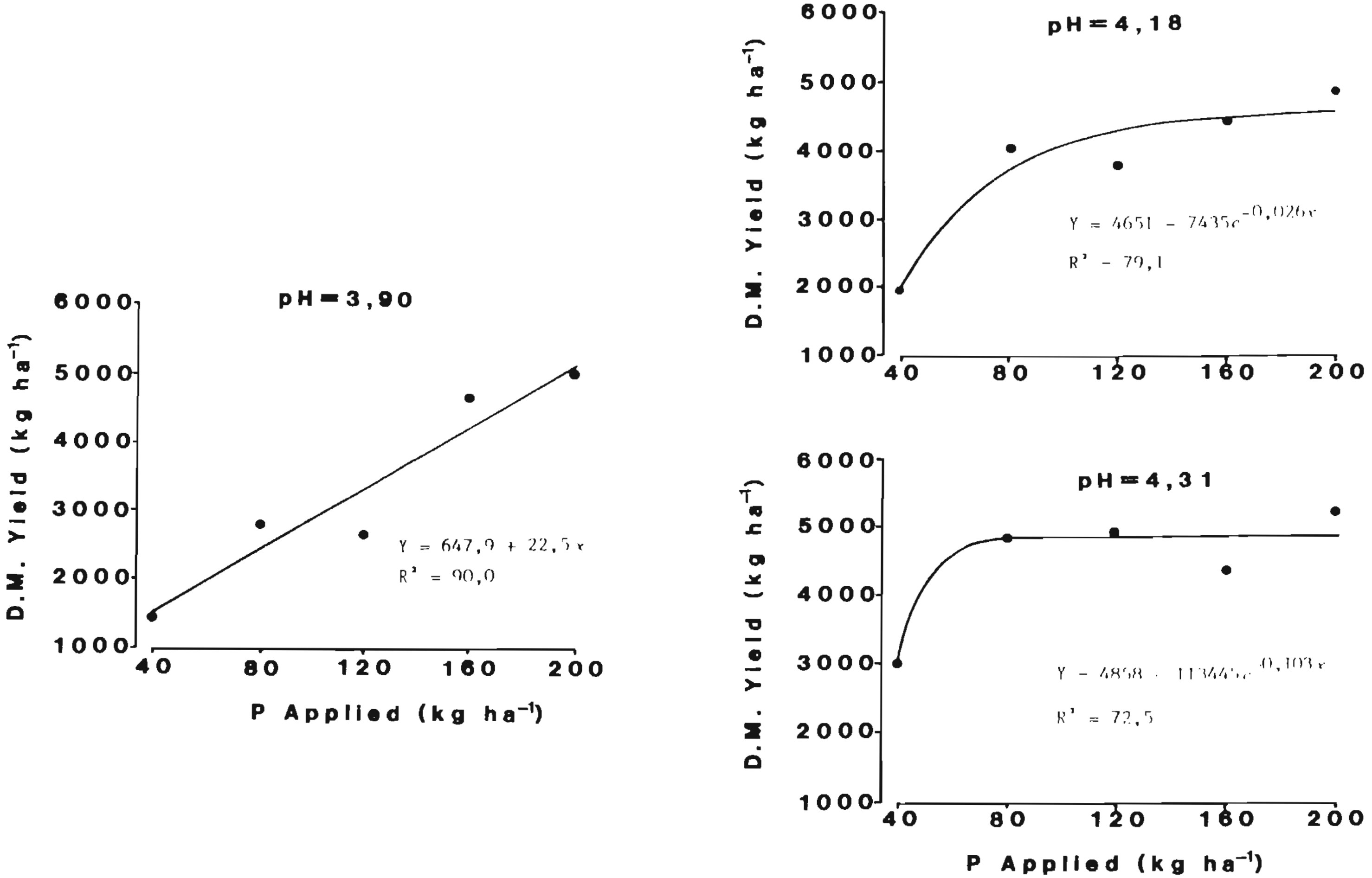


Fig. 1.4 Effects of applied P and soil pH (KCl) on the yield of tall fescue in a tall fescue/white clover sward on the Farmhill soil in the first season of experimentation.

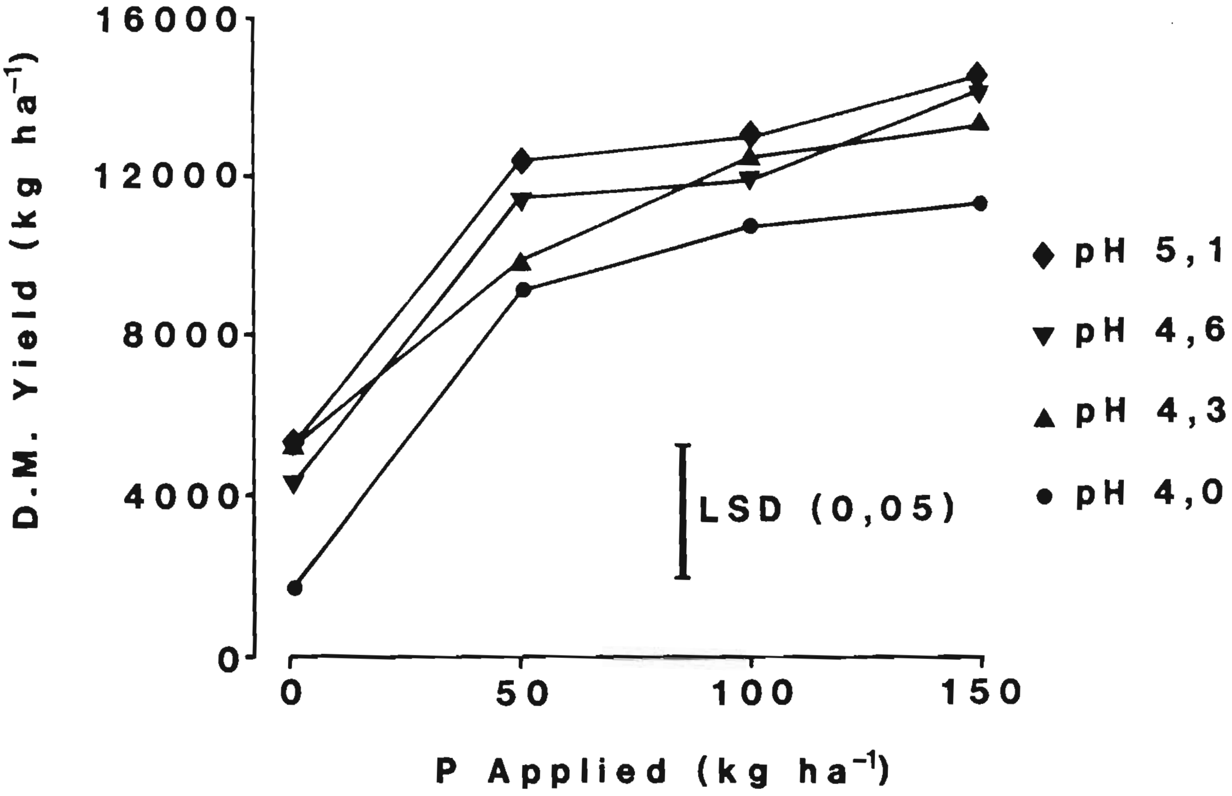


Fig. 1.5 Applied P and soil pH (KCl) effects on total dry matter production of Italian ryegrass in the 1985 season on the Cleveland soil.

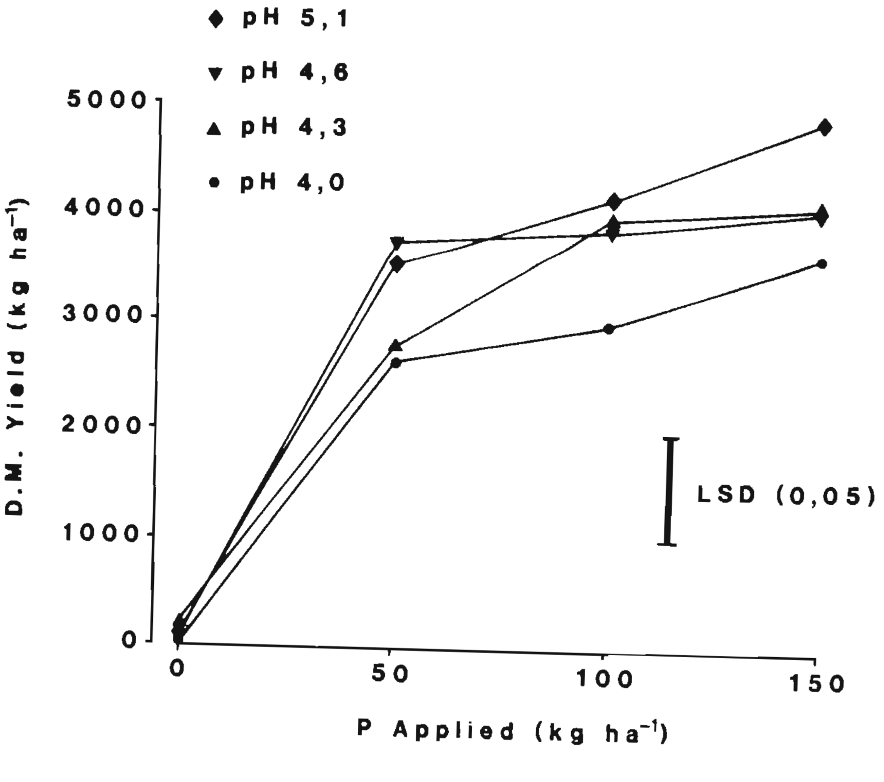


Fig. 1.6 Effects of soil pH (KCl) and applied P on Italian ryegrass dry matter production on the Cleveland soil in the March to June period of 1985.

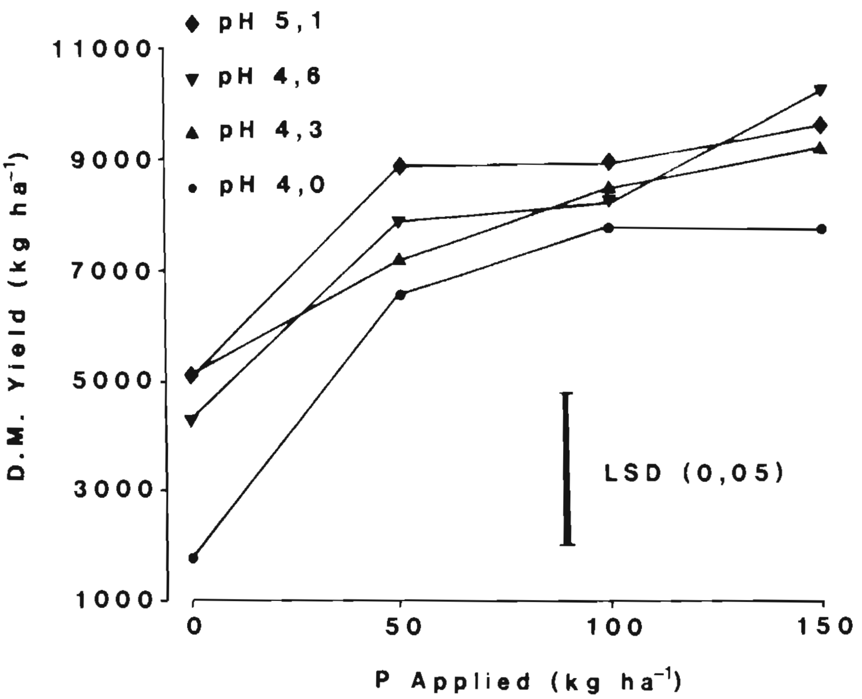


Fig 1.7 Effects of soil pH (KCl) and applied P on Italian ryegrass dry matter production on the Cleveland soil in the July to December period of 1985.

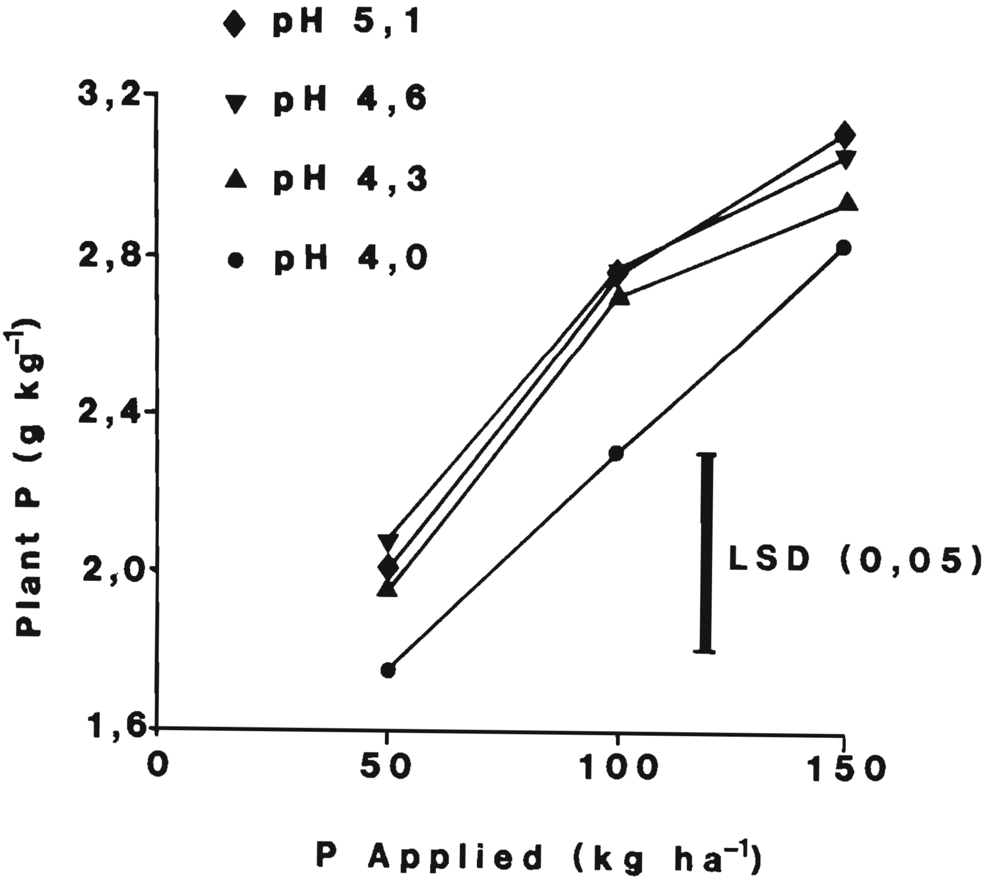


Fig 1.8 Effects of applied P and soil pH (KCl) on the P content of Italian ryegrass harvested in late May 1985 on the Cleveland soil (data for zero P treatments are not

reflecting increased P uptake with elevation of pH (Fig. 1.8). In the July to December period at zero P, however, a large response (greater than that in the presence of applied P) to lime was apparent and appreciable dry matter production occurred on limed soil (Fig. 1.7). Thus, relative to lime effects on yield at higher P levels, at zero P, lime effects in the former and latter part of the season were in direct contrast; this accounts for the absence of interactive effects in the total yield data for the season (Fig. 1.5).

Lime-P effects on ryegrass yields over the March to June period of 1986 on the Cleveland soil are presented in Fig. 1.9. The application of 20 kg P ha^{-1} at the lowest P level resulted in vastly dissimilar response trends relative to the previous season where the lowest P level was zero (Fig. 1.6). A negative lime-P interaction is suggested by these 1986 data, with the response to lime at low P being very much greater than at high P, and the response to P being most marked in the absence of lime (pH 4.0). By excluding data for the first (establishment) cut of the season and considering dry matter production over the May-June period only, the nature of this lime-P interaction is more clearly evinced (Fig. 1.10). Over this growth period, no P requirement over and above 20 kg ha^{-1} is indicated for soil limed to pH 4,4 or higher. On unlimed soil, however, a response up to the highest P level is indicated.

DISCUSSION

The highly significant yield responses to both lime and P noted here underline the sensitivity of these temperate species to acid soil conditions as well as their inability to exploit the low P reserves in the soils studied.

Much of the yield data presented contains clear evidence of P-lime interactive effects. It is noteworthy that the presence of both positive

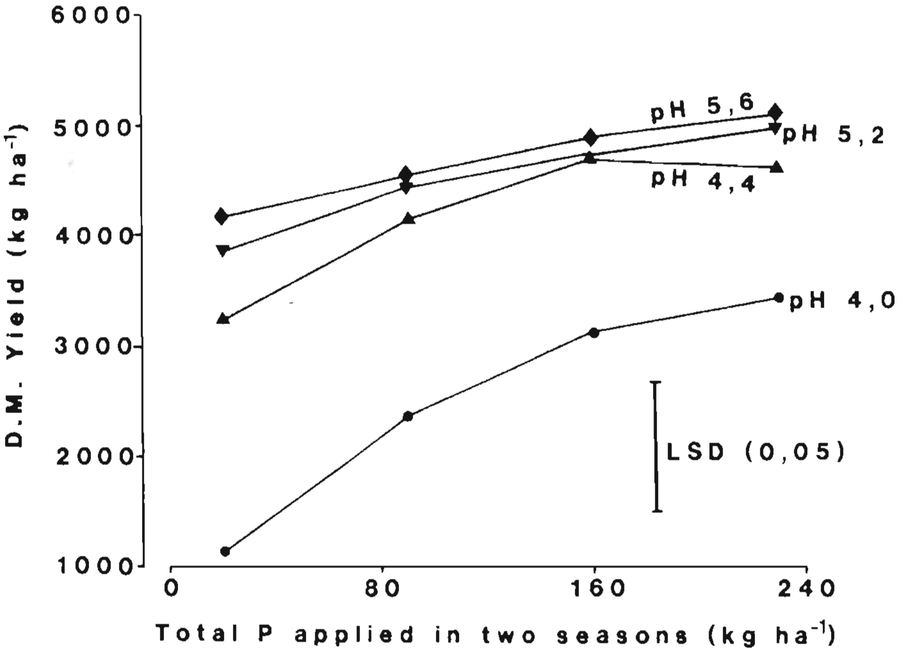


Fig. 1.9 Effects of soil pH (KCl) and applied P on Italian ryegrass dry matter production on the Cleveland soil in the March to June period of 1986.

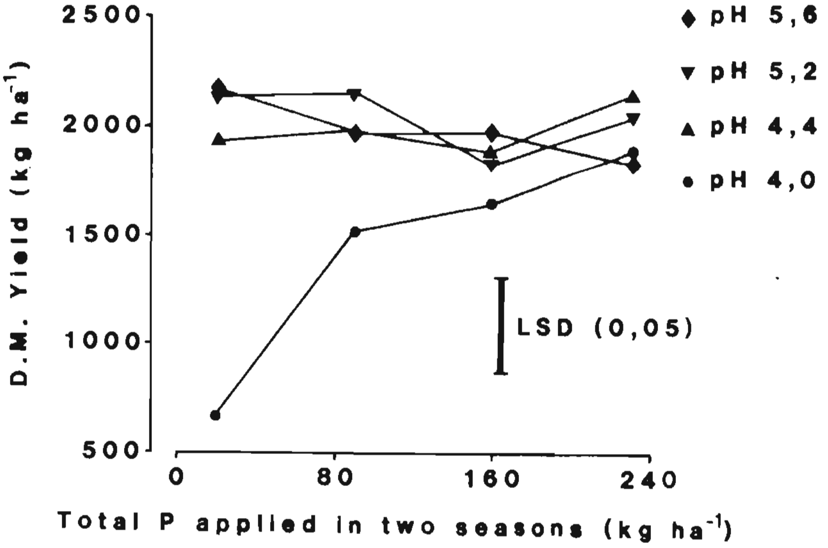


Fig. 1.10 Effects of soil pH (KCl) and applied P on Italian ryegrass dry matter production on the Cleveland soil in May and June of 1986.

and negative interactions is suggested. The Italian ryegrass yield data presented in Figures 1.9 and 1.10 are examples of negative interactions between lime and P. Positive interactive effects are contained in data reflecting the responses of white clover (Fig. 1.1) and Italian ryegrass (Fig. 1.6) to lime (all rates) and the first increment of P. Evidence of both positive and negative lime-P interactions are in fact contained in the white clover yield data in Fig. 1.1. Data reflecting the response to 100 kg P ha^{-1} at pH values of 4.0, 4.4 and 5.0 indicate positive interaction between lime and P, with the response to the combination of these amendments being very much greater than the sum of their individual effects. Over the same pH levels and at P levels in excess of 100 kg ha^{-1}, negative interactive effects are apparent, since the combined effects of lime and P are less than the sum of their individual effects.

Yield responses reflecting negative lime-P interactions on acidic soils high in soluble Al have been noted in pots with grasses and legumes as test plants (Shoop et al.,1961) and under field conditions with several crop species (Sanchez & Salinas, 1981). Munns (1965) reported both positive and negative lime-P interactions in the growth of lucerne on a severely P deficient soil under glasshouse conditions. The mechanisms responsible for lime-P interactions are not firmly established. The complex interplay between phytotoxic Al and P in the soil and within the plant root, recently reviewed by Haynes (1984), creates considerable difficulty in elucidating such interactions. A negative lime-P interaction, such as that illustrated in Fig. 1.10, reflects a decrease in P requirement with liming. A decreased response to P in limed soil together with evidence of increased P uptake following liming (e.g. Fig. 1.8) may, however, not be assumed to be indicative of lime increasing P availability in the soil per se. As observed by Kehoe and Curnow (1963), improved uptake of P from limed soil may well be due to the development of more effective and extensive root systems rather than to the creation of a more favourable P supply in the soil. Munns (1965) is of the view that "the negative interaction at high phosphate levels could represent a stage where phosphate deficiency had been corrected and the principal effect of phosphate, like that of lime, was to remedy aluminum toxicity". This hypothesis is supported by herbage P data presented here as well as by evidence of small though significant decreases in soil exchangeable Al and increases in exchangeable Ca accompanying P additions (data not presented). The positive interaction between lime and P at low levels of P supply is suggested by Munns (1965) as being due to the plant responding better to P when the degree of Al toxicity is reduced by liming.

Decreases in clover yield at intermediate P rates and the highest lime rate (pH 6.8, Fig. 1.1) are noteworthy. Depressed yields when highly weathered soils are limed to near-neutrality have been reported elsewhere (Hackland et al., 1976; Sumner, 1979; Friesen et al., 1980; Farina et al., 1982), with both micronutrient and P unavailability being proposed as causal mechanisms. Although Zn content was affected by both lime and P treatments (Fig. 1.3), concentrations of this element did not fall below the critical value of 15 mg kg^{-1} proposed by McNaught and During (1970). In studies on a Hutton soil, Sumner (1979) found that lime-induced yield depressions could be completely overcome by large applications of superphosphate. Data presented in Fig. 1.1 indicate an essentially similar finding, and when considered in conjunction with herbage P data (Fig. 1.2), the case for P being implicated in this response pattern is strengthened. In further support of this are findings, drawn attention to by Sumner (1979), of P solubility in highly weathered soils passing through a minimum at pH values just below neutrality. However, evidence presented by Farina et al. (1982) suggests that yield depressions may not be due to decreased P solubility per se, but rather to Al interfering with P nutrition following lime-enhanced decomposition of Al-rich organic matter.

Little agreement is evident in the literature concerning the effects of lime on P availability in the soil. As noted by Sumner and Farina (1986), reports of lime increasing, decreasing, or not affecting soil P availability as determined by extraction or sorption are to be found. Resolution of this issue using plant response data is, as alluded to above, complicated by the role of phytotoxic Al in root development and P uptake. In the present investigations, soil analyses indicate that the bulk of exchangeable Al is eliminated upon liming to a pH (KCl) of 4.5 (data not presented). Examination of lime effects on P response at pH values above 4.5, although well below neutrality, would possibly therefore provide the most valid approach to studying this issue using the present data (Justification for ignoring data from soil limed to near neutrality is based firstly, on the possibility referred to earlier of Al being re-introduced into the system at pH values approaching seven, and secondly, on the fact that lime-P interactive effects at such pH levels are of little practical consequence in view of the prohibitive lime costs involved). Both white clover and Italian ryegrass dry matter production reported here was little affected by increases in pH over the range 4.4 to 5.6 (cf. Figs. 1.1, 1.6, 1.7 and 1.9). Plant P concentrations, although not significantly affected by lime over this pH range, nevertheless display small though generally consistent increases with increasing pH (Figs 1.2 and 1.8). Thus an improved P supply with increasing lime rate is suggested, though root proliferation effects cannot unfortunately, be excluded. A strong case on the other hand, for lime _not_ decreasing P availability must be represented by the increase, albeit small, in yield of Italian ryegrass over the pH range 4.4 to 5.6 with a P application of only 20 kg P ha^{-1} (Fig. 1.9). In the light of the negligible dry matter production in the previous year with zero P application (Fig. 1.6), any deleterious effect of lime on P availability would most likely have been reflected in yield reductions at this low level of P supply.

The practical implications of the interactions reported in this paper warrant careful consideration. In the first place, in view of the general farming practice of applying at least 20 kg P ha^{-1} at establishment of a pasture or crop, the positive interactions at an extremely low level of P supply are of little significance from a practical standpoint. The negative interactions which develop in the zone of P supply beyond that of extreme P deficiency have, however, important management and economic implications. Such interactions reflect a decreasing P requirement with increasing lime supply, or alternatively, a decreasing lime requirement with increasing P supply. Thus a "trade-off between lime and phosphorus", as suggested by Sanchez and Salinas (1981) is implied. In view of the relatively high cost of P fertilizers, however, the aspect of lime-P interactions enjoying most prominence is the beneficial effect of lime on P requirement (the so-called "P-sparing effect"). Mansell _et al._,(1984) concluded a recent review of lime-P interactions on New Zealand pastures with the statement "although a P-sparing effect might be observed reasonably frequently, its actual impact on P requirements seems to be minor in most instances". This is clearly not the case here, with lime-P interactions in most cases reflecting major savings in P fertilizers.

PAPER 2

LIME-PHOSPHORUS INTERACTIONS IN THE GROWTH OF KIKUYU AND WEEPING LOVEGRASS ON ACID SOILS

INTRODUCTION

Effects of lime on the immobilization of P in the soil as well as on plant P uptake have over the years been intensively studied (Sumner & Farina, 1986). In the previous paper, data from field experiments using temperate pasture species provided evidence of lime decreasing fertilizer P requirement for maximum yield (Paper 1). Unfortunately, as has been the case in numerous similar studies (Shoop et al., 1961; Helyar & Anderson, 1971; Mendez & Kamprath, 1978; Bache & Crooke, 1981), the role of phytotoxic Al in root development and P uptake greatly complicated the interpretation of results. In this paper, lime-P interactions in the growth and chemical composition of two tropical grasses, kikuyu (Pennisetum clandestinum) and weeping lovegrass (Eragrostis curvula cv Ermelo), are discussed. The detailed attention afforded these interactions stems from a number of considerations. Firstly, in contrast to temperate pasture species, these grasses, by virtue of their high tolerance to soil acidity and its attendant metal toxicities (Andrew & Jayawardana, 1971; Fleming et al., 1974; Cregan, 1980), are expected to provide a sounder platform for the elucidation of lime effects on P availability. This aspect has, in the case of kikuyu, received brief attention in an earlier publication (Miles et al., 1985). Secondly, the importance of interactions in attaining maximum efficiency in agricultural production is being increasingly recognized. In this regard Cooke (1982) points out that "further progress towards maximum yields in developed agriculture will depend largely on exploiting interactions". Finally, the interactive effects discussed here are a necessary starting-point for the derivation of pasture lime and P requirements, these being aspects which will receive attention in subsequent papers.

MATERIALS AND METHODS

Data presented in this paper were drawn from field experiments on three highly weathered soils. The weeping lovegrass and two of the kikuyu experiments were located on Balmoral and Balgowan soil series in the Natal Mistbelt (altitude 1067m, mean annual rainfall 885mm and pan evaporation 1478mm) and the remaining kikuyu experiment on a Griffin soil in the Natal Midlands (altitude 1450m, mean annual rainfall 1166mm and pan evaporation 1436mm). Selected properties of these soils are presented in Table 2.1. The Balmoral and Balgowan soils were in the virgin state and the Griffin soil had previously been used for short-term pasture rotations.

For kikuyu, the experimental design employed was a 4^3 N, P, lime factorial with blocks of 16 plots, replicated twice in the case of the Mistbelt soils, and unreplicated on the Griffin soil. Nitrogen treatments and their effects are not considered here, with lime and P effects being examined at the N level of 600 kg ha^{-1} over the season. Lime, as calcium hydroxide, was applied to the Mistbelt soils at rates of 0, 1000, 2000 and 6000 kg ha^{-1}, and to the Griffin soil at 0, 2000, 4000 and 8000 kg ha^{-1}. Phosphorus treatments, as double superphosphate (19,6% P) were 0, 100, 200 and 300 kg P ha^{-1} on the Mistbelt soils, and 0, 80, 160 and 240 kg P ha^{-1} on the Griffin soil. Lime was incorporated by rotovator to a depth of 200mm. The P, together with basal dressings of Mg, S, K, B, Cu, Zn and Mo, were incorporated in similar fashion eight and one month after liming on the Mistbelt and Griffin soils, respectively. Individual plot dimensions were 9,4m X 3m (net plot 8m X 1,4m) on the Mistbelt soils and 10m

Table 2.1. Selected properties of the soils on which the experiments were conducted.

		Exchangeable cations						pH				Particle size		
Soil	Depth	Ca	Mg	K	Al+H	Mn[††]	P	KCl	H_2O	P req[†]	Org. C	Clay	Silt	Sand
	mm	$cmol(+)L^{-1}$				$mg\ L^{-1}$				$mg\ kg^{-1}$	$g\ kg^{-1}$			
Balmoral	0-150	1,35	1,25	0,30	1,62	8,7	1	4,11	4,95	800	48	540	290	130
	150-350	0,28	0,46	0,17	1,07	1,9	1	4,29	5,15	-	28	680	180	130
Balgowan	0-150	0,66	0,82	0,27	3,19	3,0	3	3,96	4,90	725	52	610	250	90
	150-350	0,27	0,44	0,17	2,98	0,5	1	3,94	4,81	-	38	630	250	120
Griffin	0-150	1,07	0,37	0,35	3,22	20,6	10	3,90	4,30	435	35	390	140	420
	150-350	1,19	0,37	0,18	1,47	3,9	1	4,22	4,62	-	13	370	130	510

[††] extracted with 0,25 M NH_4HCO_3 + 0,01 M EDTA + 0,01 M NH_4F.

[†] P sorbed at a solution concentration of 0,1 mg L^{-1} by the method of Fox and Kamprath (1970).

X 3m (net plot 7,6m X 1,2m) on the Griffin soil. Kikuyu was established vegetatively in early summer. The experiments were harvested at intervals of four weeks throughout the growing season (November to late March), with a cutting height of approximately 75mm being adhered to. Nitrogen, as urea, was applied in dressings of 200 kg N ha^{-1} in late September, late November and late January. After the second season of experimentation, basal dressings of Mg, S, B, Cu, Zn and Mo were re-applied. Basal dressings of K were applied after the second and third seasons. An insufficiency of K was however, suspected to have influenced yields in the third season on the Balgowan soil, and these data are therefore not considered here.

The lovegrass experimentation was carried out on the two Mistbelt soils. Establishment of this grass on these soils formed the final stage of a broader programme in which, following the imposition of lime and P treatments, soil samples were obtained at regular intervals over a three-year period for the monitoring of P immobilization. During this period the sites were maintained in the fallow state, with weeds being eradicated by hoeing. The experimental design was a 4P X 3 lime factorial with two replicates. Lime, as calcium hydroxide, was applied at rates of 0, 2000 and 6000 kg ha^{-1}, and P, as double superphosphate, at rates of 0, 100, 300 and 600 kg P ha^{-1}. Plot size was 6,3m X 3m with a net plot of 4,9m X 1,4m. Incorporation procedures were as in the kikuyu studies above. Following the three year fallow period, during which soil acidity increased markedly on both sites, basal dressings of K, Mg, S, B, Cu, Zn and Mo were incorporated by rotovator and the lovegrass established from seed in late summer. In the subsequent two growing seasons the grass was harvested at intervals of six to eight weeks with cutting height being approximately 75mm. Nitrogen, as urea, was applied in three equal dressings over the growing season (late October, early December and late January), with the total seasonal rate being 350 kg N ha^{-1}.

In all experiments, grab samples from individual plots were taken at harvesting. These samples were used for dry matter determination and in the case of selected harvests for chemical analysis. Soil samples from individual plots within each experiment (25 cores per plot; depth 100mm) were obtained in the second half of each growing season. Methods employed in the analysis of soil and herbage samples are detailed in Paper 1.

RESULTS

Kikuyu

Effects of lime and P on kikuyu dry matter production on the three sites are presented in Tables 2.2, 2.3 and 2.4 (On the virgin Balmoral and Balgowan soils, highly significant lime-N interactions characterized establishment season yields, and those yields are, therefore, not considered in this paper). Significant lime-P interactive effects were not apparent in these data. Overall responses to P, significant on all three soils, were largest on the Balmoral and Balgowan soils. Significant responses to lime were evident on the Balmoral and Balgowan soils, though such responses were small relative to the responses to P. Lime response on the Griffin soil did not attain significance.

Although not evident in total yields, lime-P interactive effects frequently characterized yields from individual harvests or cumulative yields over two or more harvests. Variations in yield with pH and applied P in the establishment season on the Griffin soil are illustrated in Fig. 2.1. At zero and 80 kg P ha^{-1}, yield at pH 5,38 was significantly superior to that at pH 4,08. At higher P levels, however, pH did not significantly affect yield. Statistical analysis of herbage P contents at one of the harvests contributing to the yields presented in Fig. 2.1 revealed a significant main effect of lime on P content, though no interactive effects were apparent in the data (Table 2.5). Yield data in subsequent years on the

Table 2.2. Effects of lime (as calcium hydroxide) and P on kikuyu total dry matter production in the three seasons subsequent to establishment on the Balmoral soil.

	Lime rate (kg ha^{-1})			
P rate	0	1000	2000	6000
kg ha^{-1}	- - - - - - - kg D.M. ha^{-1} - - - - - - - - - -			
0	9979	9717	11817	13227
100	18057	18038	20826	22728
200	21526	26081	22525	24835
300	26179	27746	28471	27408
LSD (0,05)	3433			

Table 2.3. Effects of lime (as calcium hydroxide) and P on kikuyu total dry matter production in the two seasons subsequent to establishment on the Balgowan soil.

	Lime rate (kg ha^{-1})			
P rate	0	1000	2000	6000
kg ha^{-1}	- - - - - - - kg D.M. ha^{-1} - - - - - - - - - -			
0	7548	7248	10649	10771
100	13429	15313	16865	17506
200	16644	16856	17330	18497
300	19999	20911	20770	24549
LSD (0,05)	3512			

Table 2.4. Effects of lime (as calcium hydroxide) and P on kikuyu total dry matter production over four seasons on the Griffin soil.

	Lime rate (kg ha^{-1})			
P rate	0	2000	4000	8000
kg ha^{-1}	- - - - - - - - kg D.M. ha^{-1} - - - - - - - - - -			
0	21286	23547	22901	25787
80	26156	28518	30078	31874
160	29913	28301	30662	31763
240	31977	27201	28625	28045
LSD (0,05)	6074			

Table 2.5. Variations in kikuyu P content with soil pH (KCl) and applied P in mid-February of the establishment season on the Griffin soil.

	Soil pH			
P rate	4,08	4,29	4,67	5,38
kg ha^{-1}	- - - - - - - - - - - g kg^{-1} - - - - - - - - - - -			
0	2,4	2,5	2,4	2,6
80	2,6	2,7	2,7	2,7
160	2,5	2,6	2,7	2,8
240	2,5	2,7	2,5	2,9
LSD (0,05)	0,3			

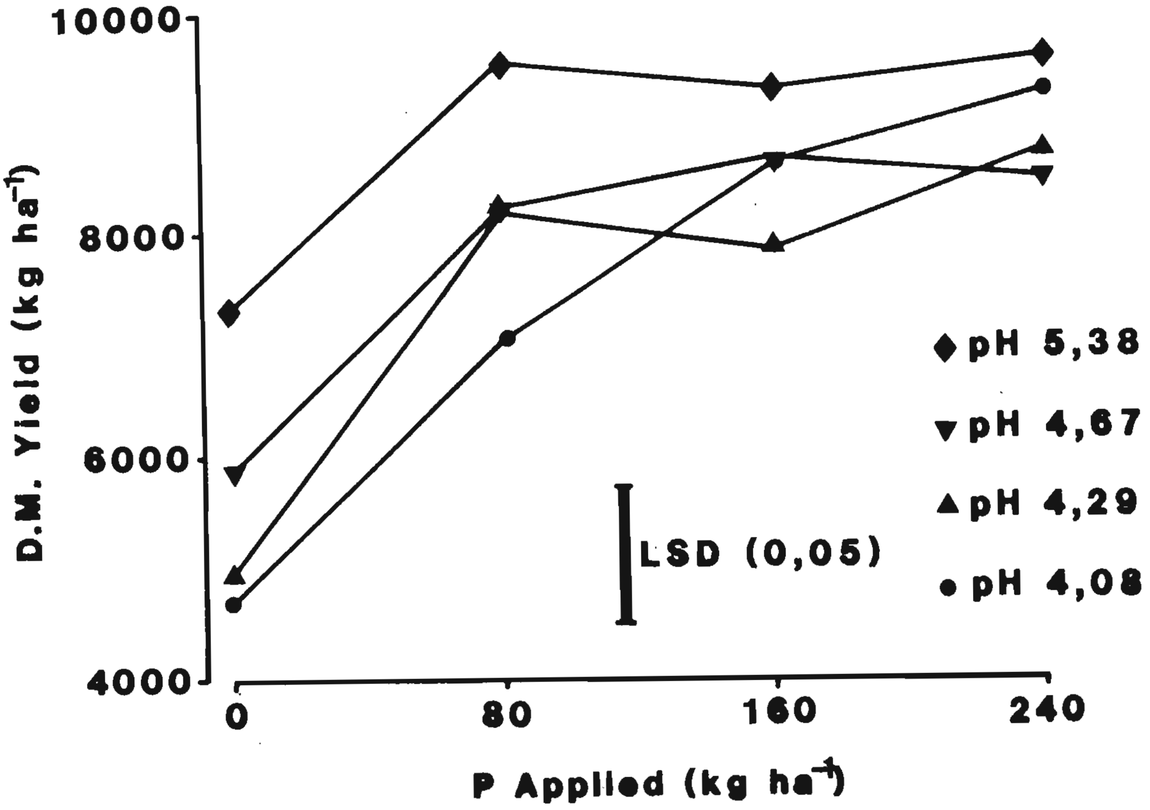


Fig 2.1 Variation in kikuyu dry matter production with applied P and soil pH (KCl) in the season of establishment on the Griffin soil.

Griffin soil did not display significant lime-P interactions.

On the Balmoral and Balgowan soils, positive lime-P interactive patterns were on occassions evident in spring/early summer growth. These patterns attained significance in the second season (Fig. 2.2 and 2.3). Addition of either lime or P on its own had little effect on yield. At the highest lime rate, however, dramatic responses to P were evident. Analysis of herbage harvested in November revealed that, on both soils, lime and P applications significantly increased Ca, Mg and P contents (Tables 2.6 and 2.7). At this time, significant ($P<0,01$) relationships between herbage P contents and yields were indicated (Fig. 2.4). Significant lime-P interactions were not apparent in mid and late season yields on these soils. It is noteworthy, however, that on both soils a tendency towards a negative lime-P interaction was contained in the cumulative yields over the December to April period of the second season. This pattern is, in the case of the Balgowan soil, illustrated in Fig. 2.5. In contrast to the early part of the season (Fig. 2.3) a maximum response to lime at zero P is suggested here.

Weeping lovegrass

Effects of lime and P on the total dry matter production of weeping lovegrass over two seasons on the Balmoral and Balgowan soils are listed in Table 2.8. Highly significant yield responses to P were evident, with an almost 100% increase in yield from the zero to the highest P rate. By comparison, responses to lime were small, though significant on both soils.

Significant lime-P interactive effects were on occassions evident in the lovegrass yield data. A positive interaction was indicated at the first harvest after establishment on the Balmoral soil (Fig. 2.6). Here, lime had no significant effect on yield at zero P, yet significantly increased yield at higher P levels. Herbage P content at this time was extremely low (Table 2.9). On the Balmoral soil, lime decreased P content at the lower P levels

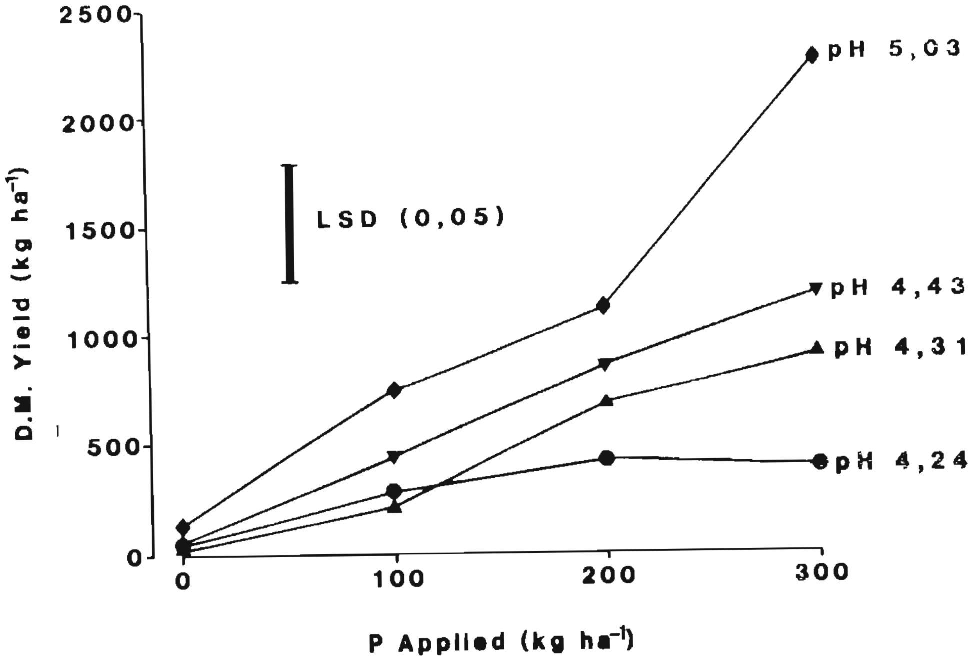


Fig 2.2 Effects of soil pH (KCl) and applied P on yields of kikuyu on the Balmoral soil in November of the second productive season.

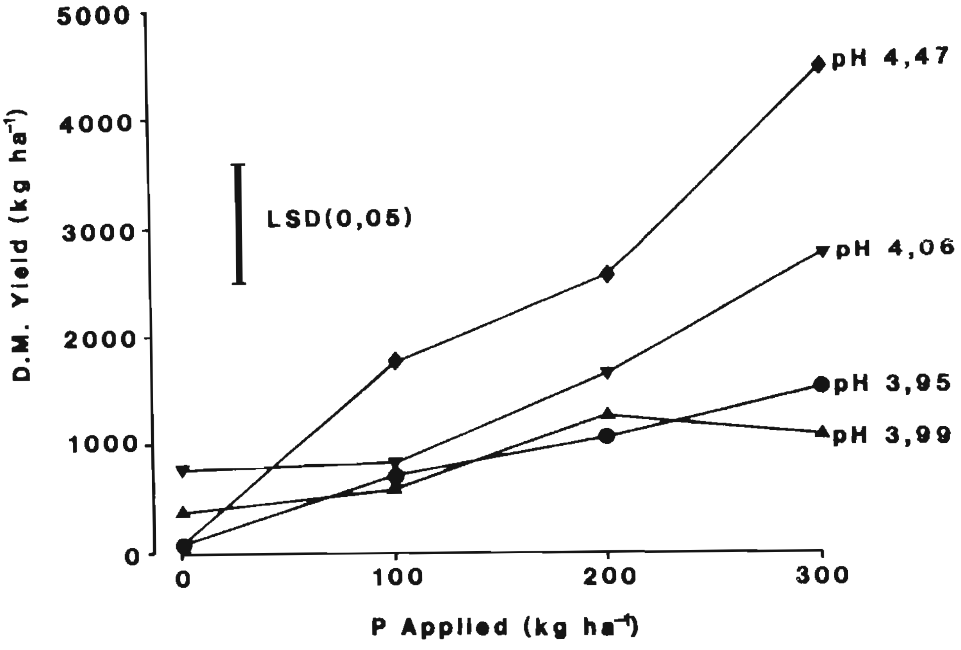


Fig 2.3 Effects of soil pH (KCl) and applied P on cumulative yields of kikuyu on the Balgowan soil over the October to December period of the second productive season.

Table 2.6. Effects of applied P on Ca, Mg and P contents of kikuyu harvested in November of the second productive season on the Balmoral and Balgowan soils (data meaned over four lime levels).

	Balmoral			Balgowan		
P rate	Ca	Mg	P	Ca	Mg	P
kg ha^{-1}			g kg^{-1}			
0	2,6	1,8	1,1	1,9	2,0	1,3
100	2,3	2,6	1,4	2,1	2,8	1,6
200	2,4	2,6	1,7	2,1	2,8	1,9
300	3,0	3,5	2,0	2,6	4,1	2,1
LSD (0,05)	0,4	0,5	0,2	0,4	0,5	0,2

Table 2.7. Effects of lime on Ca, Mg and P contents of kikuyu harvested in November of the second productive season on the Balmoral and Balgowan soils (data meaned over all P levels).

	Balmoral			Balgowan		
Lime rate	Ca	Mg	P	Ca	Mg	P
kg ha^{-1}			g kg^{-1}			
0	2,0	2,2	1,5	1,6	2,5	1,7
1000	2,3	2,7	1,4	1,9	2,7	1,6
2000	2,6	2,6	1,6	2,3	2,9	1,7
6000	3,3	3,1	1,7	3,0	3,6	1,9
LSD (0,05)	0,4	0,5	0,2	0,4	0,5	0,1

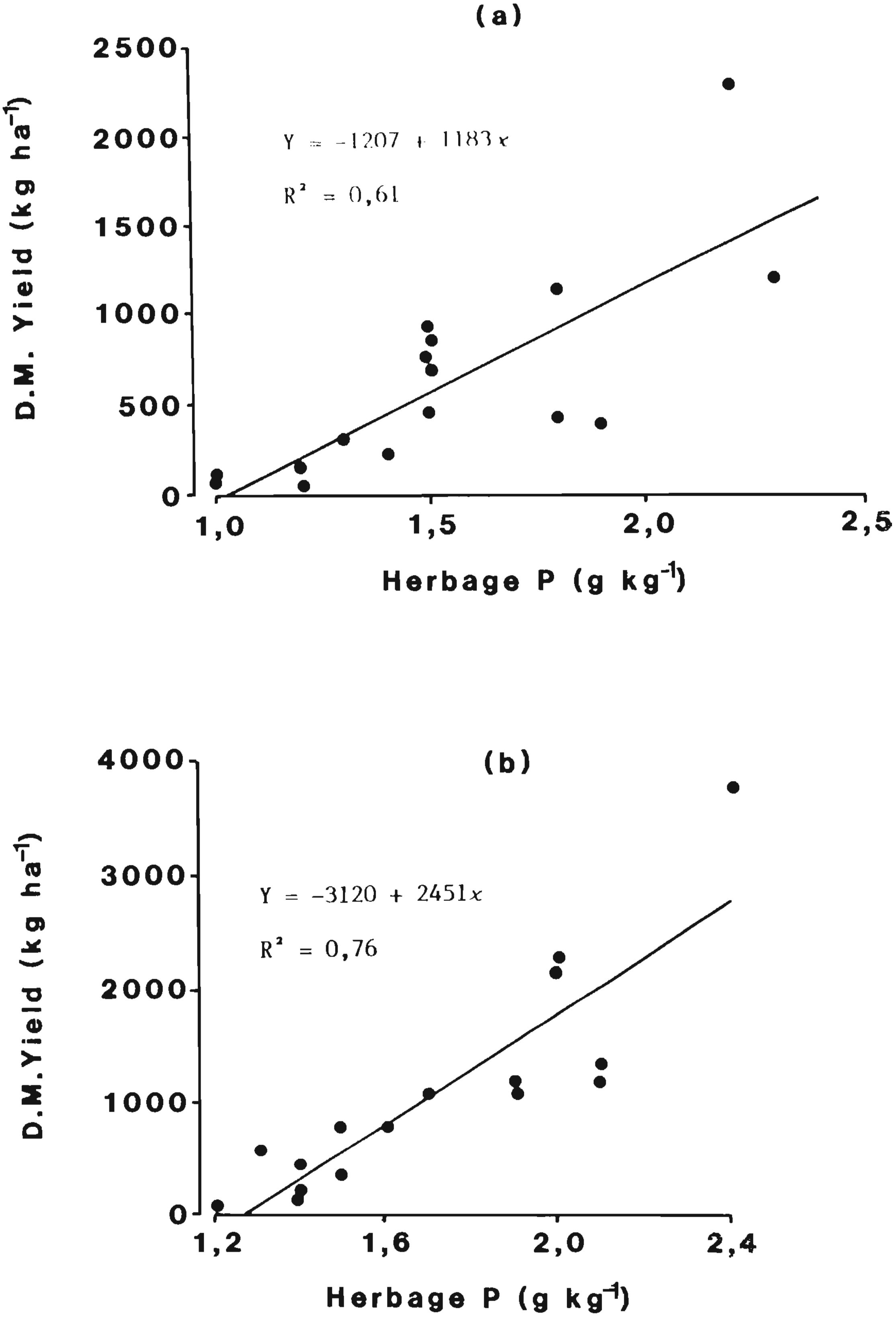


Fig 2.4 Relationship between kikuyu P contents and yields in November of the second productive season on the Balmoral (a) and Balgowan (b) soils.

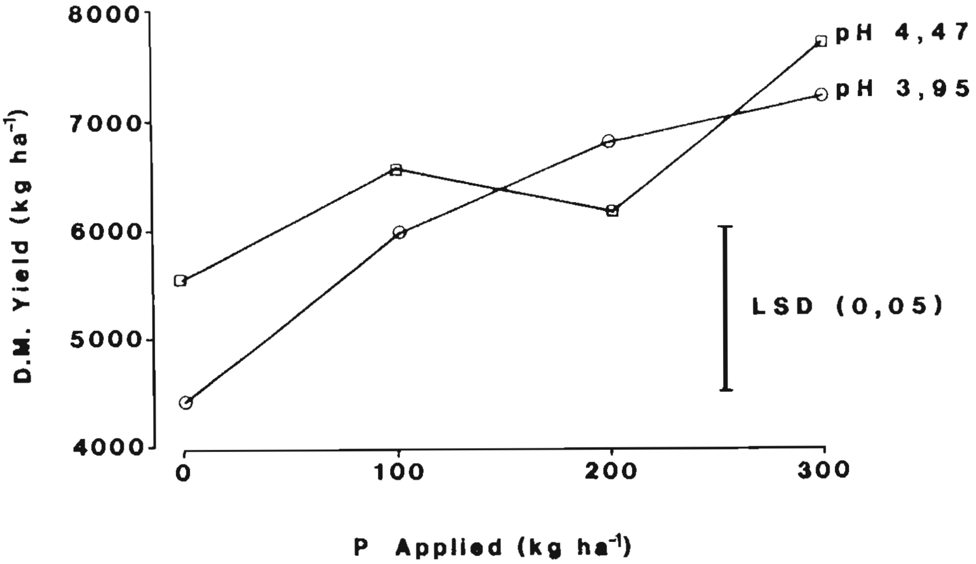


Fig 2.5 Effects of soil pH (KCl) and applied P on cumulative yields of kikuyu on the Balgowan soil over the December to April period of the second season.

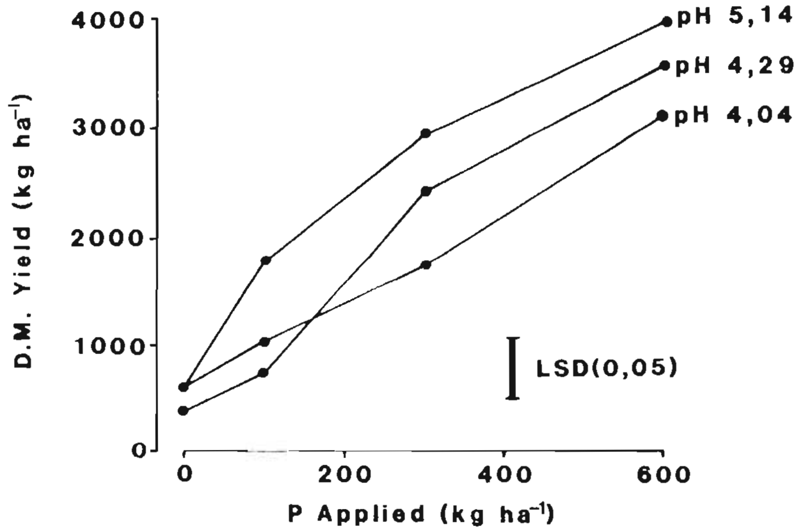


Fig 2.6 Effects of applied P and soil pH (KCl) on the yield of weeping lovegrass on the Balmoral soil at the first harvest after establishment.

Table 2.8. Variations with lime and P treatments of weeping lovegrass total dry matter production over two seasons on the Balmoral and Balgowan soils (lime responses meaned over four P levels; P responses meaned over three lime levels).

Lime rate	Balmoral	Balgowan	P rate	Balmoral	Balgowan
kg ha^{-1}	—— kg D.M. ha^{-1} ——		kg ha^{-1}	—— kg D.M. ha^{-1} ——	
0	23858	24848	0	16899	18312
2000	24065	26429	100	21911	25389
6000	26230	27089	300	28535	29415
			600	31526	31371
LSD (0,05)	1503	1076		1735	1242

Table 2.9. Variations in weeping lovegrass P content with soil pH (KCl) and applied P in the first harvest after establishment on the Balmoral and Balgowan soils.

	P rate (kg ha^{-1})			
Soil pH	0	100	300	600
	- - - - - - - - - - - g kg^{-1} - - - - - - - - - - - - - -			
	BALMORAL			
4,04	0,8	1,0	0,9	1,1
4,29	0,7	0,7	1,1	1,2
5,14	0,7	0,7	1,0	1,2
LSD (0,05)	0,1			
	BALGOWAN			
3,78	0,7	0,7	0,7	1,0
3,96	0,7	0,8	1,0	1,1
4,42	0,7	0,8	1,1	1,1
LSD (0,05)	0,2			

and increased it at the higher levels. On the Balgowan soil where no yield interactive effects were apparent at establishment, lime had no effect on P content at the zero P level, yet tended to increase P content in the presence of applied P, with this effect being highly significant at the 300 kg ha^{-1} P rate.

Total dry matter production data over the two seasons were characterized by a significant lime-P interaction in the case of the Balgowan soil (Fig. 2.7). Here responses to increases in soil pH were at a maximum at zero P.

DISCUSSION

The large responses of kikuyu and weeping lovegrass to P indicate that an insufficient supply of this nutrient is a major constraint in their growth on these acid soils. The limited responses to lime, on the other hand, confirm that these grasses are highly tolerant of soil acidity. Prior to discussing the lime-P interactions reported here, consideration of factors possibly implicated in lime responses is deemed necessary.

Yield increases accompanying lime applications to acid, highly weathered soils are generally ascribed to reductions in soluble Al and/or Mn (Pearson, 1975). However, several factors suggest that this was not the case in this study. In the first place, although relative response to lime was largely similar on all three soils (Tables 2.10 and 2.11), extractable Mn was very much higher on the Griffin (the only soil on which lime response was not statistically significant) than on the remaining two soils (Table 2.1). This, together with the fact that kikuyu is reported to be tolerant of high levels of soluble Mn in the soil (Rayment & Verrall, 1980), suggests that Mn was not a factor in lime responses. Evidence detracting from Al being implicated in lime responses is provided by the fact that yield responses continued to the highest lime levels and were not restricted to lime levels commensurate with the elimination of the bulk of exchangeable acidity

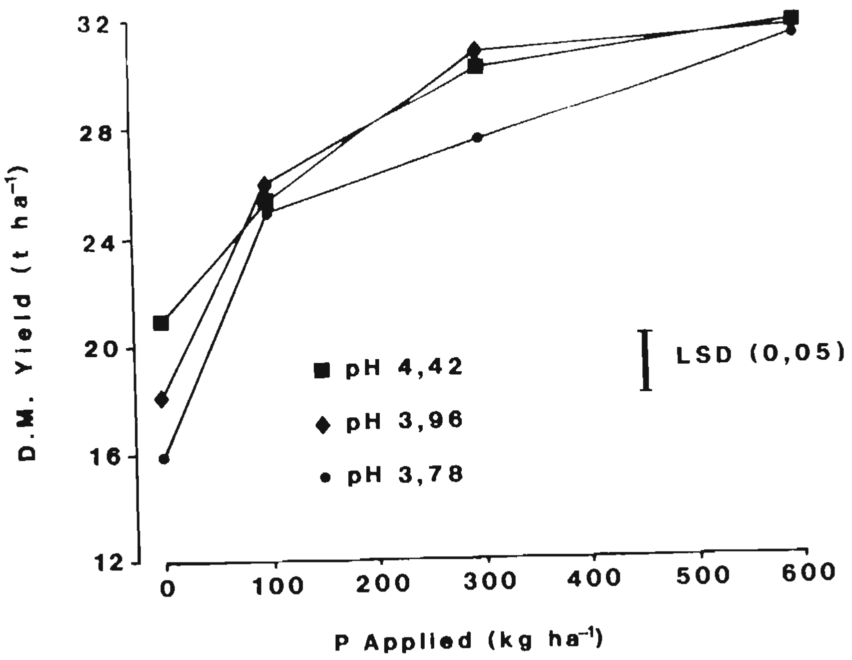


Fig 2.7 Effects of applied P and soil pH (at establishment) on the total yields over two seasons of weeping lovegrass on the Balgowan soil.

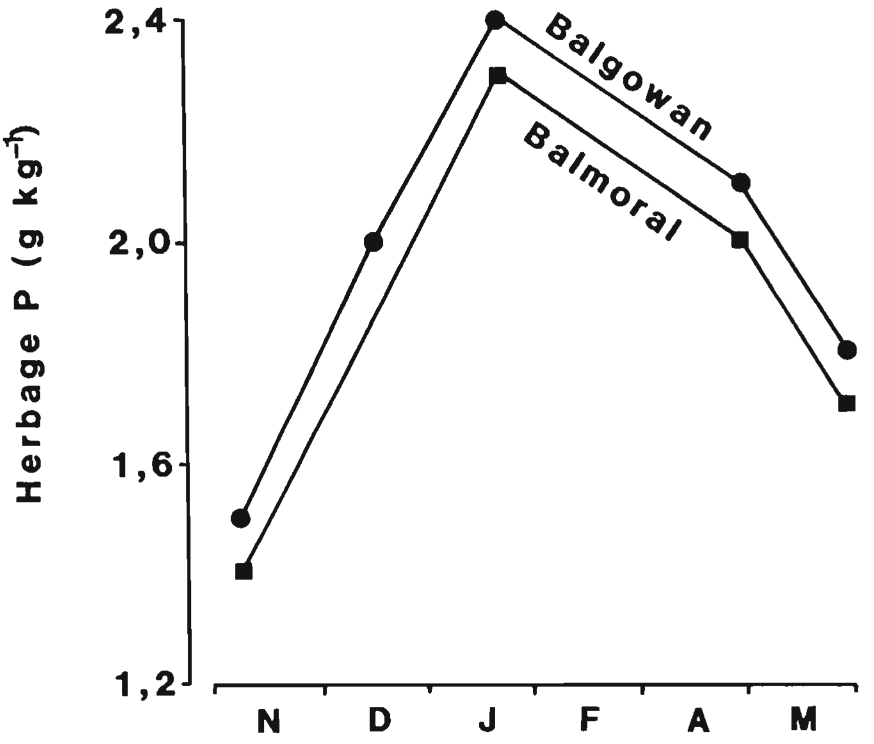


Fig 2.8 Seasonal variation in kikuyu P content on two soils (data are for a single season, meaned over four lime levels and at a P rate of 100 kg ha^{-1}).

Table 2.10. Variations, with lime level (see text), of soil pH (KCl), acid saturation and the relative yield of kikuyu on three soils (data means of four P levels; soil data from samples taken in the first season of experimentation on each site).

	Balmoral			Balgowan			Griffin		
Lime level	pH	Acid sat†	Yield††	pH	Acid sat	Yield†††	pH	Acid sat	Yield††††
		- - - - - - % - - - - - -			- - - - - - % - - - - - -			- - - - - - % - - - - - -	
L_0	4,21	39,4	86,0	3,90	65,8	83,1	4,00	46,5	86,7
L_1	4,30	23,0	90,5	4,03	49,4	84,5	4,23	19,3	92,9
L_2	4,43	10,5	92,2	4,11	32,5	92,0	4,67	7,6	90,0
L_3	5,27	0,4	100,0	4,59	5,6	100,0	5,32	0,7	100,0

† soil acid saturation $= \dfrac{Al + H}{Ca + Mg + K + Al + H} \times 100$

†† total of three seasons subsequent to establishment.

††† total of two seasons subsequent to establishment.

†††† total of four seasons including establishment.

Table 2.11. Variations, with lime rate, of soil pH (KCl), acid saturation and the relative yield of weeping lovegrass on two soils in the establishment and second seasons of growth (data means over four P levels).

	Establishment Season			Second Season		
Lime rate	pH	Acid Sat	Rel. Yield	pH	Acid Sat	Rel. Yield
$kg\ ha^{-1}$		- - - - - % - - - - - - -			- - - - - % - - - - -	
			BALMORAL			
0	4,04	52,1	91,1	3,98	76,0	90,8
2000	4,29	15,5	91,6	4,06	54,0	91,9
6000	5,14	0,6	100,0	4,49	6,5	100,0
			BALGOWAN			
0	3,78	76,7	87,5	3,81	80,2	96,4
2000	3,96	41,7	96,7	3,87	67,2	98,5
6000	4,42	6,7	100,0	4,07	29,9	100,0

(Tables 2.10 and 2.11). Furthermore, it is noteworthy that although there was an increase in exchangeable acidity with time under the experimental pastures (Tables 2.11; data not shown in the case of kikuyu), the magnitude and nature of the response to lime remained relatively constant from year to year. A final factor detracting from Al playing a dominant role in lime responses is the similarity in responses over the three soils, despite the inherently lower acidity levels in the Balmoral soil (Tables 2.10 and 2.11).

With evidence therefore suggesting that Al or Mn toxicity were not primary factors in lime responses, the question arises as to whether yield increases due to liming were related to lime effects on nutrient availability. Evidence is presented here of lime increasing Ca, Mg and P uptake (Table 2.7); furthermore, lime has been reported to increase the availability of Mo (Gupta & Lipsett, 1981) and N (Bartholomew & Miles, 1982). It would seem unlikely, in the first place, that either Mo or N was involved in lime responses. Basal fertilizer dressings of Mo were applied at establishment and after the second season of experimentation; furthermore, in separate studies on all sites (data not reported here), kikuyu did not respond to a range of micronutrients, including Mo. With regard to N, lime-P resonses were measured at relatively high application rates of this nutrient, and herbage N levels remained remarkably constant over lime levels. Assessment of a possible role of Ca and Mg in lime responses is hampered by a lack of information on sufficiency levels of these nutrients in tropical grasses. In a greenhouse study, Awad et al. (1976) found that kikuyu did not respond to Ca where herbage Ca exceeded 1,1 g kg^{-1}; it would thus seem unlikely that Ca supply affected kikuyu yield in the present studies. A critical level for Mg in kikuyu could not be found in the literature. However, with Cassidy (1972) reporting a kikuyu "sufficiency" level of 2,5 g kg^{-1} Mg, it would appear that Mg was in adequate supply in all but possibly the zero lime and P treatments. In contrast to Ca and Mg, the kikuyu P contents listed in Tables 2.6 and 2.7 were, over all lime and P levels, well below reported kikuyu critical P levels of 2,3 g kg^{-1} (Birch, 1953) and 2,2 g kg^{-1} (Andrew & Robins, 1971). Clearly, a severe P deficiency existed in kikuyu early in the season, and with lime resulting in significant increases in P content, a strong case exists for P nutrition to be implicated in lime responses, and thus also in lime-P interactions.

Interpretation of the noted lime-P interactions is complicated by wide variations in the form of such interactions together with the irregularity with which they occurred. However, a lack of consistency in interactive effects in field experiments, is, as noted by Sumner and Farina (1986), not unexpected in view of the inherent errors and numerous uncontrolled variables involved. On the Griffin soil, which had the most favourable initial P status (Table 2.1), P response was confined almost exclusively to the establishment season, when a negative lime-P interaction was noted (Fig. 2.1). In contrast, a positive lime-P interaction was apparent in the establishment of weeping lovegrass on the high P-fixing Balmoral soil (Fig. 2.6). In comparing these interactions, it is noteworthy that while P sufficiency was attained at the higher P and lime levels on the Griffin soil, this was, as suggested by the virtually linear responses to P and extremely low herbage P concentrations (Table 2.9), not true in the case of lovegrass on the Balmoral soil. Thus, these contrasting lime-P interactions were obtained at very different regions on the overall response curves, with the negative interaction occurring in a region approaching P sufficiency and the positive interaction in a zone of severe deficiency.

In the case of the early summer growth of kikuyu on the Mistbelt soils (Fig. 2.2 and 2.3), the significant positive interactions apparently occurred at a time when the pasture was under severe P stress. Phosphorus concentrations well below critical levels (Tables 2.6 and 2.7), significant relationships between herbage P concentrations and yield (Fig. 2.4), as well as a failure of P response curves to level off even at elevated pH are evidence of severe P insufficiency. Interestingly, wide variations over the season in P concentrations in kikuyu were noted (Fig. 2.8), with a maximum in mid-summer and minima in early and late summer. Furthermore, although lime-P interactions were not always significant in early season yields, responses to lime and P were consistently at a maximum early in the growing season and at a minimum in mid-summer when growth was at a maximum. An example of these seasonal response trends is provided in Fig. 2.9. It is noteworthy that the kikuyu data of Awad _et_ _al_. (1979), working in Australia, reveals seasonal variations in P content and responsiveness to lime and P identical to those reported here. The occurrence of maxima and minima in lime and P responses at the same time of the season, together with the tendency towards a negative interaction in mid-season growth (Fig. 2.5) when herbage P was at a maximum, substantiate the case for P being implicated in lime responses. Interestingly, the occurrence of both positive and negative interactions within a single season would contribute towards a lack of significant interactive effects in overall seasonal dry matter production.

Interactive patterns noted in this paper would appear, therefore, to be remarkably consistent with findings reported in the previous paper (Paper 1), as well as with those of Munns (1965), in that positive lime-P interactions are indicated under conditions of severe P stress, and negative interactions where P supply is not so severely limiting. That these trends were observed with acid-tolerant tropical species in addition to acid-sensitive temperate species, points to P supply, rather than level of phytotoxic Al, being the major factor involved.

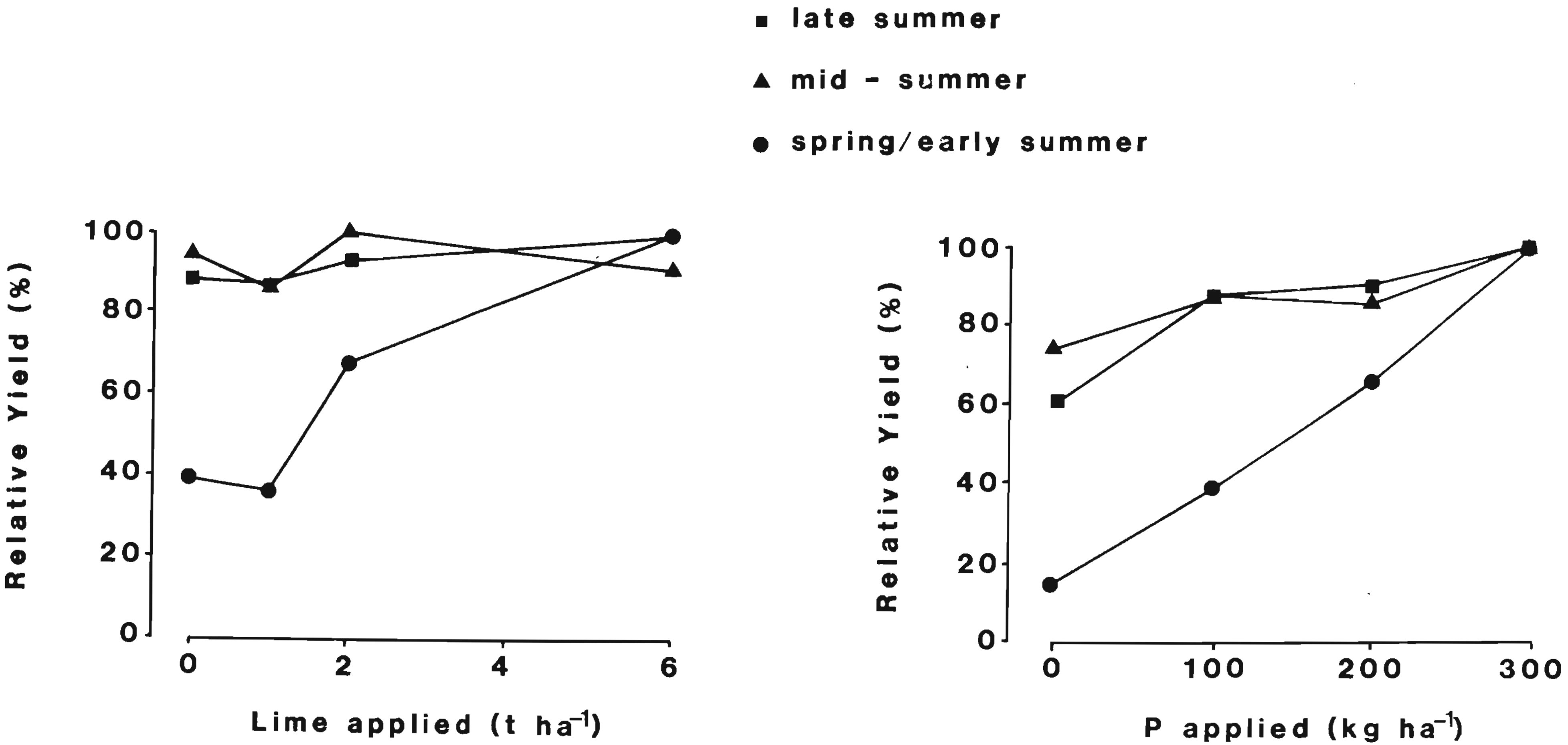


Fig. 2.9 Effects of lime and P on relative dry matter yields of kikuyu over the second growing season on the Balgowan soil.

PAPER 3

THE EFFECTS OF SOIL ACIDITY ON THE DRY MATTER PRODUCTION OF WHITE CLOVER, ITALIAN RYEGRASS, KIKUYU AND WEEPING LOVEGRASS

INTRODUCTION

Acid soil conditions have proved a major obstacle in agricultural development in tropical and subtropical areas. In the relatively moist eastern areas of Southern Africa, soil acidity has been reported to limit the performances of several crop and pasture species, including maize (Farina & Sumner, 1979), sorghum (Reeve & Sumner, 1970), sugarcane (Moberly & Meyer, 1975) and fescue and white clover (Miles *et al.*,1982).

Soil fertility investigations in Southern Africa have over the years concentrated largely on the fertilizer and lime requirements of maize and sugar cane. A dearth of information relating to pasture fertility requirements has resulted in routine lime and fertilizer recommendations for pastures being based largely on maize data. Foreign studies, together with local experience indicate, however, that pasture species frequently differ widely from maize in their responses to soil chemical factors.

In the present paper, the effects of soil acidity on the growth of kikuyu, weeping lovegrass, white clover and Italian ryegrass are reported. These species comprise more than ninety percent of the cultivated pasture in Natal.

MATERIALS AND METHODS

The data reported in this paper were drawn from field experiments on a number of acid soils located in the Natal Midlands and Mistbelt. Selected properties of these soils are presented in Table 3.1. Species included in the studies were kikuyu (Pennisetum clandestinum), weeping lovegrass (Eragrostis curvula cv Ermelo), white clover (Trifolium repens cv ladino) and Italian ryegrass (Lolium multiflorum cv Midmar). Details of experimental designs and procedures, with the exception of those relating to white clover on the Balmoral soil which will be described here, were reported in earlier publications (Papers 1, 2 and 3).

The effects of lime and P on the yield of white clover on the Balmoral soil were examined in an unreplicated 5^2 factorial design. Individual plot size was 9m X 3m (net plot 7,6m X 1,4m). Dolomitic lime was applied at rates of 0, 2000, 4000, 8000 and 12000 kg ha^{-1}. Phosphorus, as double superphosphate (19,6% P) was applied at rates of 40, 80, 120, 160 and 200 kg P ha^{-1}. The lime and P, together with 4 kg Cu ha^{-1}, 3,5 kg Zn ha^{-1} and 2 kg B ha^{-1} were incorporated by rotovator to a depth of approximately 0,2m prior to planting. The clover seed was inoculated with the appropriate Rhizobium strain, pelleted with lime and treated with Mo. Seeding rate was 3 kg ha^{-1}. Planting was in February, 1979. Three weeks after seedling emergence N, as ammonium sulphate, was applied at 60 kg ha^{-1}. Data reported here relate to dry matter production in the season following establishment (1979/80) during which the clover was harvested at intervals of six weeks.

In addition to lime and P, nutrients studied in specific trials (factorial designs) were N and K. For the purpose of this paper, lime responses were measured at the highest levels of N and at non-limiting levels of K. Selection of P levels at which to evaluate lime responses was complicated by the tendency for lime and P to substitute for one another in their effects on plant growth (Papers 1 and 2). In this discussion, lime responses are therefore reported at threshold P sufficiency levels, with these threshold P levels being the experimental P rates above which no

Table 3.1. Selected properties of the soils (0-150 mm) on which the field experiments were carried out.

	Exchangeable						pH			Particle Size		
Soil	Ca	Mg	K	Al+H	Mn†	P†	KCl	H_2O	Org. C	Clay	Silt	Sand
	cmol (+) L^{-1}				mgL^{-1}				g kg^{-1}			
Balmoral	1,35	1,25	0,30	1,62	8,7	1	4,11	4,95	48	540	290	130
Balgowan	0,66	0,82	0,27	3,19	3,0	3	3,96	4,90	52	610	250	90
Farmhill	0,76	0,57	0,35	3,40	9,9	4	3,96	4,90	49	590	220	190
Griffin	1,07	0,37	0,35	3,22	20,6	10	3,91	4,22	35	390	140	420
Cleveland	0,62	0,25	0,07	2,85	6,1	6	4,04	4,47	28	330	120	560

† 10 min extraction with 0,25 M NH_4HCO_3 + 0,01 M EDTA + 0,01 M NH_4F at pH 8,0.

significant positive responses to P were evident. Where lime-P interactions were not significant, and in the case of clover on the Balmoral soil where there was no replication, the threshold P levels were derived from the main effects of P. In the case of significant interactions in which threshold P values varied with lime level, lime response was examined at the lowest P threshold evinced in the data (lowest indicated P sufficiency level, irrespective of lime level). Where P sufficiency was not attained and a lime-P interaction occurred, as was the case in the spring/early summer growth of kikuyu on the Mistbelt soils, data where not included in the evaluation of lime responses.

Herbage and soil sampling techniques used in the field trials together with analytical methods employed were outlined previously (Papers 1 and 2). In the ensuing discussion, use is made of acid saturation (Al+H/Ca+Mg+K+Al+H X 100) as a measure of soil acidity. 'Acid' saturation as opposed to 'Al' saturation is used on account of the acidity in KCl extracts being determined by titration against NaOH and thus including some hydrogen ions. Meyer (S.A. Sugar Assoc. Exp. Station, Mount Edgcombe. 1986 pers. comm.) reports that in studies on soils of the Sugar Belt, 35% on average of the acidity determined by titration in KCl extracts is not directly attributable to Al. However, Farina _et al_. (1980, 1981) in their studies on a number of North American and South African soils, found that acid saturation and Al saturation tended to differ little in magnitude and appeared to be equally effective as predictors of soil acidity effects on plant growth.

RESULTS AND DISCUSSION

Relationship between soil pH and acid saturation

The relationship between soil pH (_M_ KCl) and soil acid saturation for the soils included in this study is presented in Fig. 3.1. It is apparent

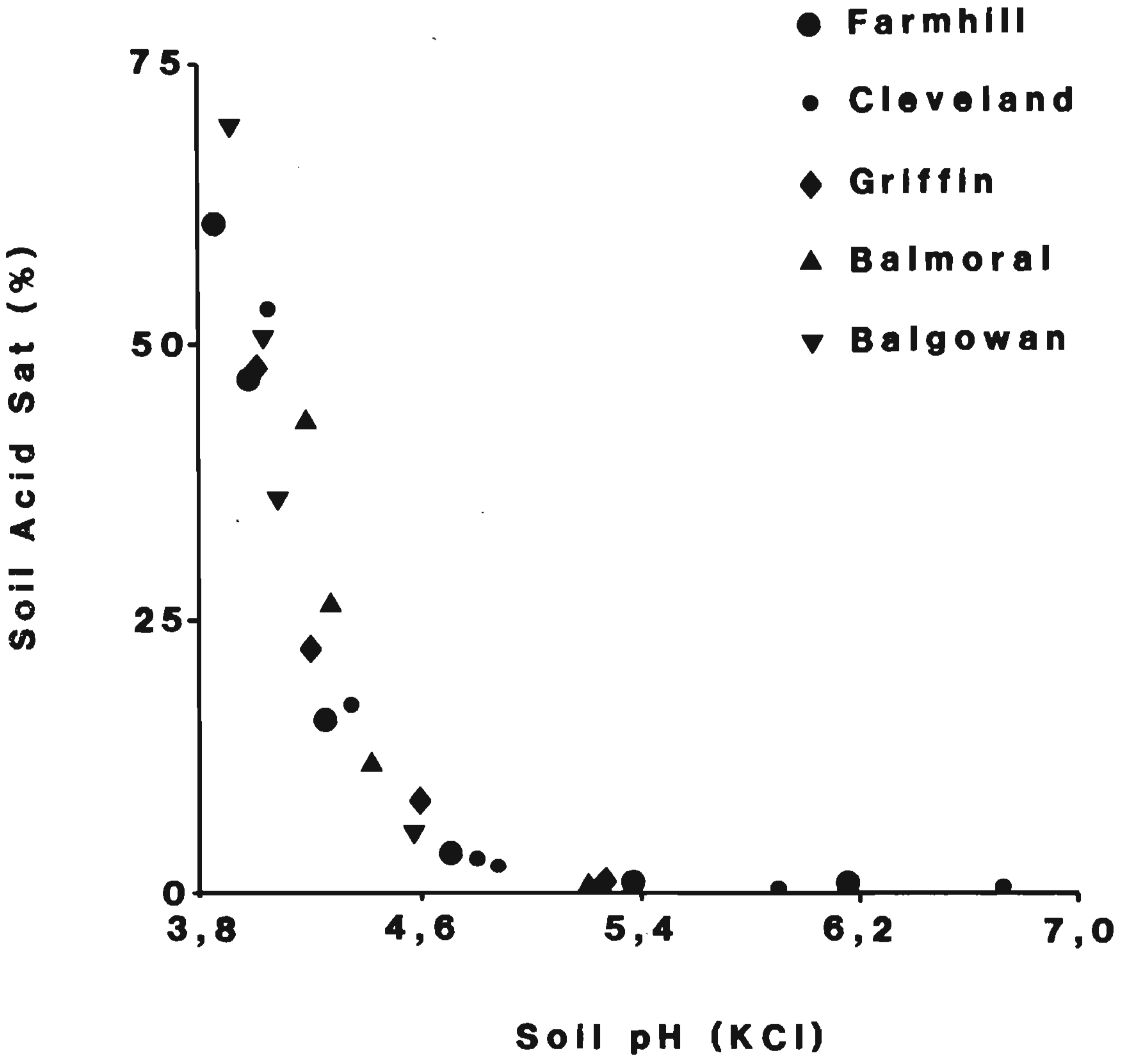


Fig. 3.1 The relationship between acid saturation and soil pH on the soils studied.

that at pH values below 4,2, acid saturation values rise to high levels. With increases in pH above 4,2 on the other hand, acid saturation decreases rapidly and is essentially zero at pH 5,0. Similar relationships have been reported for Al saturation in highly weathered soils from other parts of the world (Kamprath, 1980).

Pasture dry matter yield as related to soil pH

Variations in the dry matter production of kikuyu with soil pH are shown in Fig. 3.2a. These data reflect second season response trends, with responses remaining largely similar over the four seasons of experimentation. Clearly, kikuyu growth remained essentially unaffected by liming. This is in accordance with evidence in the literature of kikuyu having an appreciable tolerance to acid soil conditions (Awad & Edwards, 1977; Cregan, 1980). At the high N rate (600 kg N ha^{-1} as urea) at which lime responses reported here were measured, soil acidity increased markedly with time; the failure of lime to significantly improve growth of kikuyu even towards the end of the experimental period thus further underlines the ability of this grass to perform well under acid soil conditions. It should be noted that the appreciably lower yields reported in Fig. 3.2a for the Balmoral and Balgowan soils relative to the Griffin soil are largely due to the dry matter production in spring/early summer on the former soils not being included in the data; an inability to measure lime responses independently of P effects at this time (cf. Materials and Methods) made this necessary.

Effects of soil pH on weeping lovegrass dry matter production are presented in Fig. 3.2b. Significant responses to lime were evident on both soils, with a greater response being suggested on the Balmoral soil. On the latter soil a levelling-off in response to lime is not apparent. However, practical experience in the area indicates a ceiling annual yield of

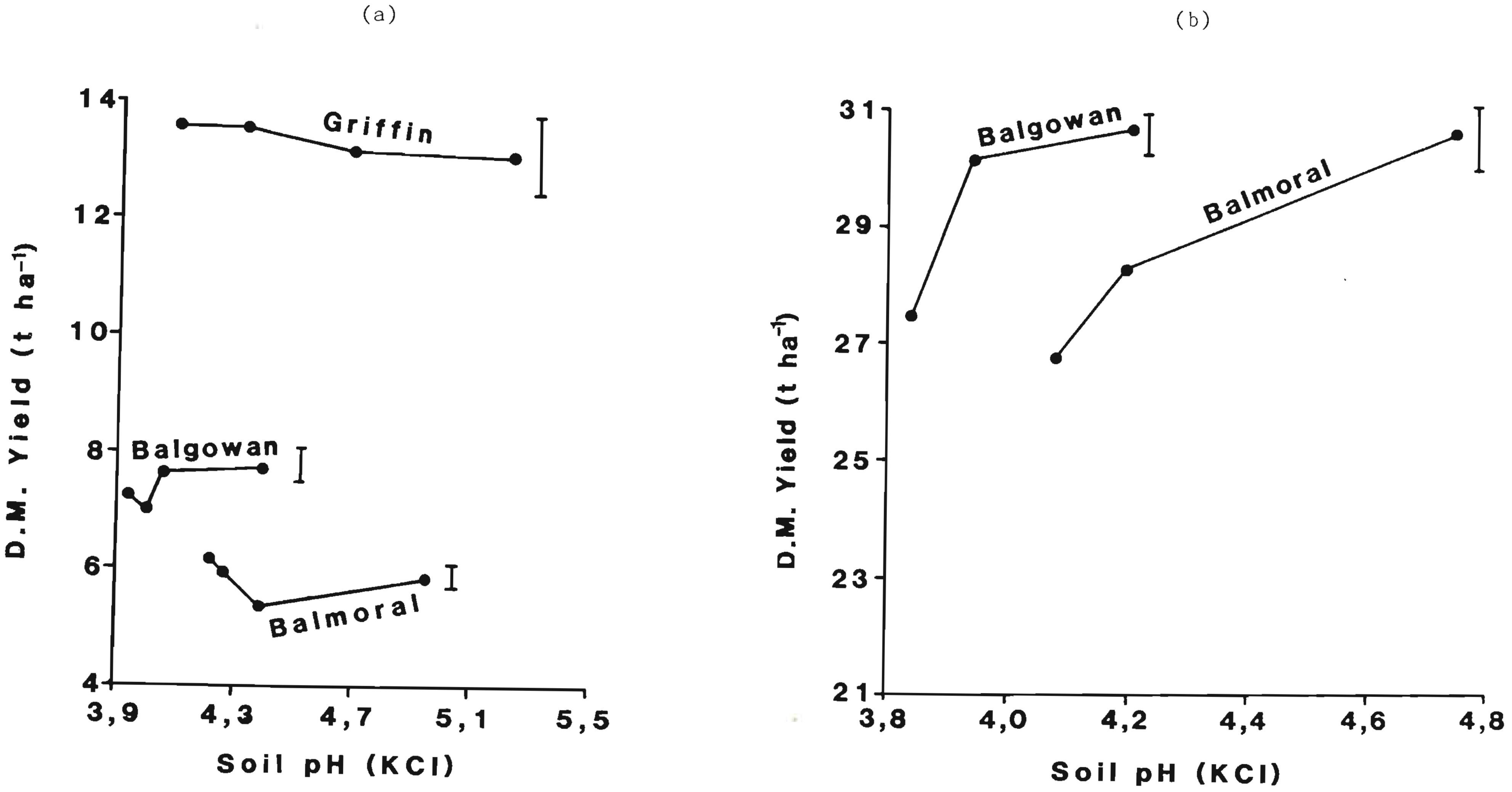


Fig. 3.2 Effect of soil pH on the dry matter production of (a) kikuyu (single season), and (b), weeping lovegrass (total of two seasons) on highly weathered soils (vertical bars indicate S.E. of plotted means).

approximately 15000 kg D.M. ha^{-1} at the N rate used here (350 kg ha^{-1}); thus an appreciably greater response to lime than that noted appears unlikely. Although significant responses to lime were apparent, it is noteworthy that yields in the absence of lime were in the region of 90% of yields recorded at the highest lime rates. A high tolerance of weeping lovegrass to soil acidity is therefore indicated; this is consistent with the findings of Fleming et al. (1974) using nutrient solutions, as well as with the successes achieved with this species in the revegetation of acid mine spoils (Vogel & Berg, 1968).

The influence of soil pH on white clover dry matter production is shown in Fig. 3.3. Initial lime increments resulted in sharp increases in yield. A levelling-off in response was apparent at a pH value of 4,4, with a yield plateau extending to approximately pH 5,0. Response to lime was particularly marked on the Cleveland soil, where yield increased by 250% with an increase in pH from 4,0 to 4,4. Poor rainfall in the course of experimentation on the Balmoral and Farmhill soils no doubt accounts for the lower yields and responses noted on those soils. Increases in pH above approximately 5,0 resulted in yield depressions on all the soils, with this being most marked on the Cleveland soil where the highest pH (6,7) was established. Effects of soil acidity on the performance of white clover have been reported on by several workers. In a field trial on a mildly acidic (water pH 5,4) Eastern Transvaal soil, Barnes (1986) found that white clover did not respond to lime. Palazzo and Duell (1974) in field studies on an acidic sandy loam (water? pH 4,2) noted response trends essentially similar to those reported here; a large positive response to lime occurred, followed by a short yield plateau and, with further increases in pH, marked yield depressions. In pot studies, largely indentical responses to those presented in Fig. 3.3 (including yield depressions) have been reported (Shoop et al., 1961; Lowther & Adams, 1970). The positive responses of white clover to lime in this and other studies appear to be co-incident with

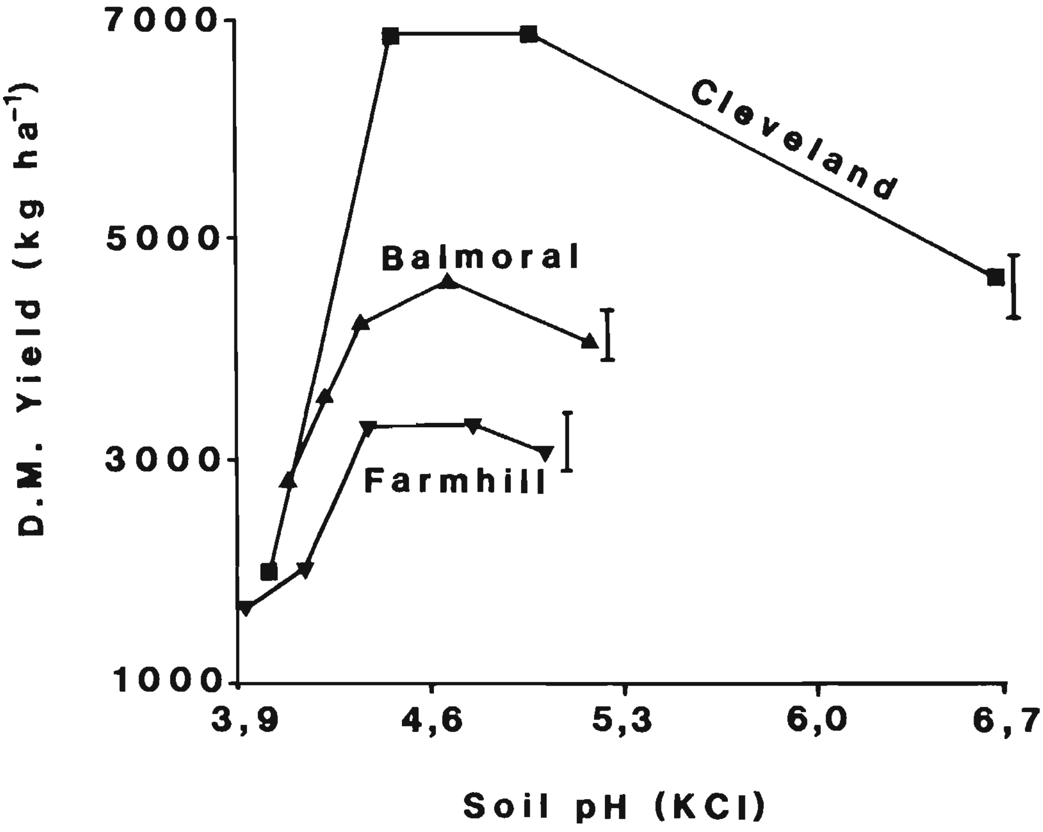


Fig. 3.3 The variation in white clover dry matter production with soil pH (Cleveland: total dry matter production over first three harvests of initial productive season; Balmoral and Farmhill: total dry matter production over first productive season; vertical bars indicate S.E. of plotted means)

a reduction of exchangeable Al. In this respect it is noteworthy that in the field study of Barnes (1986), where clover did not respond to lime, soil acid saturation was relatively low (16%). The limited pH range, noted here and by other workers cited above, at which clover yield is at a maximum, emphasizes the importance of a judicious liming programme in the propagation of this legume. Furthermore, the marked yield depressions at higher lime rates underline the sensitivity of this species to overliming, as well as the hazards of 'traditional' liming methods in which pH is raised to a selected value which is often close to neutrality (Shoemaker et al., 1961). Possible factors implicated in lime-induced yield depressions received attention in an earlier publication by this author (Paper 1) and will not be considered here.

In the Italian ryegrass studies on the Cleveland soil, significant yield increases in response to liming were noted in both seasons of experimentation (Fig. 3.4a). As in the case of white clover, yield reached a maximum at a pH value in the vicinity of 4,5, this being coincident with the elimination of the bulk of exchangeable acidity (Fig. 3.1). Furthermore, in the 1986 season, a suggestion of yield depression was evident at the highest pH (5,7). On comparing the ryegrass response curves (Fig. 3.4a) with those of clover (Fig. 3.3), it is apparent that yield reduction in the absence of lime was appreciably greater in the case of clover. A greater tolerance on the part of ryegrass to soil acidity is thus indicated. However, the adverse effects of soil acidity were very much more marked during the establishment phase of ryegrass growth than in the period subsequent to establishment (Fig. 3.4b). It is noteworthy that in the case of P, too, responses were at a maximum at establishment (data not presented). These findings are consistent with reports of Al inhibiting root development and P uptake (Foy, 1971). Other than a recent pot study by Curtin and Smillie (1986), in which Italian ryegrass responded dramatically to lime on a soil high in exchangeable Al, no information on lime responses

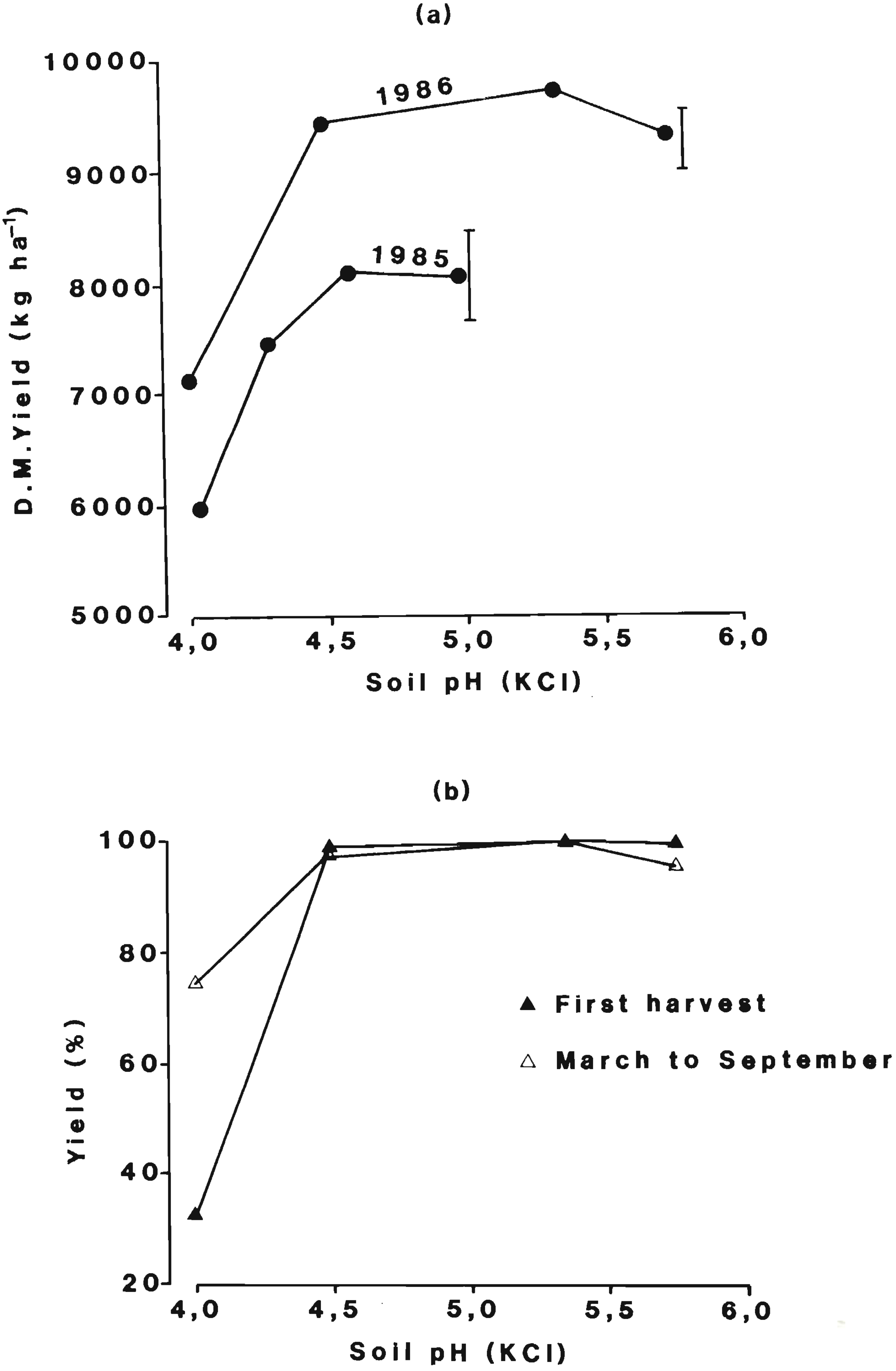


Fig. 3.4 The variation in dry matter production with soil pH (Cleveland soil) of Italian ryegrass. Plotted in (a) are the cumulative yields over March to September of 1985 and 1986, and in (b), percentage yields at the first harvest and cumulated yields over the March to September period of 1986 (vertical bars indicate S.E. of plotted means)

for this grass was uncovered in the literature.

Prediction of lime requirements

Field studies have shown that the performance of most crops can be correlated with Al saturation (Pearson, 1975; Sanchez & Salinas, 1981), and that Al saturation is generally a better predictor of plant performance than pH (Fox, 1979; Kamprath, 1980). Farina et al (1980, 1981) found Al saturation and acid saturation to be equally reliable as predictors of soil acidity effects on plant growth, with these measures being superior to pH in this respect. Relationships between percent yield and soil acid saturation for the species studied here are presented in Fig. 3.5. Data presented in Figs 3.2-3.4 were used in the development of these relationships; in the case of white clover, however, data reflecting yield depressions at high lime levels were not included. The relationships presented in Fig. 3.5 highlight the differences between the tropical (kikuyu and weeping lovegrass) and temperate (white clover and Italian ryegrass) species in their responses to soil acidity. Thus, while with the tropicals, near maximum yields may be expected on soils with acid saturations as high as 70%, with the temperate species, acid saturations in excess of 15% are likely to result in substantial yield reductions. These findings have obvious important implications on the establishment costs of the respective pasture species. In order to minimize lime costs, a strategy increasingly favoured by farmers is to establish the tropical species on the more acidic upland sites and the temperates on the higher base status bottomlands. Such an arrangement has the added advantage of providing the relatively less drought resistant temperates with the sites having the more favourable moisture regime.

It should be pointed out that lime applications in excess of those

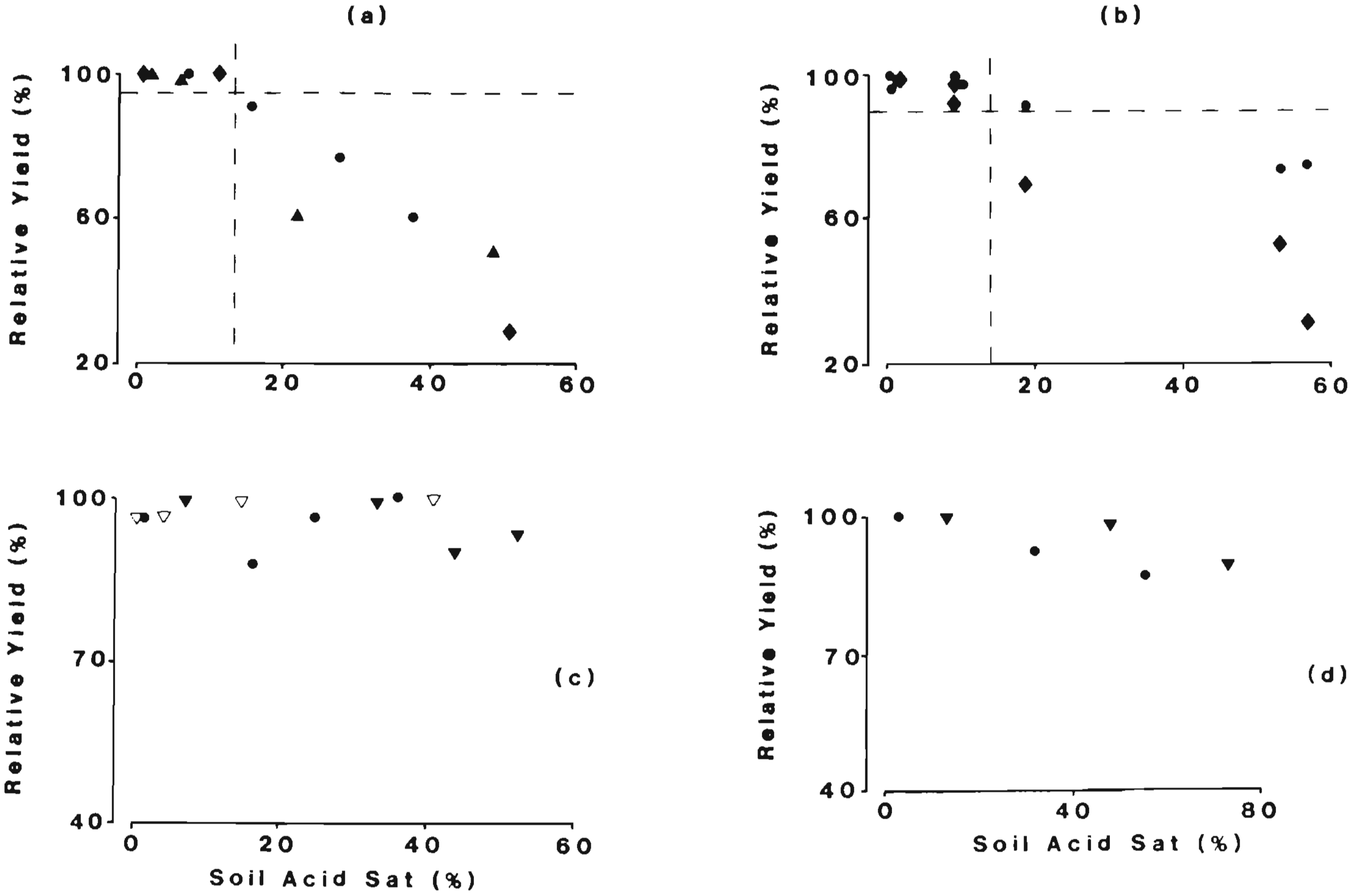


Fig. 3.5 Relationships between soil acid saturation and the relative yields of (a) white clover (● Balmoral soil, ◆ Cleveland, ▲ Farmhill), (b) Italian ryegrass (● March - September, ◆ first harvest of season), (c) kikuyu (● Balmoral, ▼ Balgowan, ▽ Griffin) and (d) weeping lovegrass (● Balmoral, ▼ Balgowan).

indicated by the straight-forward yield acid saturation relationships may under certain circumstances be warranted. Thus in the case of the tropical species, analyses have shown that the levels of certain minerals, in particular Ca and Mg, may be below animal requirements. Under these conditions the costs and implications in terms of animal performance of liming to improve herbage mineral levels as against providing mineral supplements directly to the animals necessitates evaluation. In the case of the acid-sensitive temperate species, lime additions based on the observed thresholds may for several reasons prove inadequate in the long-term. In the first place, as noted by Pearson (1975), soil pH changes induced by liming tend to be transient in highly weathered soils. In addition, indications are that a number of factors contribute towards accelerated acidification under intensive pastures. Thus in the case of Italian ryegrass, which is generally propagated under intensive management (irrigation, 350-550 kg N ha^{-1} per annum), the acidifying effect of N fertilizer would result in a recurring lime requirement on pastures limed to the indicated threshold level. By way of illustration, the marked increases in soil pH and acid saturation over the season on the Cleveland soil at a high level of N fertilization are presented in Table 3.2. In addition, overseas workers have demonstrated a tendency on the part of legumes to acidify the soil on which they grow; the processes involved were recently reviewed by Haynes (1983). Legume-induced soil acidification, although not as severe as fertilizer N effects, may be implicated in the noted poor persistence of white clover swards in Natal, particularly where establishment lime additions on such swards were sufficient only to reduce Al to low levels.

Table 3.2 Changes over the season in pH and acid saturation of a Cleveland soil supporting an Italian ryegrass pasture. The pasture received a total of 675 kg N ha^{-1} as urea, with the N being applied at monthly intervals at a rate of 75 kg N ha^{-1}.

	March 1985		December 1985	
Lime rate[†]	pH (KCl)	Acid Sat.	pH (KCl)	Acid Sat.
kg ha^{-1}		%		%
0	4,03	55,2	3,91	78,1
1500	4,28	20,2	4,05	54,3
3000	4,57	7,9	4,25	25,9
4500	5,08	1,6	4,55	12,1

† lime as calcium hydroxide

PAPER 4

THE RESPONSES OF KIKUYU AND WEEPING LOVEGRASS TO APPLIED PHOSPHORUS ON ACID SOILS

INTRODUCTION

In much of the relatively moist eastern region of Southern Africa, potential animal production per unit area off natural grassland is only a fraction of that attainable off introduced pastures. A major obstacle in pasture introduction programmes, however, is the correction of soil chemical constraints, in particular high acidity and low P status. The considerable limitations imposed by soil acidity on the growth and quality of pastures were discussed in an earlier paper (Paper 3). The correction of P deficiencies poses, however, from an economic point of view, a sometimes even greater obstacle than that of soil acidity in the introduction of improved pastures. The P problem is two-fold since not only are native P reserves very low, but furthermore, with kaolinite, iron and aluminium oxides and poorly crystalline material predominating in the clay fractions (de Villiers, 1969; Fey, 1974), immobililzation of added P is generally very high.

In this paper, the field responses of kikuyu and weeping lovegrass to P on three acidic Natal soils are reported.

MATERIALS AND METHODS

Information reported in this paper was obtained from field studies carried out on three acid soils in Natal. The Balmoral and Balgowan soils were located in the Natal Mistbelt (annual rainfall 885mm) and were in the virgin state. The Griffin soil was located in the Midlands of Natal (rainfall 1166mm) on a site previously used for short term pasture rotations and with an uncertain history of P fertilization. Selected properties of the soils are presented in Table 4.1, while P sorption isotherms, determined by the method of Fox and Kamprath (1970), are presented in Fig. 4.1. Based on the classification system proposed by Juo and Fox (1977), the Balmoral and Balgowan soils may be defined as 'high' (P sorbed at 0,2mg L^{-1} between 500 to 1000 mg P kg^{-1}) P sorbers and the Griffin as a 'medium' (100 to 500 mg P kg^{-1}) P sorbing soil.

Kikuyu (Pennisetum clandestinum) trials were carried out on all three soils, with the design being a 4^3 N, P, lime factorial, replicated twice on the Balmoral and Balgowan soils, and unreplicated on the Griffin soil. Phosphorus, as double superphosphate (19.6% P) was provided at rates of 0, 100, 200 and 300 kg ha^{-1} on the Balmoral and Balgowan soils, and at 0, 80, 160 and 240 kg ha^{-1} on the Griffin soil. Lime, as calcium hydroxide, was applied to the Balgowan and Balmoral soils at rates of 0, 1000, 2000 and 6000 kg ha^{-1}, and to the Griffin soil at 0, 2000, 4000 and 8000 kg ha^{-1}. The lime and P were mechanically incorporated to a depth of 200mm prior to pasture establishment. Nitrogen, as urea (46% N), was applied in three equal dressings over the growing season (October to April), with total annual rates being 0, 200, 400 and 600 kg N ha^{-1}. Responses were studied over four seasons. Elements other than those under study (including micronutrients) were provided in what was deemed from practical experience to be adequate amounts. However, in the third year of experimentation on the Balgowan soil, growth of kikuyu under high N fertilization was suspected to have been restricted by an inadequate K supply; data for that season were not therefore considered in the evaluation of P responses.

The lovegrass (Eragrostis curvula cv Ermelo) experimentation was carried out on the Balmoral and Balgowan soils. Establishment of the grass on these soils formed part of a broader program in which, following the imposition of

Table 4.1. Selected properties of the soils (0–150 mm) on which the field experiments were carried out.

	Exchangeable						pH			Particle Size		
Soil	Ca	Mg	K	Al+H	Mn†	P†	KCl	H_2O	Org.C	Clay	Silt	Sand
	---- cmol (+) L^{-1} ------				- mg L^{-1} -				-------- g kg^{-1} ------			
Balmoral	1,35	1,25	0,30	1,62	8,7	1	4,11	4,95	48	540	290	130
Balgowan	0,66	0,82	0,27	3,19	3,0	3	3,96	4,90	52	610	250	90
Griffin	1,07	0,37	0,35	3,22	20,6	10	3,91	4,22	35	390	140	420

† 10 min extraction with 0,25 M NH_4HCO_3 + 0,01 M EDTA + 0,01 M NH_4F at pH 8,0.

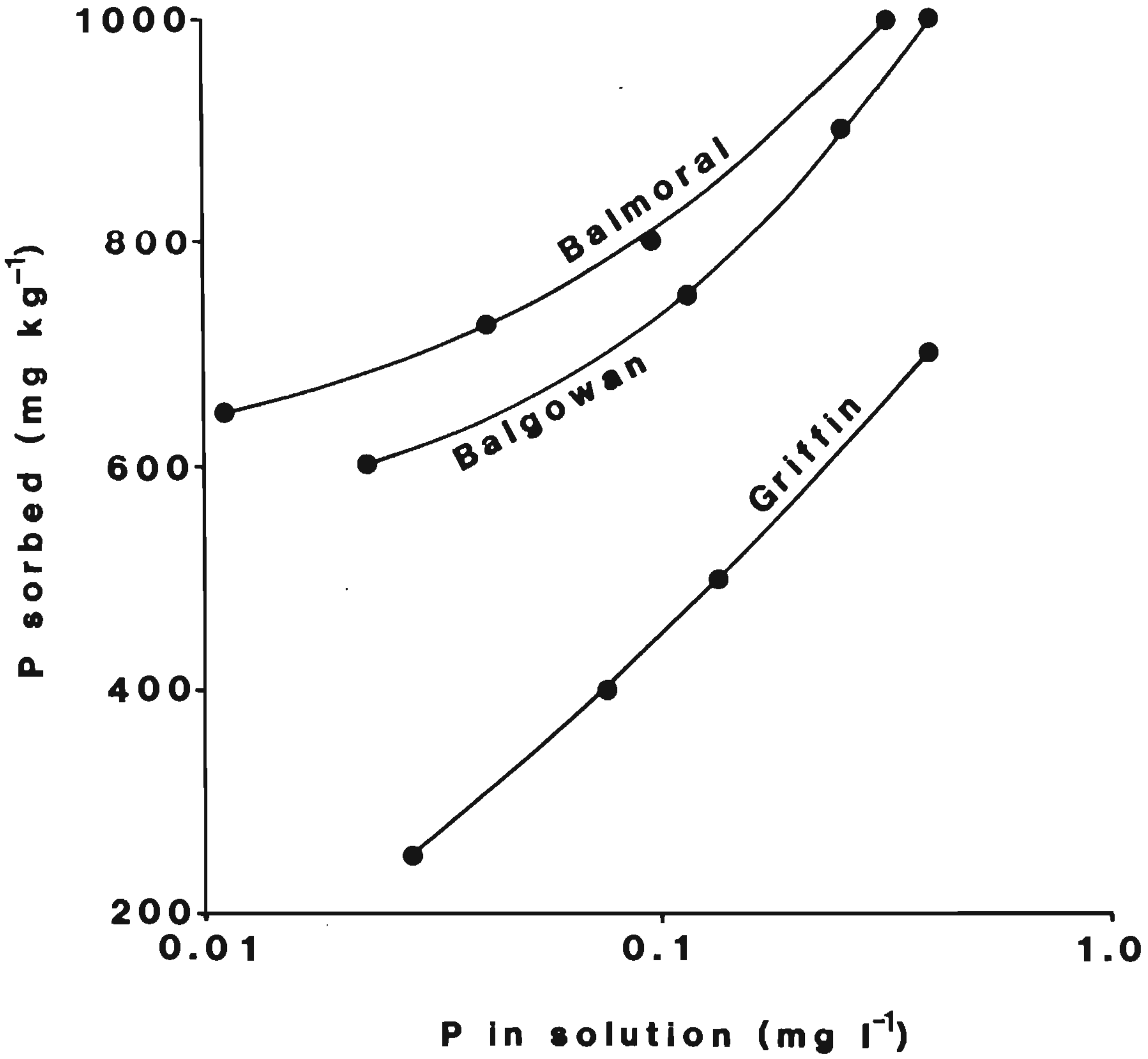


Fig. 4.1 P sorption isotherms for the soils on which P responses of tropical pasture species were studied.

lime and P treatments, soil samples were obtained at regular intervals over a three year period for the monitoring of P immobilization. During this period the sites were maintained in the fallow state, with weeds being eradicated by hoeing. The experimental design was a 4P X 3 lime factorial with two replicates. Lime, as calcium hydroxide, was applied at rates of 0, 2000 and 6000 kg ha^{-1}, and P, as double superphosphate, at rates of 0, 100, 300 and 600 kg P ha^{-1}. Following the three year fallow period, basal dressings of other essential elements were included and the lovegrass established. Nitrogen, as urea, was applied in split dressings with the total annual rate being 350 kg N ha^{-1}.

In practice, kikuyu and lovegrass pastures have been found to respond strongly to N, and, as reported previously (Paper 3), to exhibit little or no response to lime. In the present discussion, therefore, P effects are, unless otherwise specified, examined over the zero and lowest lime applications, and in the case of kikuyu, at the highest N level.

RESULTS

Kikuyu responses to phosphorus

Effects of applied P on the total dry matter production of kikuyu over the periods of experimentation on the three soils are presented in Table 4.2. Significant responses were evident on all the soils. However, whereas a levelling-off in response was apparent with the addition of 80 kg P ha^{-1} on the Griffin soil, on the high P-fixing Balmoral and Balgowan soils, a continuous response to the highest P level (300 kg P ha^{-1}) is indicated.

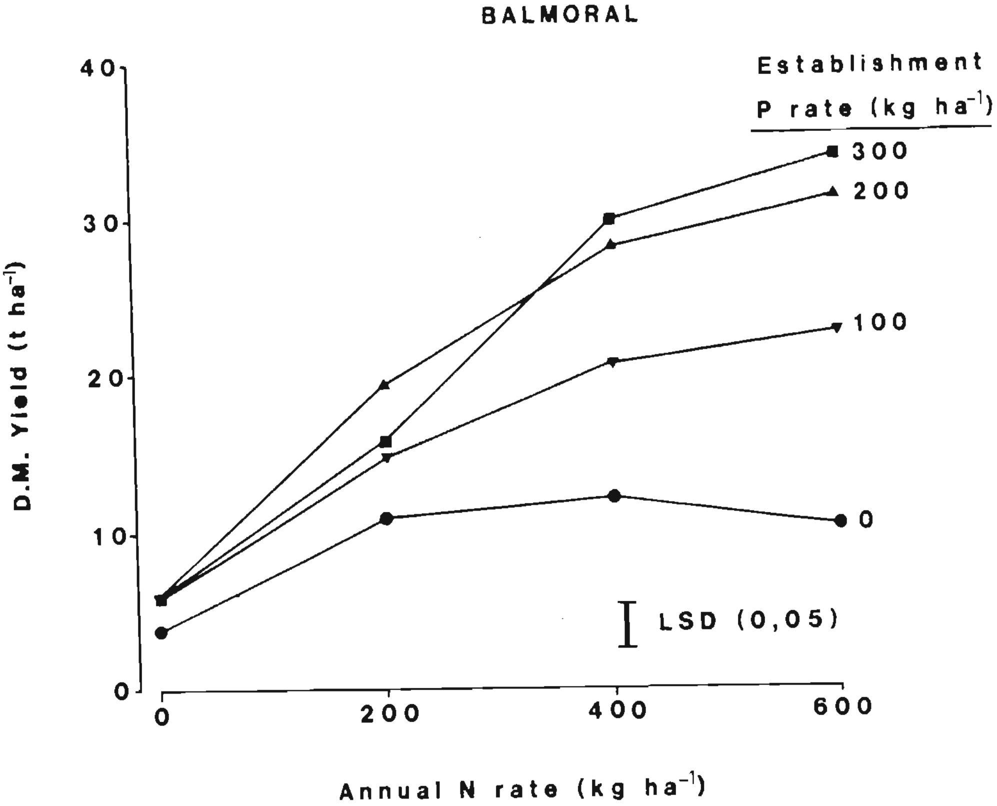
A highly significant N - P interaction characterized growth on the Balmoral and Balgowan soils. This is illustrated, in the case of the Balmoral soil in Fig. 4.2 (upper). Maximum response to P occurred at the

Table 4.2: Effect of applied P on the total dry matter production of kikuyu over four seasons on Balmoral and Griffin soils and three seasons on the Balgowan soil.

P rate	Balmoral	Balgowan	P applied	Griffin
kg ha^{-1}	- - - kg D.M. ha^{-1}	- -	kg ha^{-1}	kg D.M. ha^{-1}
0	10441	7934	0	34215
100	22926	18778	80	45012
200	31289	22324	160	43043
300	33964	26766	240	44285
LSD (0,05)	2795	2667		6074

Table 4.3. Effects of applied P on kikuyu dry matter production at the first two harvests in the seasons of establishment on two soils.

	Balmoral		Balgowan	
P rate	1st cut	2nd cut	1st cut	2nd cut
kg ha^{-1}	- - - - - - - -	kg D.M. ha^{-1}	- - - - - - - -	- - - - -
0	0	37	0	58
100	484	1432	1052	2034
200	1263	2106	1562	2412
300	1597	2385	2090	2238
LSD (0,05)	556	417	412	479



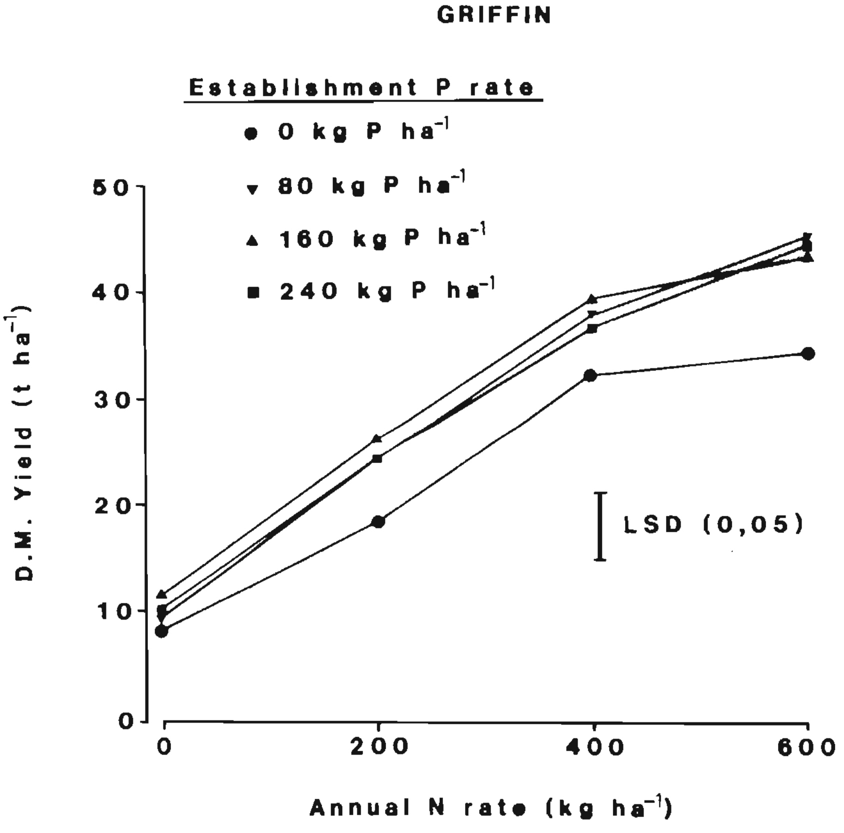


Fig. 4.2 Variation in kikuyu dry matter production with applied N and P on two soils (total production over four seasons; in the case of the Griffin soil, meaned over all lime treatments).

highest N level, and little response to either of these nutrients occurred at zero or low levels of the other nutrient. In contrast, as indicated in the lower graph of Fig. 4.2, a N - P interaction did not occur on the Griffin soil, with the P reserves in that soil being sufficient to allow a highly significant response to N in the absence of applied P. It is noteworthy, however, that response to P was at a maximum at the highest rate of N.

Responses to P were most marked at establishment and, in subsequent seasons, during the spring/early summer periods. The dramatic effect of applied P on kikuyu establishment is illustrated by the data presented in Table 4.3. A particularly steep response was evident at the first cuts with 1.6 to 2.1 tonnes being produced at the 300 kg P ha^{-1} level, and zero yield in the absence of applied P. In contrast to P, lime and N had virtually no effect on dry matter production during this establishment phase (data not shown). The extremely slow rate of sward formation in the absence of P resulted in a severe weed problem (weeds were removed by hand prior to the second harvest). In the seasons subsequent to establishment, P responses were consistently at a maximum in the spring/early summer period (Figs 4.3 and 4.4). This seasonal variation in P response was particularly marked on the virgin Griffin and Balmoral soils, with little growth occurring early in the season at low levels of P fertilization (the low production at the January harvest on the Griffin soil was due to temporary drought over the December-January period). Chemical analyses of herbage from selected harvests revealed that P concentrations in kikuyu were at a minimum in spring and reached a peak in mid-summer (Table 4.4). Thus, the steep yield responses evinced in spring/early summer coincided with low herbage P concentrations.

Use of the data obtained in these studies for the determination of a critical herbage P content as well as a threshold P soil test value was impeded by the failure, in most years, of yield responses on the Mistbelt

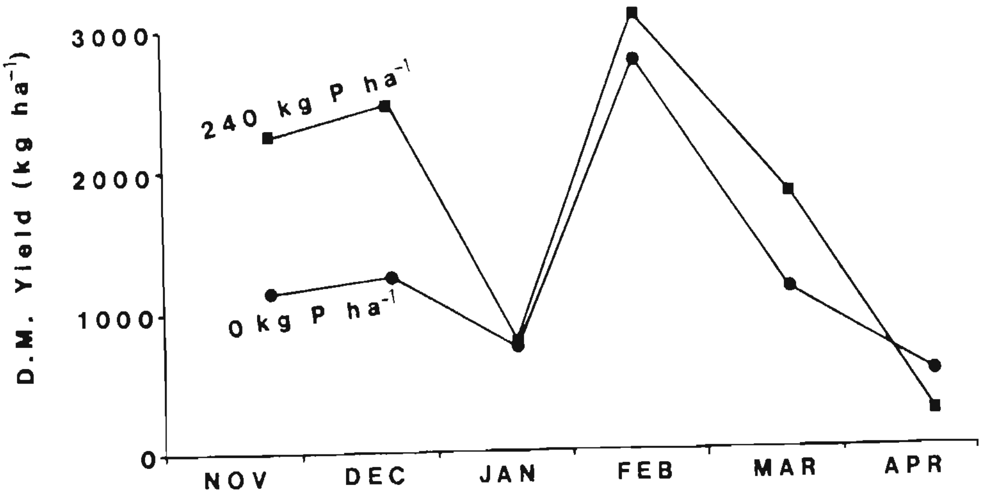


Fig. 4.3 Kikuyu dry matter production at two P levels in the fourth season on the Griffin soil (P applied at establishment)

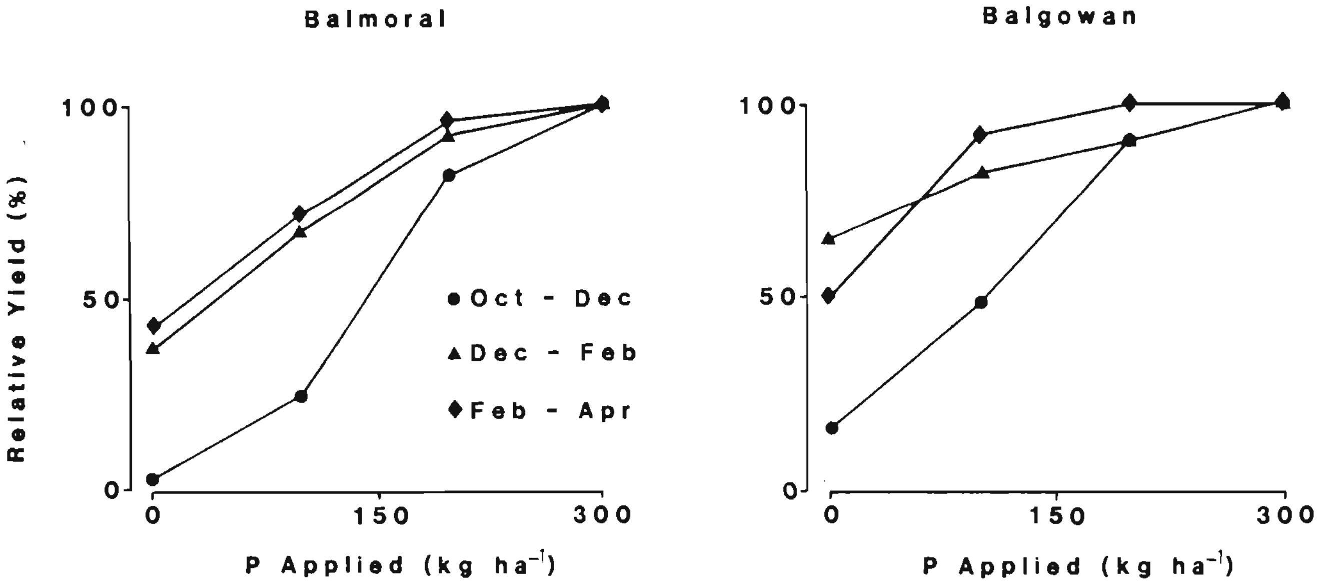


Fig. 4.4 Seasonal variation in response to applied P of kikuyu on two soils (data from second seasons of production)

Table 4.4. Seasonal variation in kikuyu P and Ca contents on two soils (data meaned over all N treatments, at 300 kg P ha^{-1} and at zero lime).

		Sampling Date				
		8/11	14/12	18/1	28/3	28/4
		- - - - - - - - - - - - - - g kg^{-1} - - - - - - - - - - - -				
Balgowan	P	1,8	2,2	3,2	2,5	2,1
	Ca	1,7	2,4	1,9	2,0	2,2
Balmoral	P	1,8	-††	3,0	2,7	2,0
	Ca	2,3	-	2,1	2,0	2,3

†† not determined

Table 4.5. Effects of applied P on the total dry matter production of weeping lovegrass over two seasons on two soils.

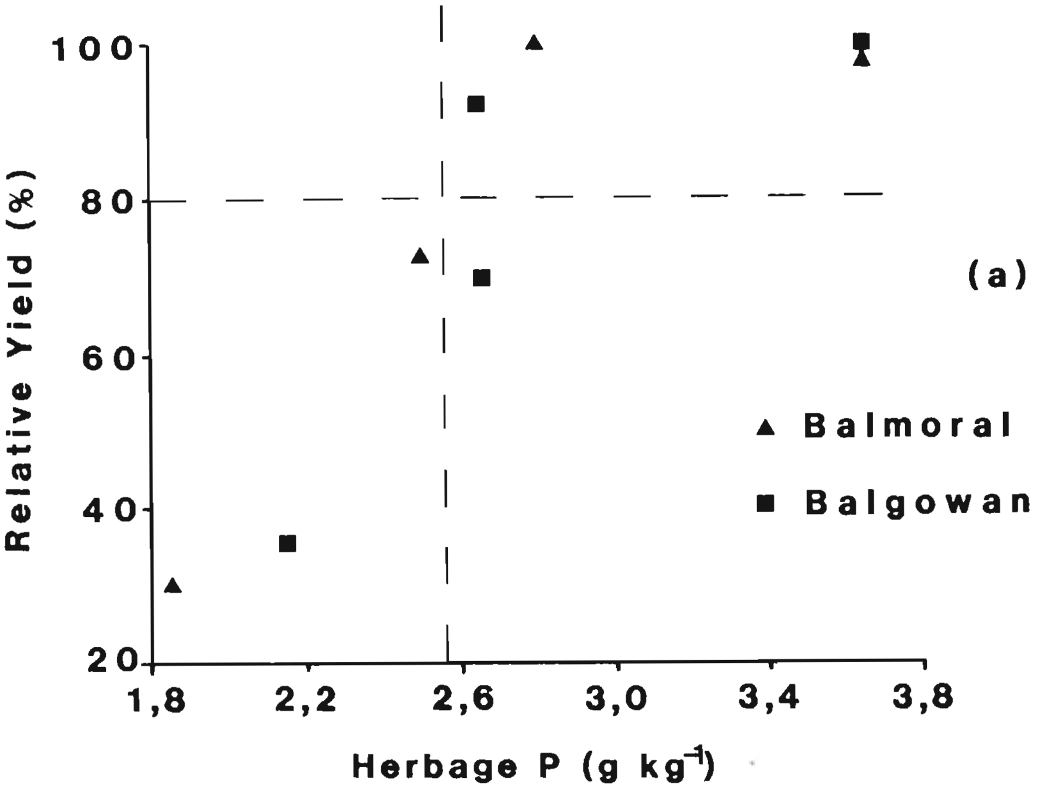
	Establishment P (kg ha^{-1})				
Soil	0	100	300	600	LSD (0,05)
	- - - - - - - - kg D.M. ha^{-1} - - - - - - - - - - - - - - - -				
Balmoral	16319	20888	27498	31141	3006
Balgowan	17014	25397	28766	31377	2151

soils to exhibit a definite levelling-off (limited resources did not permit chemical analysis of herbage from the Griffin soil). A yield plateau was, however, evident in selected mid-and late-summer harvests of the second season on these soils, and percentage yield-P concentration relationships are presented in Fig. 4.5. In mid-January, a critical P concentration in the vicinity of 2,6 g kg^{-1} was indicated and in late March a somewhat lower value of approximately 2,2 g kg^{-1}. For the determination of a critical soil P test value, (NH_4HCO_3/EDTA/NH_4F), total yield data from the second seasons on the Balgowan and Griffin soils were used. The relationship presented in Fig. 4.6 suggests a P test threshold of approximately 10 mg L^{-1}.

Weeping lovegrass responses to phosphorus

The effects of P, incorporated three years previously, on the total dry matter production of weeping lovegrass over two seasons on the Mistbelt soils are presented in Table 4.5. Highly significant responses were evident on both soils, with yields almost doubling from the zero to the 600 kg P ha^{-1} level. However, greatest yield increases were found in the zero to 300 kg P ha^{-1} range. Examination of P responses over individual harvests in the first season indicated maximum responsiveness during the establishment phase of growth. This is illustrated, in the case of the Balgowan soil, by the relationships between soil P test values (at sowing) and dry matter production at the first three harvests (Fig. 4.7). The fitted curves were based on the Mitscherlich equation, with the vertical arrows indicating 90% of maximum yield as predicted by the equations. Clearly, a very much greater P requirement is indicated at the first harvest relative to subsequent harvests.

Yield-herbage P content and yield-soil P test relationships are presented in Figs 4.8 and 4.9, respectively. A critical herbage P content



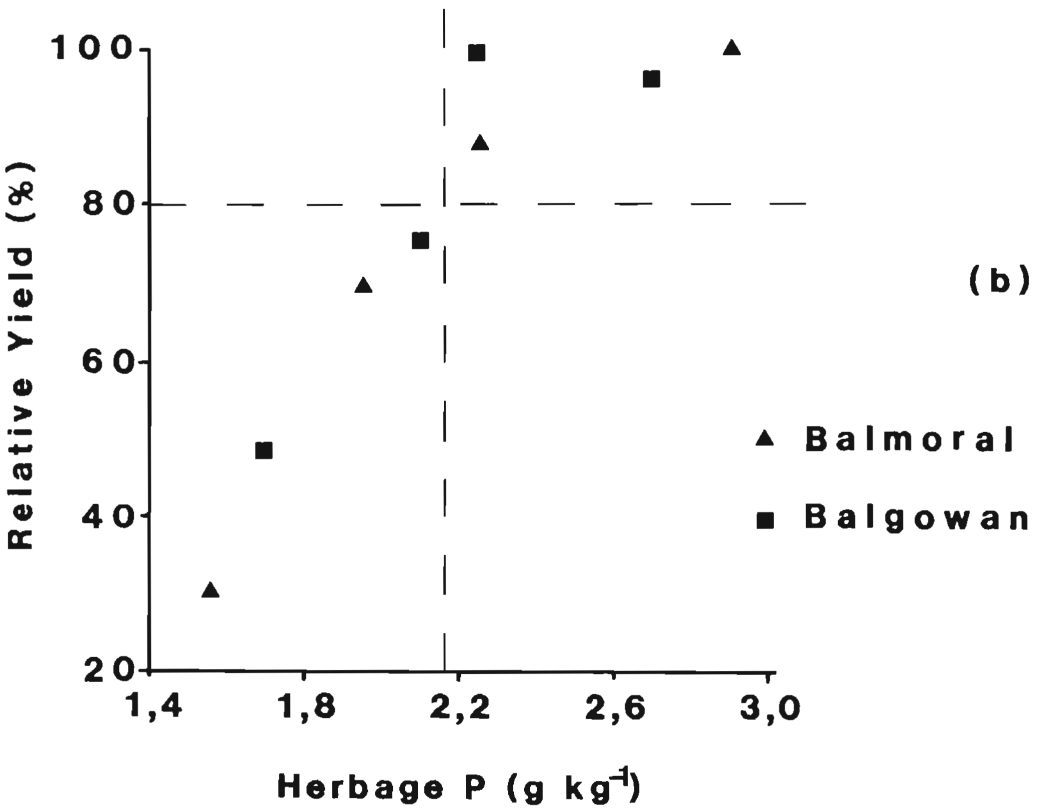


Fig 4.5. Variation on two soils of the percentage yield of kikuyu with with herbage P content. (a) mid-January; (b) late March.

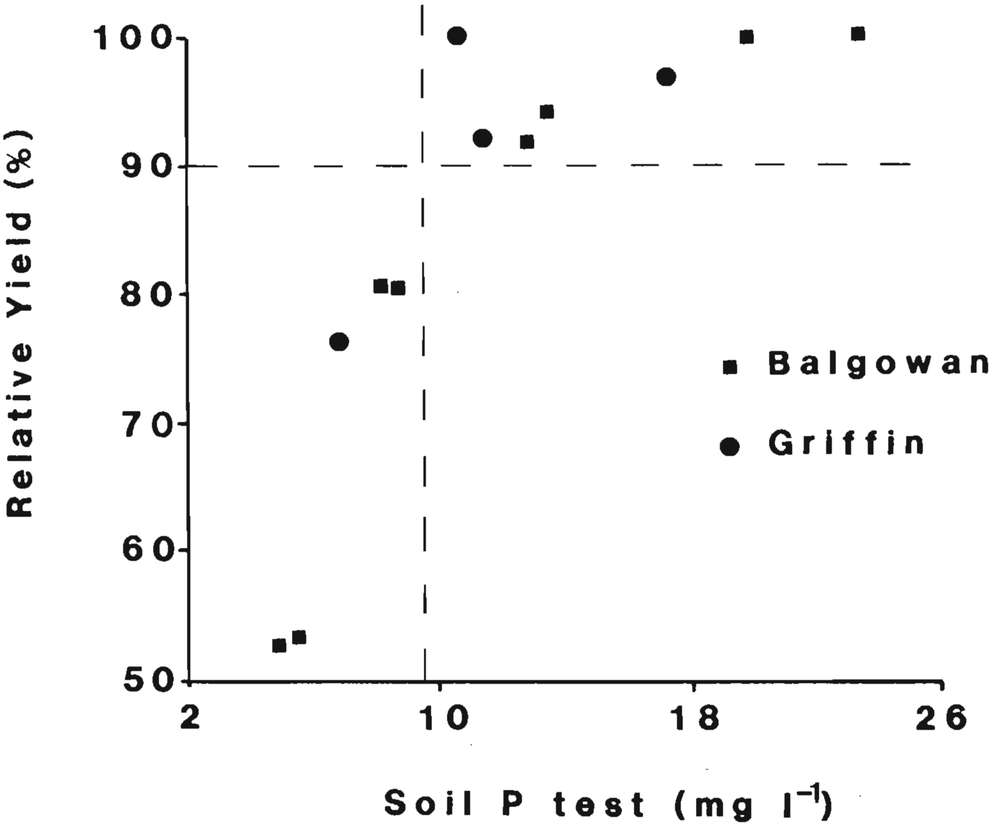


Fig. 4.6 The relationship between soil P test ($NH_4HCO_3/EDTA/NH_4F$) and the percentage yields of kikuyu in the second seasons of production on two soils.

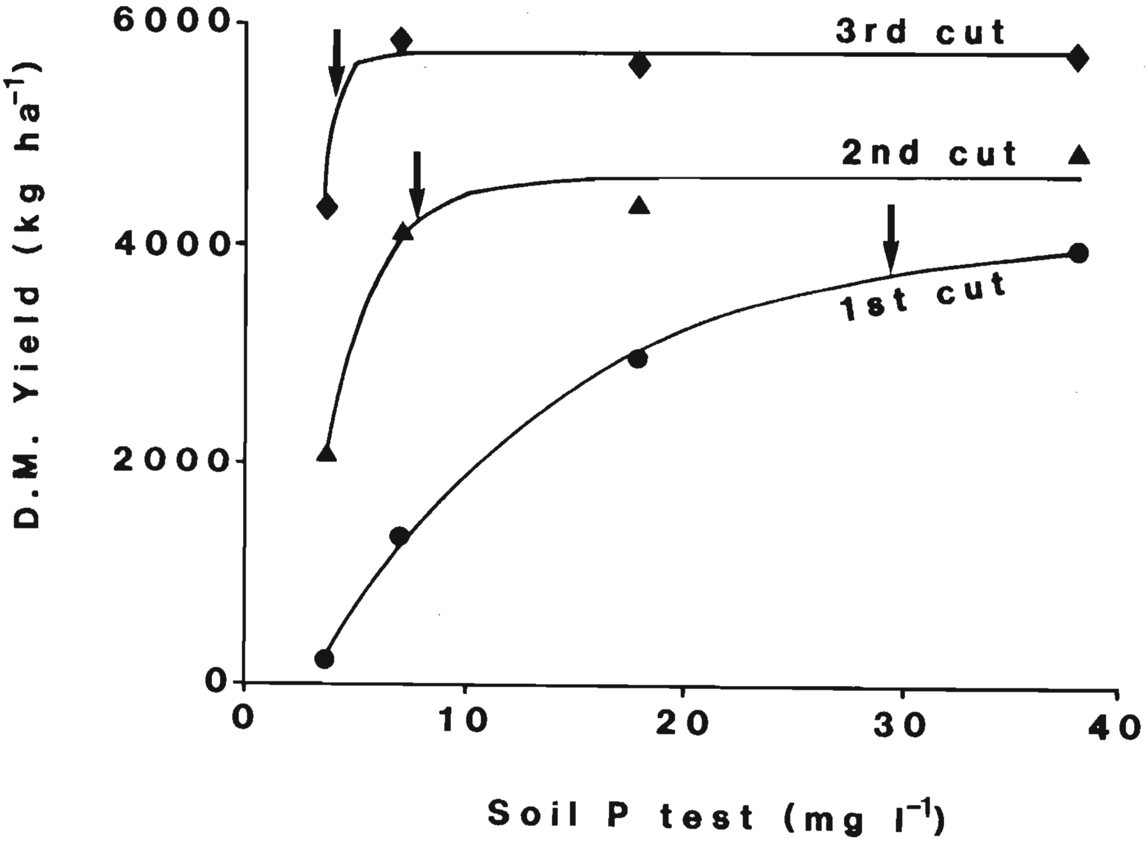


Fig. 4.7 Variation with soil P test ($NH_4HCO_3/EDTA/NH_4F$) of the dry matter production of weeping lovegrass in the first three harvests following establishment

of 1,5 g kg^{-1} is suggested. The relationship between soil P test values and yield is particularly well defined, with a threshold value of 10 mg L^{-1} being indicated.

DISCUSSION

The relative P responses on the soils studied are consistent with the measured differences in P sorption (Fig. 4.1) as well as with the variations in initially extractable P (Table 4.1) in these soils. On comparison of overall responses to P (Table 4.2 and 4.5) it is apparent that kikuyu was the more responsive of the two grasses; thus, at zero P on the Mistbelt soils, kikuyu produced 30% and lovegrass between 50% and 60% of their respective maximum yields. However, these differences in P responsiveness could conceivably be due to more favourable rainfall in the years of experimentation with lovegrass (annual rainfall data for kikuyu: 682mm, 475mm, 563mm and 820mm; for lovegrass: 820mm and 750mm). A reduction in P uptake in response to water deficits is widely reported (Olsen et al., 1961; Gates, 1974; Andrew & Jones, 1978), and field studies have shown that the amount of P required for maximum yield increases with increasing moisture stress (Matocha et al., 1970; Vig & Singh, 1983). The higher average rainfall in the case of lovegrass also, no doubt, accounts to a large extent for the superior yields of that grass relative to kikuyu.

The highly significant N - P interactions on the virgin Mistbelt soils are of particular relevance to grass pastures in Natal where annual N rates usually range from 200 to 500 kg N ha^{-1}, depending on moisture availability and desired production. Clearly, on soils initially deficient in P, an increasing P requirement with increasing N rate is indicated for optimal response to applied N.

Data presented here indicate that the steepest response to P fertilizer occurs at pasture establishment; furthermore, in established kikuyu

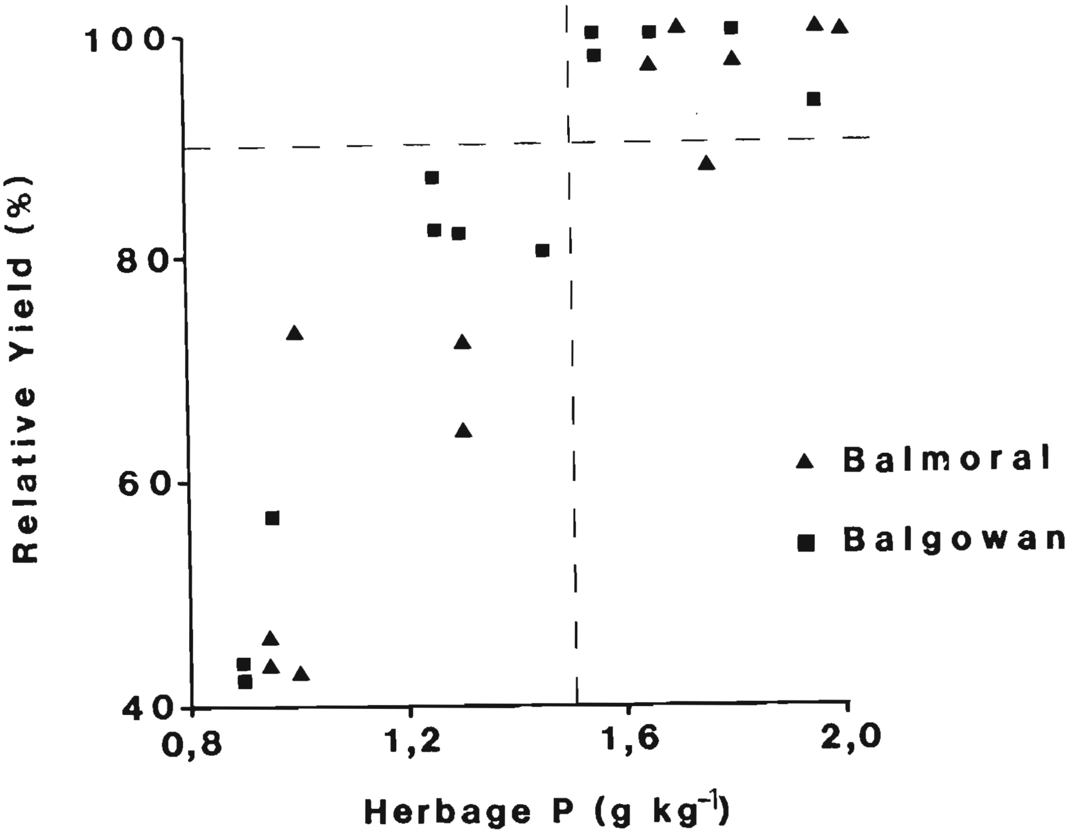


Fig 4.8 Variation in the percentage dry matter yield of weeping lovegrass with P content in the herbage (data over all lime levels).

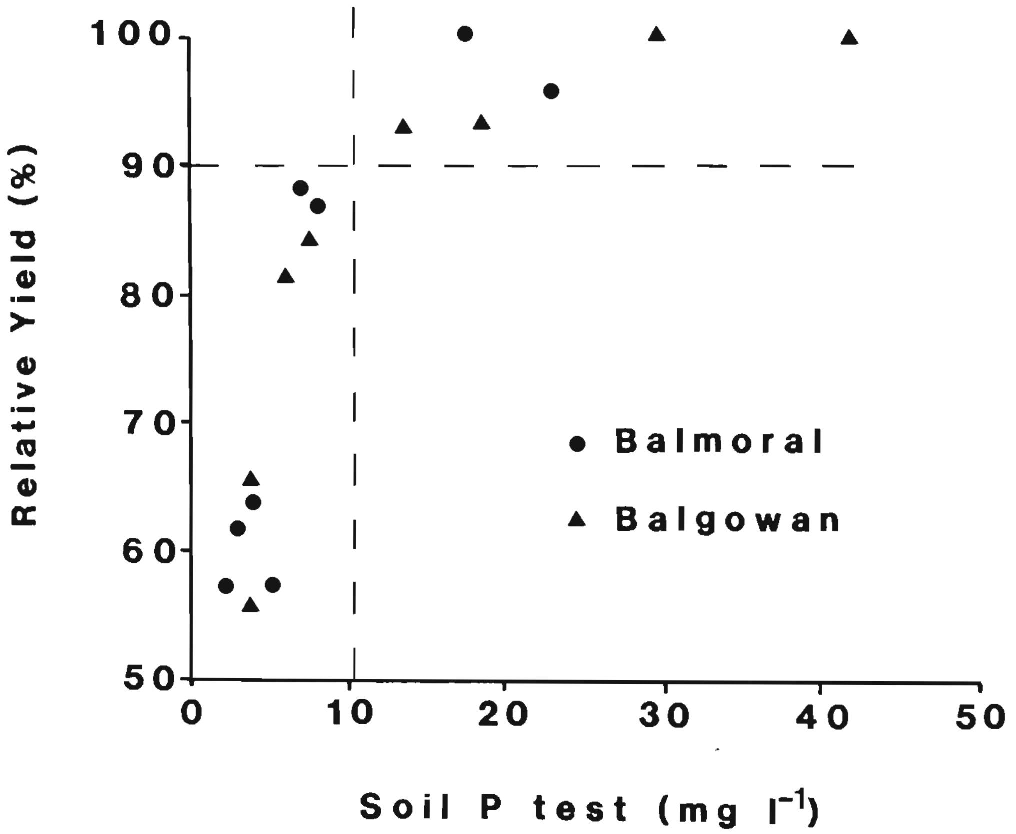


Fig 4.9 The relationship between soil P test (NH_4HCO_3/EDTA/NH_4F) and the percentage yields of weeping lovegrass in second seasons of production on two

pastures, a seasonal pattern in P response is evident, with the greatest P requirement being indicated at the start of the growing season. It is noteworthy that the dramatic effects of P fertilization on pasture establishment were evident for species propagated from both seed (lovegrass) and stolons (kikuyu). Clearly, an adequate P level at planting not only ensures rapid pasture establishment and, thus, earlier pasture utilization, but also serves to minimize weed competition. The consistent steep response to P in spring/early summer on all the sites suggests that, even under relatively high levels of P fertilization, an insufficient supply of this nutrient limits the growth of kikuyu early in the season. Nutrient content data, presented in Table 4.4, support this observation. The greater response to P early in the season by this grass was referred to in a previous publication (Paper 2), where it was shown that lime additions served to a large extent to alleviate P stress during this period. Several factors could, either singly or collectively, account for the apparent poor ability of kikuyu to utilize P early in the season. In spring, soil temperatures would presumably be relatively low, as would soil moisture content; these conditions are reported to restrict P supply to the roots (Barber, 1980). Furthermore, as noted by Beard (1973), the root systems of many grass species exhibit a seasonal periodicity of growth and death, with a major portion of root initiation occurring in early summer. Although no reports relating specifically to kikuyu were found in the literature, it appears possible that the more marked P response early in the season is due to the root system not having attained its full potential.

The relationships presented here indicate that both soil P test using the NH_4HCO_3/EDTA/NH_4F extractant as well as herbage P concentrations provide reliable estimates for the prediction of P sufficiency on a routine basis. Somewhat surprisingly, the indicated threshold soil P test values for kikuyu and lovegrass are almost identical, despite the fact that the internal P requirement of lovegrass is appreciably lower than that of kikuyu. Variations in sorption capacities (quantity/intensity) reflected by the sorption isotherms were consistent with the relative responses to P on the three soils. However, the sorption isotherms do not lend themselves to routine use due to the laboriousness of the technique and, as reported also by Sanchez and Salinas (1981), the difficulties encountered in measuring extremely low levels of P in solution. Based on the noted kikuyu responses to P in this study, for example, it would appear that the critical solution intensity for the growth of this grass is well below the 0.01mg P L^{-1} limit imposed by analytical techniques in our laboratory at present.

Appreciable differences between kikuyu and lovegrass in their internal P requirements for maximum yield were noted in these studies. These differences assume particular importance when considered in terms of animal requirements. A kikuyu P content of between 2,2 and 2,6 g kg^{-1} P proved critical, while for lovegrass, this was only 1.5 g kg^{-1}. No literature reports were found to substantiate this figure for lovegrass; however, the range of 2,2 to 2,6 g kg^{-1} for the critical P content of kikuyu is in general agreement with the values of 2,3 and 2,2 g kg^{-1} reported by Birch (1953) and Andrew and Robins (1971), respectively. Although the P requirements of different classes of animals vary considerably (Reid, 1980), the suggested minimum P content of forage for the maintenance of grazing animals is 3,0 g kg^{-1} (Baylor, 1974). Viewed in the light of this figure, it is clear that the P contents of lovegrass in particular, and kikuyu for much of the growing season (cf. Table 4.4), are well below animal requirements. That the P contents of these grasses are not commensurate with animal needs does not, however, pose a serious constraint to their use, since as observed by Sanchez and Salinas (1981) in discussing a similar problem in Latin American pastures, the extra P required by the animals may be supplemented directly via salt licks. Of greater concern than the low levels of P <u>per se</u>, however, is the tendency in kikuyu for P levels to exceed Ca levels in mid and late summer (Table 4.4) when growth is generally at a maximum. An optimum Ca: P ratio for the nutrition of dairy cows is reported to be within the range of 1.1 to 2.1, and wide aberrations from this range have been implicated in the disease of milk fever and in reproductive disturbances (Reid, 1980). The seasonal trend in the Ca: P ratio is largely ascribable to P uptake being at a maximum in mid-to-late summer; however, as observed by Miles _et al_. (1985), in practice, suppression of herbage Ca uptake by excessive K fertilization may be an important contributory factor. Using licks to compensate for unfavourable Ca: P ratios in herbage, particularly where herbage P levels are relatively high, has met with limited success locally.

PAPER 5

THE RESPONSES OF ITALIAN RYEGRASS AND WHITE CLOVER TO APPLIED PHOSPHORUS ON ACID SOILS

INTRODUCTION

Severe P deficiency presents a major obstacle in the establishment of improved pastures on acidic soils in Natal. Practical experience in the area, together with literature reports (Mays, *et al*., 1980), indicate appreciable differences between species with respect to their P requirements. In the previous paper (Paper 4), highly significant responses of the tropical grasses, weeping lovegrass and kikuyu, to P were reported. In this paper, the responses of the temperate species, Italian ryegrass and white clover, are considered. Climatically, these species are well-suited to the Mistbelt and moist phase of the Highland Sourveld of Natal. However, having evolved under less hostile overseas soil conditions, their propagation locally presents a particular challenge from a soil fertility point of view.

MATERIALS AND METHODS

Responses of Italian ryegrass (*Lolium multiflorum* cv Midmar) and white clover (*Trifolium repens* cv Ladino) to P were studied in field factorial trials on four acidic soils in the Natal Midlands and Mistbelt. Selected properties of these soils are listed in Table 5.1, while P sorption isotherms, prepared by the method of Fox and Kamprath (1970), are presented in Fig. 5.1. Particularly high sorption is indicated in the Balmoral soil.

Table 5.1 Selected properties of the soils (0-150mm) on which the P responses of Italian ryegrass and white clover were studied.

	Exchangeable cations						pH			Particle size		
Soil	Ca	Mg	K	Al+H	Mn†	P†	KCl	H_2O	Org C	Clay	Silt	Sand
	- - - cmol(+)L^{-1}				- - mg L^{-1} - -				- - - - - - g kg^{-1} - - - - - -			
Cleveland	0,62	0,25	0,07	2,85	6,1	6	4,04	4,47	28	330	120	560
Farmhill	0,76	0,57	0,35	3,40	9,9	4	3,96	4,90	49	590	220	190
Balmoral	1,35	1,25	0,30	1,62	8,7	1	4,11	4,95	48	540	290	130
Metz	3,80	1,11	0,06	0,60	4,3	8	4,39	5,15	25	370	280	350

† extracted with 0,25 M NH_4HCO_3 + 0,01 M EDTA + 0,01 M NH_4F

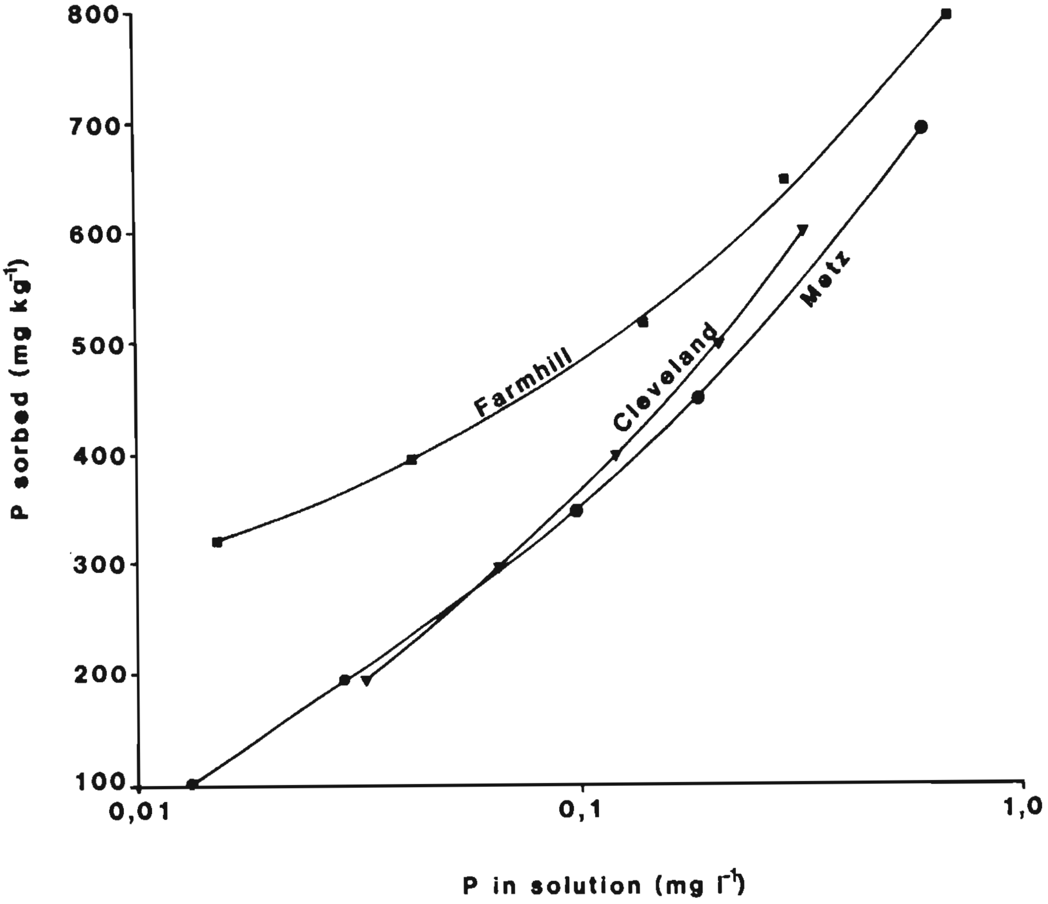


Fig. 5.1 P sorption isotherms for the soils on which P responses of temperate pasture species were studied.

According to the sorption classification categories proposed by Juo and Fox (1977), the Balmoral and Farmhill soils are 'high' (P sorbed at 0.2 mg L^{-1} between 500 and 1000 mg P kg^{-1}) P sorbing soils, and the Cleveland and Metz 'medium' (100 to 500 mg P kg^{-1}) P sorbers. With the exception of the study on the Metz soil, which is detailed below, experimental designs and methodology were outlined in previous papers (Papers 1 and 3) and will not be repeated here.

On the Metz soil, which had an unknown history of P fertilization, an unreplicated 4 X 4 X 2 factorial design was used to study the response of Italian ryegrass to P and K at two levels of N fertilization. In the first year of experimentation, levels of P were 0, 50, 100 and 150 kg ha^{-1}, with double superphosphate (19.6% P) as source. N was applied at rates of 37,5 and 75 kg ha^{-1} at establishment and after each cut, with limestone ammonium nitrate (28% N) being the source used. Rates of K and their effects are not relevant to this discussion. A basal dressing consisting of Mg, S, B, Cu, Zn and Mo at rates of 100, 133, 4, 6, 15, and 0.3 kg ha^{-1}, respectively, was applied to the experiment as a whole. Plot size was 10m X 4m (net plot 7,2m X 1,4m) with individual plots being separated in the direction of tractor movement by a 2m wide border. Fertilizers were incorporated by rotovator to a depth of 0.2m. Planting was in late February, with the seeding rate being 25 kg ha^{-1}. Rainfall was supplemented by irrigation to ensure an application of 25mm of water per week. Harvesting (70mm cutting height) was at intervals of four weeks from late April through to December. The site was ploughed in late December. In early March, 1986, uniform applications of Mg (50 kg ha^{-1}), S (66 kg ha^{-1}) and calcuim hydroxide (2000 kg ha^{-1}; this to counteract the increase in acidity over the previous year) were incorporated by rotovator. Two weeks later, P was reapplied at rates of 0, 20, 40 and 60 kg ha^{-1} and the ryegrass re-established. Irrigation and harvesting were as in the previous seasons; however, N rates were reduced, with 25 and 50 kg ha^{-1}, as limestone ammonuim nitrate being applied at establishment and after each cut. Collection of soil and herbage samples and the methods used in their analysis were as detailed in Paper 1.

The inclusion of more than one factor in individual experiments necessitates the specification of the levels of nutrient supply at which P responses were examined. In the ryegrass experiment on the Metz soil (details above), P effects are reported as a mean over N levels (a P - N interaction was not evident). In experiments having K as a factor, P effects are examined at non-limiting levels of this nutrient. The tendency for P and lime to substitute for one another (Paper 1) made it necessary to report P responses at a specific lime level. In this discussion therefore, P responses are, where possible, reported at threshold lime sufficiency levels, with these threshold lime levels being the experimental lime rates above which no significant positive response to lime was evident. Where lime-P interactions were not significant, the threshold lime levels were derived from the main effects of lime. In the case of significant interactions in which threshold lime values varied with P level, P responses are examined at the lowest lime threshold evinced in the data (lowest indicated lime sufficiency level, irrespective of P level, and with negative responses to lime not being considered).

RESULTS

Italian ryegrass

Variations in the total dry matter production of Italian ryegrass with applied P in the first seasons (April to December) of experimentation on the Cleveland and Metz soils are shown in Fig. 5.2. On the Metz soil a small, though statistically significant response to P occurred. In contrast, an enormous response was evident on the Cleveland soil, with yield at zero P

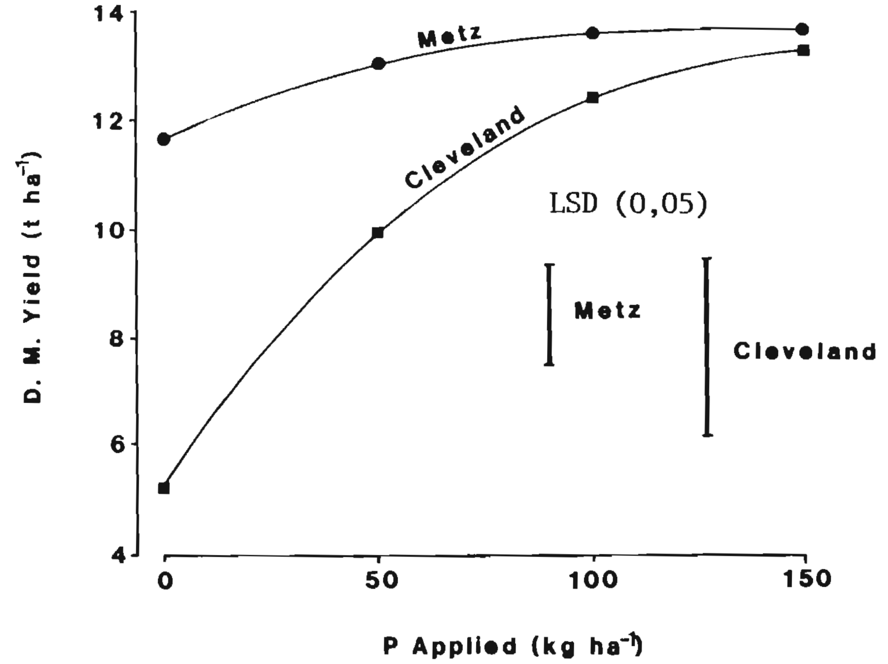


Fig. 5.2 Variations in the total dry matter production of Italian ryegrass (April to December, first season) on two soils at four P application levels.

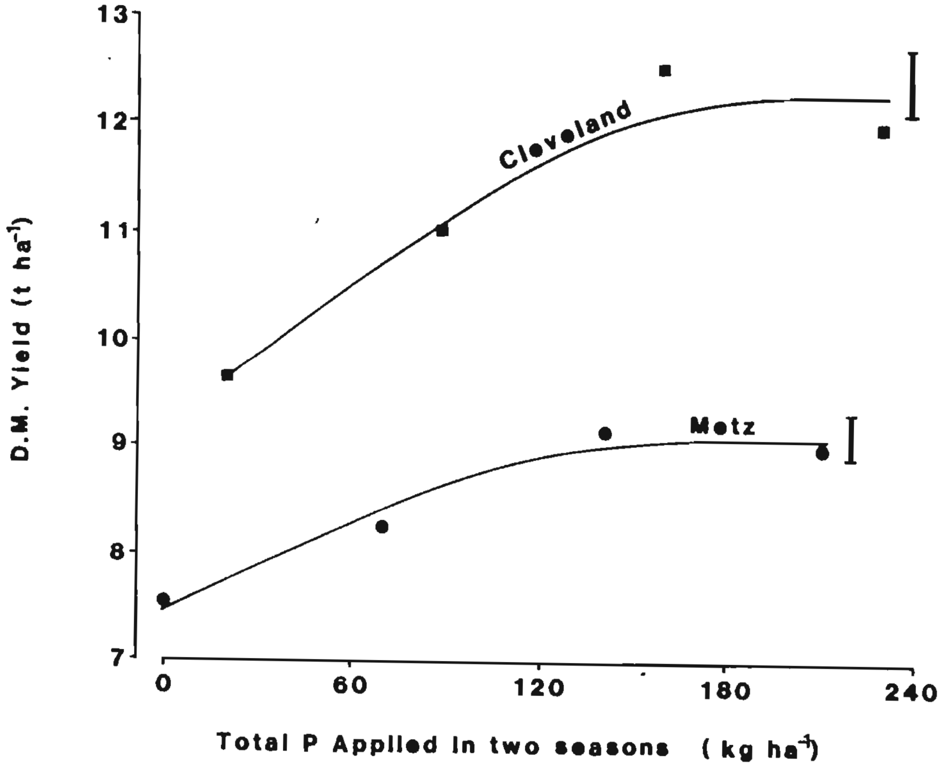


Fig 5.3 Variations in the dry matter production of Italian ryegrass with P fertilization in the second season (April to October) of experimentation on two soils (curves fitted by hand; vertical bars reflect SE of mean).

being 39% of that at the 150 kg P ha^{-1} rate. It is noteworthy that despite the vastly dissimilar responses to P in this first season of experimentation, maximum yields on the two soils were virtually identical. Second season (April to October) effects of P on dry matter yield are presented in Fig. 5.3. Significant responses were once again evident on both soils. However, with the lowest P level on the Cleveland soil being 20 kg ha^{-1}, as opposed to zero P in the previous season, the overall response on that soil was diminished, relative to the previous year. The relatively low dry matter production in the second season on the Metz soil is largely ascribable to reduced N fertilization (cf. Materials and Methods).

On both sites, responses to P were not consistent over the season, but tended to be at a maximum during the establishment phase of growth. In the case of the Metz soil, P responses were in fact significant only during the March to June period (Table 5.2). On the Cleveland soil, curves presented in Fig. 5.4, reflecting dry matter production over the season at varying P levels, illustrate the dramatic effects of P at establishment (the production curve for the 150 kg P ha^{-1} level was largely coincident with that of the 100 kg P ha^{-1} level and therefore omitted). Particularly noteworthy is the fact that at zero P essentially no dry matter was produced over the pre-July period, yet an appreciable yield was obtained over the remainder of the season with this same treatment.

The effects of P on ryegrass P content at selected harvests over the 1985 season are presented in Tables 5.3 and 5.4. On the Cleveland soil at the first harvest, when a continuous response to P occurred, herbage P content was appreciably higher than that in harvests over the remainder of the season. Similarly, on the Metz soil at the first harvest, when P response was most marked, herbage P concentrations tended to be relatively high. Examination of yield-herbage P relationships on both sites for harvests subsequent to the first harvest suggests a critical P content for

Table 5.2 Effects of applied P on the dry matter production of Italian ryegrass over three periods within the first growing season on the Metz soil.

	P rate (kg ha^{-1})				
Growth period	0	50	100	150	LSD (0,05)
	- - - - - - - - kg D.M. ha^{-1} - - - - - - - - - -				
March - June	3495	4781	4929	5086	714
June - September	4266	4645	4631	4508	576
Sept - December	3895	3867	3919	3893	390

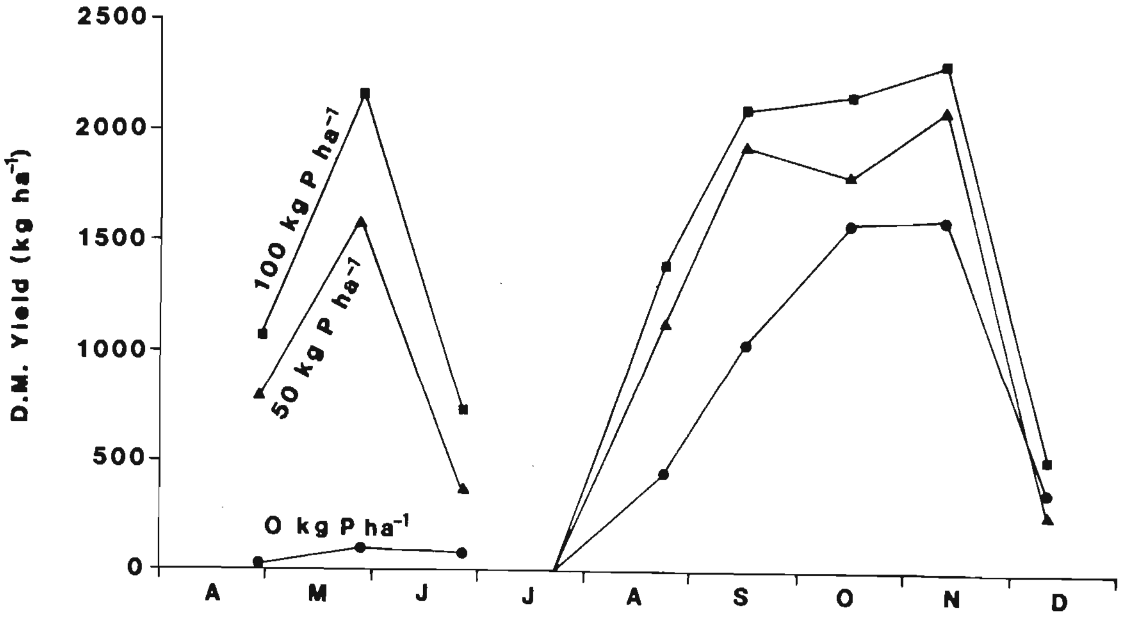


Fig. 5.4 Seasonal variation in the dry matter production of Italian ryegrass on the Cleveland soil at three levels of P fertilization (the discontinuity of the curves over the June-July period is due to zero yield being recorded, at all P levels, at the July harvest).

Table 5.3 Variation over the season and with applied P, of Italian ryegrass dry matter yield and P content on the Cleveland soil (means over two K treatments and four lime treatments).

	APRIL*		MAY		JUNE		AUGUST		SEPTEMBER		OCTOBER	
P rate	Yield	P	Yield	P	Yield	P	Yield	P	Yield	P	Yield	P
kg ha^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
0	0	-†	37	-	30	1,5	221	1,2	733	1,3	1198	1,6
50	951	2,6	1660	2,0	546	2,1	1222	1,7	1936	1,4	2194	2,3
100	1218	3,4	1834	2,7	667	2,7	1598	2,0	2084	1,6	2157	2,5
150	1679	3,8	1864	3,1	616	3,0	1978	2,6	2377	2,3	2173	2,7
LSD (0,05)	249	0,4	213	0,3	150	0,4	373	0,2	347	0,2	452	0,4

* first harvest after establishment

† insufficient herbage for analysis

Table 5.4 Variation over the season, of Italian ryegrass dry matter yield and P content with applied P on the Metz soil (means over two N and two K treatments)

	APRIL*		MAY		JUNE		JULY		AUGUST		NOVEMBER	
P rate	Yield	P	Yield	P	Yield	P	Yield	P	Yield	P	Yield	P
kg ha^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
0	545	2,2	1683	2,1	1120	2,2	1082	2,0	1264	2,3	1480	2,5
50	1406	2,6	2164	2,1	1194	2,3	1114	2,3	1418	2,5	1604	2,5
100	1690	2,7	1857	2,3	1300	2,6	1322	2,5	1389	2,6	1513	2,6
150	1898	2,6	1877	2,3	1361	2,6	1326	2,5	1436	2,8	1560	2,8
LSD(0,05)	637	0,4	412	0,3	182	0,5	161	0,2	242	0,5	324	0,3

* first harvest after establishment

ryegrass within the range 2.0 to 2.3 g kg $^{-1}$.

Percentage ryegrass dry matter production in the autumn periods on both soils was related to P extractable with NH_4HCO_3/EDTA/NH_4F, with an optimum P test value of approximately 14 mg L $^{-1}$ being suggested by a Cate-Nelson separation (Fig. 5.5).

White clover

The influence of applied P on the dry matter production of white clover over three seasons on the Farmhill and Balmoral soils is presented in Table 5.5. The low yields obtained in these experiments are largely ascribable to the drought which prevailed at the time (rainfall for 1979/80, 1980/81 and 1981/82 was 541mm, 625mm and 780mm respectively, with the long-term annual average being 885mm). However, despite this limitation, highly significant yield responses to P were evident on both soils in all three seasons. In the first season, no suggestion of a levelling-off in response to P was evident; however, with P topdressings being applied at the end of that season, indications are that P sufficiency was approached on the Farmhill soil in subsequent seasons, though this was not clearly the case on the Balmoral soil.

Attempts to relate percentage clover yields for the second and third seasons on the Farmhill and Balmoral soils with soil P test values revealed that data for the two seasons followed separate curves (Fig. 5.6). In the 1980/81 season, a steep response was indicated, with there being no indication of a response threshold. In the 1981/82 season, however, percentage yields were appreciably higher at low soil test values than in the previous year, and a suggestion of a threshold P test value of 10-11 mg L $^{-1}$ is contained in the data.

The effects of applied P on white clover dry matter production on the Cleveland soil are presented in Table 5.6 (clover experimentation on this

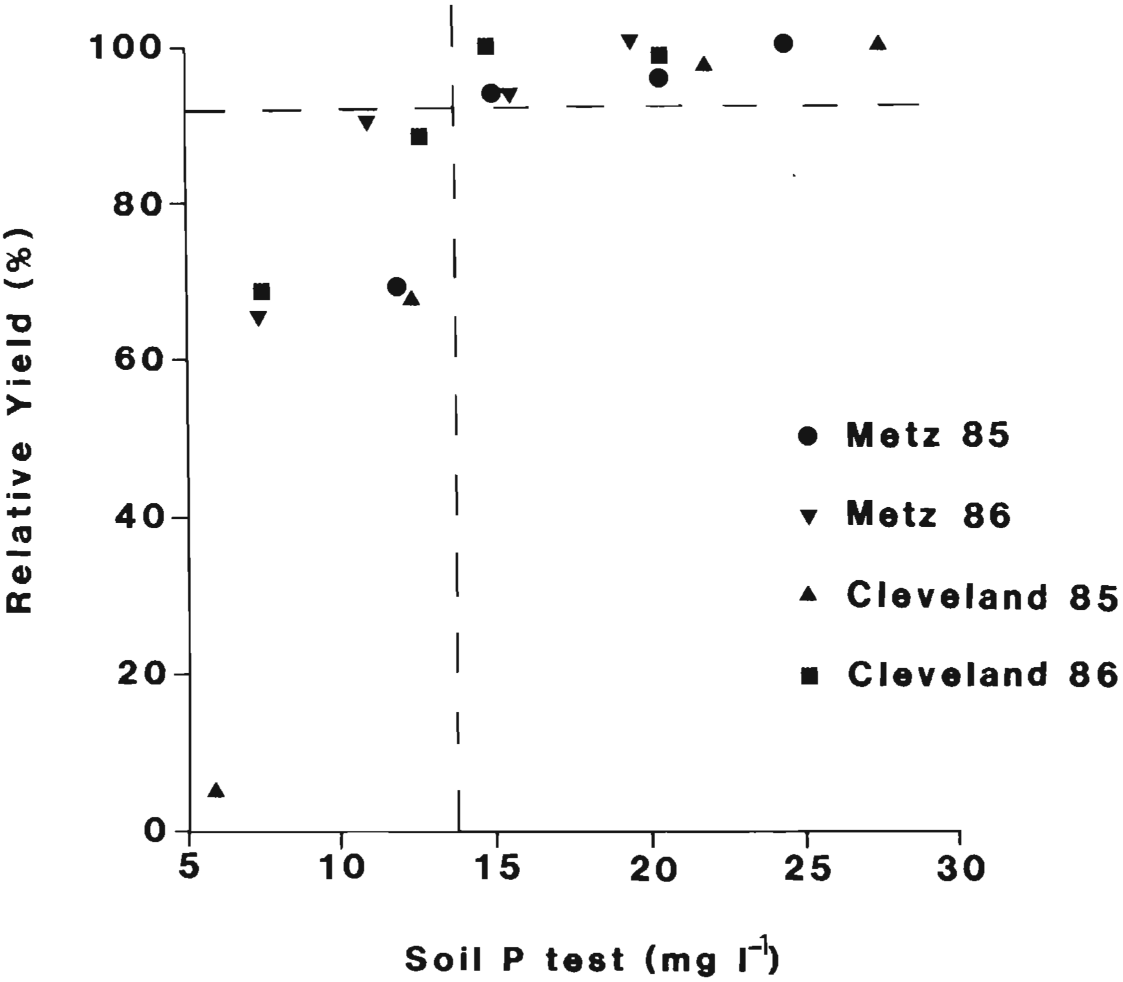


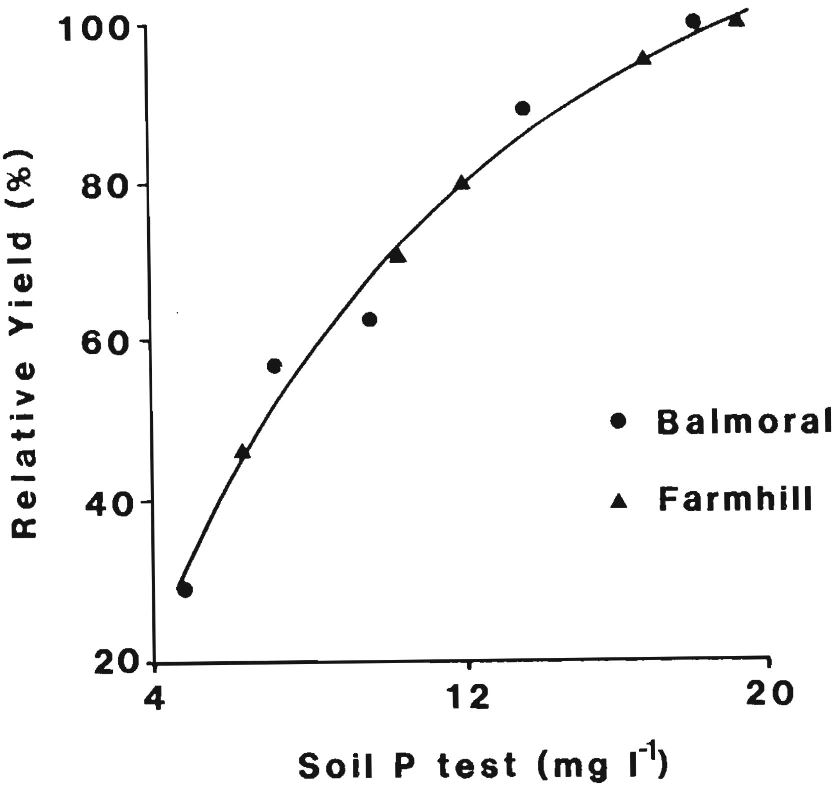
Fig. 5.5 The relationship between soil P test (NH_4HCO_3/EDTA/NH_4F) and the percentage yield in autumn (March-June) of Italian ryegrass over two seasons on the Cleveland and Metz soils.

Table 5.5 The influence of P applications on the dry matter production of white clover on two soils over three seasons (data meaned over all lime levels).

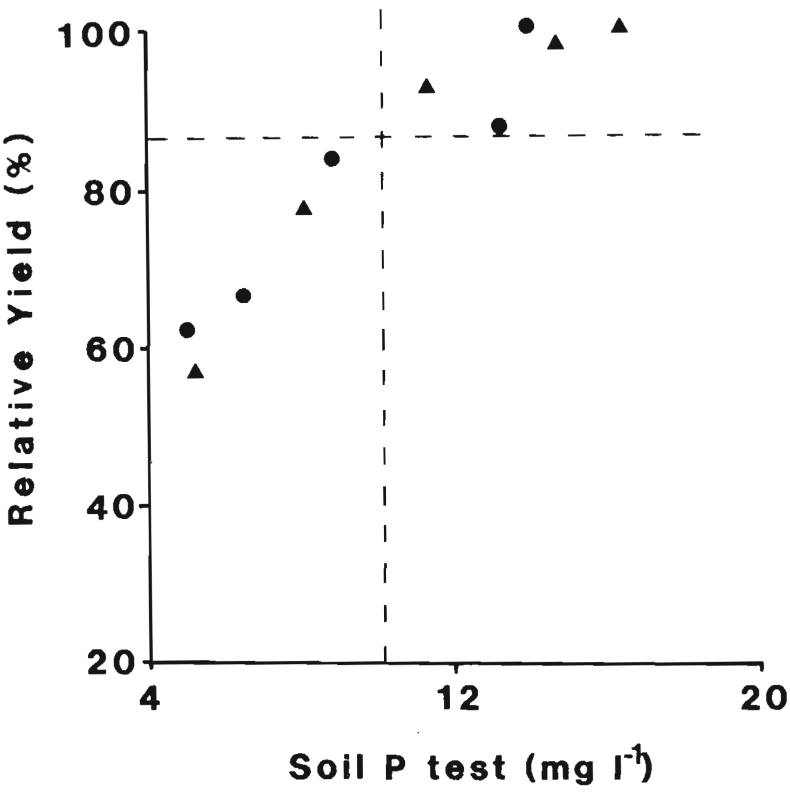
FARMHILL					BALMORAL				
P rate*	1979/80	P rate†	1980/81	1981/82	P rate*	1979/80	P rate†	1980/81	1981/82
kg ha^{-1}	kg D.M. ha^{-1}	kg ha^{-1}	-- kg D.M.	ha^{-1} --	kg ha^{-1}	kg D.M. ha^{-1}	kg ha^{-1}	-- kg D.M.	ha^{-1} --
40	1008	86	1014	1387	40	1454	99	669	2179
80	2095	164	1547	1877	80	2527	193	1324	2327
120	1965	242	1754	2225	120	2723	277	1455	2914
160	2671	306	2097	2359	160	3379	358	2054	3051
200	3110	373	2198	2413	200	4362	434	2307	3484
LSD 0,05	678		317	331	LSD (0,05)	779		284	520

* P applied at establishment

† Total of P applied at establishment and that applied as topdressings at the end of the 1979/80 season.



(a) 1980/81



(b) 1981/82

Fig. 5.6 The relationships between the percentage clover yields on two soils and soil P test values ($NH_4HCO_3/EDTA/NH_4F$) for (a) the 1980/81 season (equation for fitted curve: $Y = 116 - 150e^{-0,119x}$,) and (b), the 1981/82 season soil was for a single season only - cf Paper 1). A highly significant yield response accompanied the application of 100 kg P ha^{-1} to this soil; however, further P additions had no significant effect on yields. Examination of P effects over the October to January and January to May periods reveals that the response to P was confined largely to the former period.

Presented in Table 5.7 are the yields and P contents of clover at a number of the harvests taken on the Cleveland soil. Herbage P concentrations were at a minimum in November. Disturbingly, in most harvests where a yield response to P was evident, little or no change in plant P status was apparent.

DISCUSSION

The large amounts of fertilizer P required for maximum growth on most sites are evidence of the severity of the P problem on these acidic soils. Correction of P deficiencies undoubtedly poses a major obstacle to the replacement of low potential natural grassland with improved pasture. The problem is most severe in the Mistbelt (represented here by the Balmoral and Farmhill soils), where the natural grassland is unacceptable to animals for most of the year and the P requirement for pasture growth on virgin soils is extremely large.

The relative responses of white clover to P (Tables 5.5 and 5.6) on the Balmoral, Farmhill and Cleveland soils were consistent with the variations in P sorption (Fig. 5.1) and in initially extractable P (Table 5.1) on these soils. Thus clover P requirement on the Balmoral soil, which had the lowest extractable P and the highest P sorption, was appreciably greater than that on the remaining two soils. In the case of Italian ryegrass on the Cleveland and Metz soils, however, the virtually identical sorption characteristics of these soils were not consistent with yield responses to

Table 5.6 The effects of P applied to the Cleveland soil, on the total (seasonal) dry matter production of white clover and on dry matter production over specific periods within the growing season.

	P rate (kg ha^{-1})				
	0	100	200	300	LSD (0,05)
	- - - - - kg D.M. ha^{-1} - - - - -				
Total	5636	9946	9336	9211	1283
October - January	3170	6492	5969	5548	1439
January - May	3131	3587	3132	3533	- †

† L.S.D. not determinable

Table 5.7 Seasonal variation with applied P of white clover yield and P content on the Cleveland soil (data means over four lime levels and two K levels).

	NOVEMBER		DECEMBER		JANUARY		FEBRUARY		APRIL	
P rate	Yield	P	Yield	P	Yield	P	Yield	P	Yield	P
kg ha^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
0	150	1,6	1144	3,2	1471	3,1	927	2,6	1481	3,2
100	950	2,0	2274	3,1	1861	3,2	908	3,1	1806	3,2
200	1061	2,3	2505	3,2	2075	3,2	788	3,4	1739	3,2
300	962	2,5	2438	3,1	2111	3,2	896	3,4	2005	3,2
LSD(0,05)	513	0,5	474	0,2	184	0,2	106	0,1	291	0,1

P, which were far greater on the Cleveland soil. Initially extractable P was somewhat lower on the Cleveland than on the Metz soil (6 vs 8 mg L^{-1}), however, and extractable P proved a satisfactory index of P sufficiency for ryegrass over the autumn period (Fig. 5.5). Although a strong case for the use of sorption isotherms for predicting plant P requirement has been put forward by Fox and his associates (Fox, 1978; Vander Zaag et al., 1979; Fox, 1980), data presented here thus appear to indicate a lack of sensitivity on the part of the isotherms to variations in field P requirement of up to 50 kg P ha^{-1} or possibly even more. Unpublished work by this author using samples from field maize trials also points to an insensitivity on the part of the isotherms to identify small though highly significant (in terms of grain yield) variations in P requirement. A further problem with the isotherms is that, as observed in the case of tropical grasses (Paper 4), upon expression of noted field P requirements in terms of the amounts of P sorbed (vertical axis, Fig. 5.1), optimum solution intensities for the growth of these grasses of well below 0.01 mg P L^{-1} are indicated. Measurement of such low levels of P using laboratory equipment designed for routine work is a formidable task.

Differences in the relationship between clover yields and soil P test in the 1980/81 and 81/82 seasons on the Farmhill and Balmoral soils are possibly due to markedly lower rainfall in the former season relative to the latter (625mm vs 780mm, respectively). Moisture supply is reported to have a pronounced effect on P uptake (Andrew & Jones, 1978), and data from field studies indicating increases in P requirement with increasing moisture stress have been presented by Matocha et al. (1970) and Vig and Singh (1983). In the clover studies on the Balmoral and Farmhill soils, rainfall patterns would be expected to have a particularly marked effect on P availability for two reasons. In the first place, a large proportion of the P was applied in the form of topdressings, and as indicated by soil extraction (data not shown), remained at the immediate soil surface in these high clay content soils. Furthermore, white clover is reported to have 80% of its total root activity in the top 25mm of soil (Jackman & Mouat, 1972). For these reasons, drying out of the surface soil would be expected to greatly influence P supply to the clover, and could contribute towards a higher P requirement in years of lower rainfall.

As was the case with the tropical species considered in the previous paper (Paper 4), response to P was at a maximum during the establishment phase of the pastures studied here. The importance of an adequate P supply during the early stages of plant growth has been noted elsewhere (Baylor, 1974; Rhykerd & Overdahl 1972; Mays et al., 1980). Fox et al. (1974) measured field responses of the forage legume, Desmodium aparines, on a Hydrandept and found that whereas 0.2 mg L^{-1} P in solution was required for establishment, 0.01 mg L^{-1} was adequate for regrowth after the first harvest. In the present study, the ryegrass yield data (Fig. 5.2 and Fig. 5.4) provide particularly clear evidence of the greater P requirement at establishment. Little justification may be derived from these data for the practice, now favoured by a number of advisers, of providing P in several split dressings over the season rather than as a single dressing at establishment. With high quality green forage availability proving a taxing problem on most farms during the autumn and mid-winter periods, the benefits to be derived from high P inputs at establishment in late summer should be exploited.

Interestingly, not only was the response of ryegrass to applied P at a maximum at establishment, but data presented in Table 5.3 and 5.4 indicate that the internal (plant) P requirement of this grass was appreciably higher in the first harvest relative to subsequent harvests. Similar results have been reported by Plucknett and Fox (1965). These workers grew Desmodium intortum and Digitaria decumbens on a Gibbsihumox and found that although a large yield response to P was apparent at the first harvest, little or no evidence of response occurred at subsequent harvests, despite the P content of leaf tissues decreasing with each successive cutting.

The absence of a definite relationship between yield and P content of white clover is disturbing, more especially since such relationships have been noted elsewhere, with critical P contents of 2.3 g kg^{-1} (Andrew, 1960) and 2.8 to 3.0 g kg^{-1} (Rayment & Bruce, 1979) being reported. In the present study, macro and micro nutrients analysed for appeared, on the basis of published nutrient requirements of white clover (Andrew, 1960; McNaught, 1970) to be in adequate supply; this included Ca and Mg, which generally increased in concentration in the plant with increasing fertilizer P level. It would thus seem unlikely that some nutrient other than P was implicated in the noted P responses. Interestingly, in a glasshouse study, Rangeley and Newbould (1982) found no relationship between the percentage P content of white clover and yield; however, the P extracted from the dried herbage with 2% acetic acid was closely related to yield. Of note too, is the report of White and Haydock (1970), based on the field responses of the legume siratro (Phaseolus atropurpureus) to P. These workers found that the P concentration in siratro was poorly correlated with responsiveness to P, with critical values ranging from 1.6 to 2.9 g kg^{-1} being indicated. This variation in critical value was found to be significantly related to variations in rainfall in the 28 days prior to sampling. The aspects raised by the above studies warrant further consideration in the local pasture research programme. Furthermore, both the white clover and ryegrass herbage data reported here suggest limitations in the use of herbage data for assessing P sufficiency, particularly where sufficiency is gauged in terms of a 'universal' critical value.

SYNTHESIS AND SUMMARY

Data presented here emphasize the important role of lime and P as determinants of pasture productivity on acid, well drained soils of the Midlands and Mistbelt of Natal. A multiplicity of factors, including species choice, age of pasture, time of the season, rainfall patterns and soil properties were found to be implicated in responses to these amendments. These numerous factors, together with the tendency for lime and P to substitute for one another in their effects on plant growth, render the evaluation of lime and P responses an exacting task.

Meaningful (in terms of yield) interactions between lime and P are reported in this thesis. Two types of interaction, positive and negative, were noted, with positive interactions being restricted to situations of extreme P deficiency and the negative interactions occurring where P was in more favourable supply. Numerous literature reports have emphasized the complex interplay between phytotoxic Al and P in the soil and within the plant root. In the light of these reports it is convenient to attribute lime-P interactions, in the case of the Al-sensitive species, to Al effects on P uptake and root proliferation. However, that such interactions were particularly well developed in the case of the highly Al-tolerant tropical grasses presents a strong, albeit not conclusive case, for lime having a beneficial effect on P availability <u>per se</u>.

Lime-P interactions noted here are of considerable practical significance. This is in sharp contrast with findings in temperate overseas countries, where lime-P interactions are generally poorly developed or non-existent. The results reported here indicate that, particularly in the case of temperate species, major savings in P fertilizer may be effected by applying lime rates commensurate with the elimination of the bulk of exchangeable Al. This finding is of particular significance when viewed in the light of the high P fixation in these soils. That liming to neur-neutral pH values reduces yield and increases P requirement underlines the dangers of indiscriminate liming practices.

Differences between the temperate and tropical species, in particular with regard to their tolerance of soil acidity, but also in their requirements for fertilizer P, became evident in this study. The tropicals, kikuyu and weeping lovegrass, were able to produce near-maximum yields at soil acid saturation values in excess of 50%. Yields of Italian ryegrass and white clover, on the other hand, declined sharply with increases in acid saturation above 15% In the case of P, a comparison of responses on the Mistbelt soils reveals that at low levels of P supply, kikuyu and lovegrass performed markedly better than white clover (a comparison of P requirement of the tropical grasses and ryegrass is precluded by the fact that these species were not grown on the same soils). Variations between species in their respective lime and P requirements indicate that in pasture establishment programmes, species choice has an important bearing on lime and P costs. Thus pasture introduction on acid, infertile sites using the tropical species studied here would require appreciably lower capital investment than would be the case with the temperates. The use of plants adapted to soil constraints, a practice of major significance to the 'agricultural revolution' in Central and South America over the past two decades (see Sanchez & Salinas, 1981), would appear to be a principle that should be exploited in pasture intensification programmes in this country.

Noteworthy findings in these studies were the marked variations in response to P, and to a lesser extent, lime, with pasture age and time of the season. The dramatic responses to P in newly planted pastures indicate quite clearly that a favourable supply of this nutrient is a prerequisite for successful pasture establishment and early utilization. In addition, the more marked responses to lime at establishment indicate a greater susceptibility to soil acidity during this growth phase. In the case of kikuyu, convincing evidence for P deficiency limiting spring/early summer growth on high P fixing soils is presented; indications of lime alleviating P stress at that time are particularly fascinating. The identification of periods of maximum P responsiveness in the life of pastures is of value in the practical planning of fertilization programmes. In the case of annuals, such as Italian ryegrass, where the response to P diminishes sharply over the season, maximum benefits are quite clearly to be realized by the application of total pasture P needs at establishment. Likewise, with the perennials, the bulk of the pasture P requirement would appear to be most profitably applied at establishment; however, here a case for strategic P dressings in spring on established pastures is suggested, with this being an aspect in need of further study.

The development of relationships for predicting responsiveness to lime and P on soils having similar properties to those on which these trials were located represents possibly the most important aspect of these investigations. Soil extractable (NH_4HCO_3/EDTA/NH_4F) P and acid saturation emerged as useful indexes of lime and P requirement. The close relationships between extractable P and yield, particularly where more than one soil type was represented in such relationships, were particularly encouraging. Sorption isotherms proved an insensitive measure of P requirement; this insensitivity, together with high analytical demands, detracts from their use for routine advisory purposes. Herbage analyses would appear, on the basis of a steady increase in samples submitted to local laboratories, to be gaining in popularity as a method of assessing nutrient sufficiency. Sound relationships between the concentration of a given nutrient in the plant and yield do under many circumstances undoubtedly exist; data presented here indicate, however, that appreciable variations may occur in critical P content, with pasture age and time of the growing season appearing to be the most important factors implicated. The need for caution in the interpretation of plant analytical data is thus emphasized.

In a general appraisal of land use in the Highlands and Midland Mistbelt of Natal, van der Eck _et_ _al_. (1969) concluded, ".... this zone is pre-eminently suited to intensive agricultural utilization. Large - scale production of grains, fodder and pasturage for dairying, fattening of beef cattle and production of small stock is the indicated direction for future intensification. The economics of intensification will, however, remain somewhat uncertain until research has provided a firmer foundation than that which presently exists for assessing fertility status, making accurate fertilizer recommendations, ameliorating soil acidity, and preventing further acidification of soils under cultivation". The investigations reported in this thesis have hopefully contributed in some way to the "firmer foundation" referred to above.

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