NUTRITIONAL RELATIONSHIPS BETWEEN PAMPAS GRASS (*CORTADERIA* SPP.) AND *PINUS RADIATA*

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ABSTRACT

Historical use of fertiliser to encourage the productivity of pampas grass (*Cortaderia selloana* (Schult.) Asch. et Graeb. and *C. jubata* (Lem.) Stapf) in agriculture suggested that growth of this aggressive forest weed may be encouraged by fertiliser treatment of *Pinus radiata* D.Don. In glasshouse trials, pampas showed a positive growth response to (a) ammonium nitrate added to a coastal sand, and (b) sodium dihydrogen phosphate added to a silty clay loam soil. Response (b) was increased when ammonium nitrate was also present. These results were consistent with field observations of increased pampas frequency associated with superphosphate treatment of *P. radiata* on a clay soil, and with reduced tree growth response to calcium ammonium nitrate treatment on a coastal sand. A glasshouse trial showed that pampas residues resulting from herbicide treatment can have a negative effect on *P. radiata* productivity. Field evidence suggested that fertiliser nitrogen immobilised by decomposing pampas residues was released gradually and utilised by the trees up to 4 years after treatment. Where pampas growth is uncontrolled, a large proportion of the fertiliser intended to promote *P. radiata* growth may never reach the trees.

Keywords: nitrogen; phosphorus; sand; clay; decomposition; *Cortaderia selloana*; *Cortaderia jubata*; *Pinus radiata*.

INTRODUCTION

A preliminary investigation of the weed problem caused by introduced pampas grass in New Zealand exotic forests (Gadgil *et al.* 1984) showed that knowledge about the biology of these species is limited. Although it is generally accepted that survival of recently planted trees and growth rates in established forest stands are reduced by pampas infestation (Dale & Todd 1988; West *et al.* 1988), the exact nature of the competitive advantage is unknown. Physical interference is almost certain from plants which can produce tussocks over 2 m in height and more than 1 m in diameter at the base. Gadgil *et al.* (1984) presented no factual evidence for their suggestion that pampas has the ability to compete with trees for moisture and nutrients. They stated that soil fertility does not appear to limit colonisation of areas disturbed by logging, land clearing, and road construction.

Little information exists about the response of pampas to fertiliser treatment. Aston & Grimmett (1936) stated that pampas does not require fertiliser, but their experience with the plant as a source of alternative stock fodder may have been limited to particularly fertile soils. Jacques (1955) provided clear evidence of increased growth rates resulting from application of sulphate of ammonia and, to a lesser extent, superphosphate. His trial was conducted on an agricultural soil of low fertility.

Extensive areas of *Pinus radiata* forest in New Zealand have been established on coastal sand dunes and on eroded clay soils. Tree growth on sand dunes is limited by nitrogen (N) availability, but fixation of atmospheric nitrogen by perennial tree lupin (*Lupinus arboreus* Sims), grown from seed sown during the initial sand stabilisation procedure, has provided a supply of this element (Mead & Gadgil 1978). Phosphorus (P) availability, and to a smaller extent nitrogen availability, limit *P. radiata* growth on eroded clays. Routine fertiliser applications are made on these soils to promote satisfactory tree growth (Ballard 1978; Mead & Gadgil 1978). Large areas of forest on both soil types are heavily infested with pampas grass and it is important that the capacity of this aggressive weed to divert nutrients from the soil-tree pathway should be understood. We report here the results of glasshouse and field studies investigating firstly the response of pampas to added nitrogen and/or phosphorus, and secondly the effect of decomposing pampas plant residues, resulting from herbicide treatment, on the response of *P. radiata* to added nitrogen.

MATERIALS AND METHODS

Glasshouse Trials

Soils selected for this study were a coastal sand from Waiuku Forest and a silty clay loam from Maramarua Forest. These forests lie respectively 50 km south and 65 km south-east of Auckland and pampas control is a major problem in both of them. Samples (0–300 mm depth) collected in recently clearfelled stands were air-dried and sieved (0.5 mm). The clay soil was carefully re-wetted with deionised water in a concrete mixer to avoid compaction. Analytical data for the two samples are given in Table 1.

Black plastic pots 160 × 160 × 190 mm were filled to a predetermined weight with sand or with re-wetted clay soil. The pots were undrained and were watered to just under field capacity twice weekly. Pampas seed (*C. selloana*) was germinated on acid-washed sand and seedlings were transplanted at the rate of two per pot when 12 days old. Nutrients were added in solution at time of transplanting.

TABLE 1–Analytical data for sand and clay soil used in the glasshouse trials

	Waiuku sand	Maramarua silty clay loam
pH	5.97	4.50
Total N (%)	0.007	0.049
Bray P (ppm)	47.5	2.68
Bray cations (me%)		
Ca	0.9	0.3
Mg	0.5	0.5
K	0	0.1
Carbon (%)	0.33	2.45
C/N ratio	47	50

All treatments in Trials 1–3 were replicated four times. Each trial was laid out as a complete randomised block experiment with individual blocks representing different locations in the glasshouse.

Oven-dry weight of plant tops and roots in each pot was determined after 7 months' pampas growth in Trials 1 and 2 and after 9 months' *P. radiata* growth in Trial 3. The nitrogen and phosphorus contents of plant samples were determined using methods described by Nicholson (1984).

Trial 1–Response of pampas growing in Waiuku sand to nitrogen addition rate

Ammonium nitrate (14.640 g/*l*—Solution A) was added at a rate of 0, 25, 50, 75, or 100 ml/pot, equivalent to 0, 50, 100, 150, or 200 kg N/ha.

Trial 2—Response of pampas growing in Maramarua clay to phosphorus addition rate and to phosphorus + nitrogen

Sodium dihydrogen phosphate (25.783 g/*l*) was added to two sets of pots at the rate of 0, 25, 50, 75, or 100 ml/pot, equivalent to 0, 50, 100, 150, or 200 kg P/ha. One set also received 25 ml of Solution A (Trial 1), an addition equivalent to 50 kg N/ha.

Trial 3—Response of P. radiata seedlings to nitrogen added in the presence of pampas residues

A complete set of pots was prepared as for Trial 1. After 7 months' growth the pampas in each pot was sprayed with glyphosate (3.6 g a.i./*l*). After 18 days the few remaining green shoots were painted with glyphosate. On the following day, two 3-week old *P. radiata* seedlings that had been raised in perlite were transplanted into each pot. Care was taken to see that these seedlings did not touch the treated pampas. Each pot received 50 ml of Solution A (Trial 1) to provide the equivalent of 100 kg N/ha. Dead pampas material was placed on the sand surface as soon as it became detached. This material was wetted at each watering.

Field Observations

Response of pampas grass seedlings to superphosphate applied to recently-planted P. radiata in a clay soil

Volunteer pampas seedlings were measured in a 1-year-old plantation of *P. radiata* growing on Maramarua silty clay loam in Maramarua Forest. The site, which had received no fertiliser during the first rotation, was known to be chronically deficient in phosphorus (Ballard 1978). Second-rotation trees had been planted at 1.5 × 4.5 m spacing and 170 g superphosphate had been applied by hand, close to the base of each tree, immediately after planting. Three months later the whole area had been broadcast-sown with *Lotus uliginosus* Schkuhr. (2 kg seed plus 10 kg serpentine superphosphate/ha).

Starting from a common baseline, a 20-m line transect was laid in each of two tree rows and also along a line midway between each tree row and the next. A vertical rod lowered into the vegetation at 1-m intervals along each transect was used to measure the height of the tallest pampas plant part intercepted by the rod.

Response of mid-rotation P. radiata growing on coastal sand to nitrogen application and pampas control

A trial was established in 1983 in a 12-year-old second-rotation pine stand at Waiuku Forest. Trees had been thinned to 200 stems/ha and the stand contained a dense understorey of large pampas tussocks. Attempts to control pampas by cutting and grazing were being made but were discontinued when the trial started.

Factorial combinations of two levels of nitrogen treatment (0 or 200 kg N/ha as broadcast calcium ammonium nitrate) and two levels of pampas control (no control or spray treatment with glyphosate in June 1983, November 1983, and again in 1984) were applied to 0.09-ha plots. The trial was laid out in four randomised blocks. Tree basal area was measured in 1983, 1985, 1986, and 1987. Data for the final 3 years were subjected to covariance analysis, using 1983 basal area as the covariate.

RESULTS

Glasshouse Trials

Trial 1—Pampas response to nitrogen in Waiuku sand

Dry matter production by pampas plants was increased by nitrogen addition (Table 2), the 50 and 100 kg/ha rates being more effective than 150 or 200 kg/ha. The response patterns of plant tops and roots were similar.

Nitrogen content of plants (tops + roots) was significantly greater at each higher nitrogen level (Table 2). There was no evidence that the nitrogen demand of the seedlings had been satisfied even where 200 kg/ha had been added. At the 50, 100, 150, and 200 kg N/ha levels, the amount of nitrogen in plant tissues represented 95, 89, 86, and 78% respectively of the nitrogen added per pot. Uptake of phosphorus increased with nitrogen level up to 150 kg N/ha (Table 2).

TABLE 2–Effect of nitrogen on dry matter production and nutrient uptake in 7-month-old pampas seedlings on Waiuku sand

N addition level (kg/ha equivalent)	Dry weight (g)	N content (mg)	P content (mg)
0	8.3 a*	41 a	16 a
50	26.1 c	122 b	32 b
100	26.2 c	229 c	38 c
150	21.0 b	329 d	42 d
200	18.3 b	397 e	44 d

* Within columns, values followed by the same letter do not differ at the 5% probability level (LSD test).

Trial 2—Pampas response to phosphorus and to phosphorus + nitrogen in Maramarua clay

Phosphate addition increased dry matter production of pampas, the response at the 50 kg P/ha rate being greater than that at the three higher rates (Table 3). Addition of nitrogen increased the magnitude of the dry weight responses to phosphorus ($p = <0.001$). In this series the greatest response was observed at rates of 100 kg P/ha or more.

TABLE 3–Effect of phosphorus and phosphorus+nitrogen on dry matter production and nutrient uptake in 7-month-old pampas seedlings on Maramarua silty clay loam

Nutrient addition level (kg/ha equivalent) P	N	Dry weight (g)	P content (mg)	N content (mg)
0	0	6.2 a*	3 a	57 a
0	50	4.5 a	3 a	89 c
50	0	25.4 c	19 b	99 d
50	50	39.7 d	22 c	263 ef
100	0	21.4 b	23 c	85 bc
100	50	51.5 e	26 d	274 f
150	0	18.8 b	23 c	78 b
150	50	52.6 e	40 e	279 f
200	0	20.7 b	29 d	88 bc
200	50	52.2 e	53 f	259 e

* Within columns, values followed by the same letter do not differ at the 5% probability level (LSD test).

Phosphorus uptake increased with phosphorus level (Table 3), and was greater at all levels where nitrogen had also been applied. There was no evidence that the demand for phosphorus had been satisfied. Where no nitrogen was added, the amount of phosphorus in plant tissues was equivalent to 14, 9, 6, and 6% of the phosphorus added at the 50, 100, 150, and 200 kg/ha levels respectively. Where nitrogen had been added, the proportions were 17, 10, 10, and 10% respectively.

Nitrogen uptake was increased if phosphorus was present, but was not affected by phosphorus level. The amount of nitrogen immobilised was equivalent to 69, 205, 213, 218, and 202% of added nitrogen at the 0, 50, 100, 150, and 200 kg P/ha levels respectively.

Trial 3—Effect of pampas residues on P. radiata seedlings

Total productivity of pine seedlings was greatest where the amount of pampas residue was least (8 g/pot) (Table 4). Amounts greater than 18 g/pot had no significant additional effect. Growth suppression was not associated with any significant change in the nitrogen or phosphorus status of the seedlings.

TABLE 4–Effect of pampas residues on dry matter production and nitrogen and phosphorus status of *P. radiata* seedlings

Original N addition (kg/ha equivalent)	Estimated dry wt of pampas when killed (g)	Dry wt of *P. radiata* (g)	N content of *P. radiata* (mg)	P content of *P. radiata* (mg)
0	8 a*	16.8 b	179 a	19 a
50	26 c	10.2 a	139 a	15 a
100	26 c	8.7 a	150 a	14 a
150	21 b	7.5 a	143 a	14 a
200	18 b	5.5 a	130 a	12 a

* Within columns, values followed by the same letter do not differ at the 5% probability level (LSD test).

Field Studies

Response of pampas to superphosphate application in a clay soil

More pampas plants were intercepted within the tree rows, where the maximum distance from a phosphorus-treated tree was 0.75 m, than in transects between tree rows where the minimum distance from a treated tree was 2.25 m (Table 5). Although there was a tendency for the height of intercepts to be greater within tree rows, the difference was not significant.

TABLE 5–Pampas development in a 1-year-old *P. radiata* stand at Maramarua Forest

Position of transect	No. of intercepts/20 m		Height of intercept (cm)	
	Mean	S.D.	Mean	S.D.
Within tree rows	8	1.4	45.6	16.1
Between tree rows	4	0	34.3	10.5

Response of P. radiata to nitrogen application and pampas control in a coastal sand

Pampas control alone had no effect on tree basal area in 1985 (2 years after treatment), but the trees did respond to nitrogen treatment (Table 6). This response was greater in plots where pampas had been treated with glyphosate. After 1985, tree growth response to nitrogen treatment was apparent only in sprayed plots, and reponse to pampas control was detected only in plots that had received nitrogen. Treatment with both glyphosate and nitrogen resulted in a basal area increase of 7.8, 11.2, and 11.8% in 1985, 1986, and 1987 respectively.

TABLE 6–Effect of 1983 pampas control and treatment with nitrogen fertiliser on subsequent growth of *P. radiata* at Waiuku

Treatment	Basal area (m^2/ha)					
	1985		1986		1987	
	N fertiliser	No N	N fertiliser	No N	N fertiliser	No N
Pampas sprayed	17.16 c*	14.89 a	20.82 b	17.60 a	23.46 b	19.83 a
Pampas not sprayed	15.92 b	14.89 a	18.73 a	17.45 a	20.99 a	19.80 a

* For each year, values followed by the same letter do not differ at the 5% probability level (LSD test).

DISCUSSION

Response of Pampas to Added Nitrogen and Phosphorus

The glasshouse trials showed that when moisture supply was adequate, pampas growth was limited by nitrogen supply in Waiuku sand and by phosphorus supply in Maramarua clay. In Waiuku sand a secondary factor appears to have limited growth of plants supplied with more than 50 kg N/ha. This factor has not been identified, but analytical data suggest that it is unlikely to have been phosphorus supply. Although growth was reduced, uptake of nitrogen was not, and it is clear that pampas is capable of so-called "luxury consumption" of nitrogen—in this trial when amounts greater than 50 kg/ha were supplied.

In Maramarua clay, nitrogen was the secondary factor limiting pampas growth. It is not clear whether the plants would have responded to levels of nitrogen greater than 50 kg/ha when phosphorus was present at levels greater than 100 kg/ha. In the presence of nitrogen there was no evidence that phosphorus uptake had reached a maximum at the 200 kg/ha level.

Glasshouse Trials 1 and 2 showed that pampas can benefit from nutrients added to forest soils. The potential for uptake of nitrogen applied to Waiuku sand and for uptake of phosphorus and nitrogen when both were supplied to Maramarua clay, suggests that pampas could benefit from fertiliser treatment designed to improve tree growth. Field observations provided support for this suggestion. At Maramarua, greater pampas development in terms of intercept frequency within tree rows was associated with superphosphate placement. It can be inferred that pampas was utilising phosphorus supplied to the trees although the possibility of an additional sulphur effect cannot be ruled out. At Waiuku, pampas development was not measured, but the field trial showed that actively growing pampas and pampas residues interfered with tree nitrogen nutrition in a way that herbicide-treated residues did not. There was no evidence of physical interference with tree growth. This was an unexpected result, since in a concurrent trial established in a 5-year-old intensively managed *P. radiata* stand at Waiuku Forest a basal area response to the spraying of pampas with glyphosate was apparent in the second, third, and fourth years after treatment (West *et al.* 1988). It is not possible to estimate the absolute effect of pampas in either trial because none of the plots had been totally pampas-free from the beginning of the rotation. Comparisons could be made only between plots containing growing pampas and those containing large amounts of pampas residues after herbicide treatment.

Effect of Pampas Residues

The dependence of the positive tree growth response to nitrogen fertiliser on pampas mortality can be interpreted in two ways. Firstly, it could imply that growing pampas had utilised a large proportion of the added nitrogen, leaving little available for the trees by 1985. Secondly, it could mean that the residues of pampas which had been treated with nitrogen were exerting a stimulatory effect between 1985 and 1987. Both these effects were probably operating. Tree response to added nitrogen in unsprayed plots was not sustained after 1985 and allocation of fertiliser nitrogen between the species appears to have been complete by 1985. In contrast, tree response to added nitrogen in sprayed plots increased between 1985 and 1987, indicating that fertiliser nitrogen retained in pampas residues during the decomposition phase was being released in a form that was available to the trees.

In Glasshouse Trial 3 (Waiuku sand) *P. radiata* seedlings grew better in the presence of small amounts (8 g o.d.wt/pot) of pampas residues than where larger amounts (18–26 g/pot) were present. This trial demonstrated that pampas does not have to be alive to exert a negative influence on growth of *P. radiata*, and that trees are sensitive to pampas residues even when nitrogen and phosphorus are in good supply. In the Waiuku field trial, it is possible that an early but unmeasured negative effect of pampas residues on tree growth was obscured by a later (1985–87) positive effect of slow nitrogen release. Where no nitrogen had been added, the absence of any observable effect of pampas on tree growth in the sprayed plots can be explained by the presence of large quantities of dead and decomposing pampas material which has a high C/N ratio (Dunlop & Coup 1951). In a nitrogen-limited ecosystem, organisms decomposing the pampas residues are likely to be as effective as living pampas in competing with the trees for nitrogen, and decomposition would slow down if no additional nitrogen became available. The increased tree growth response in nitrogen-treated sprayed plots in successive years was probably due to a higher rate of decomposition leading to a decrease in the amount of decomposable material and a release of the nitrogen immobilised in the microbial biomass. The possibility that a chemical inhibitor of *P. radiata* growth may be associated with growing pampas plants or with pampas residues cannot be ruled out. On the other hand, the observed results can be explained on the basis of competition for scarce nutritional resources.

It has been estimated that pampas can accumulate dry matter above ground at the rate of 7–8 t/ha/yr in New Zealand forest soils (Gadgil *et al* 1990). Taking the lowest and highest plant tissue concentrations for nitrogen and phosphorus from Glasshouse Trials 1 and 2, pampas in a forest stand can be expected to divert 34–158 kg N/ha/yr and 4–13 kg P/ha/yr from the nutrient cycling pathway between soil and tree. Higher concentrations of phosphorus have been reported in pampas leaves collected in the field (Gadgil *et al.* 1984) but these may not have been representative of all the above-ground material.

The only way to prevent pampas from competing with forest trees for nutrients that are in short supply is to eliminate it completely. Current practical control methods involve either cattle grazing, or herbicide treatment, or a combination of the two. The management of pampas to provide a continuous feed resource should be viewed with caution until it can be shown that effective compensation in terms of tree growth has been ensured through grazing plus fertiliser treatment or grazing plus oversowing with nitrogen-fixing legumes.

CONCLUSIONS

Pampas grass, an aggressive weed in *P. radiata* forests planted on coastal sands and on silty clay loam soils, responds to nutrient treatment when grown in these soil types in the glasshouse. Productivity can be increased by the addition of nitrogen to a coastal sand. The response of pampas to phosphorus in a silty clay loam is much greater when nitrogen is also added.

Increase in pampas plant frequency associated with superphosphate treatment of trees growing on a silty clay loam soil, and reduction of tree response to nitrogen fertiliser treatment on a coastal sand, both suggest that pampas utilises fertiliser intended to improve tree productivity in *P. radiata* forests.

Data from glasshouse trials and previously published field biomass studies indicate that uncontrolled pampas can accumulate significant amounts of nitrogen and phosphorus which would otherwise be available for tree growth in nutrient-limited ecosystems.

Pampas plant residues remaining after herbicide treatment can reduce *P. radiata* productivity. There is evidence that in a nitrogen-limited ecosystem, fertiliser-nitrogen immobilised by pampas residues is released slowly as decomposition proceeds, and is utilised for tree growth.

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