RGS.

Aust. J. Agric. Res., 1976, **27**, 583–92

Importance of Phosphorus and Nitrogen in the Nutrition of Grass Seedlings growing in Mulga Soil

R. G. Silcock[A], *A. Noble*[B] *and R. D. B. Whalley*[C]

[A] Charleville Pastoral Laboratory, Queensland Department of Primary Industries,
Charleville, Qld. 4470.

[B] Agricultural Chemistry Branch, Queensland Department of Primary Industries,
Brisbane, Qld. 4000.

[C] Botany Department, University of New England,
Armidale, N.S.W. 2351.

Abstract

A pot experiment was conducted to compare the importance of nitrogen and phosphorus fertilizers to seedling growth of four grasses on mulga soil. Two native species, *Monachather paradoxa* (mulga oats) and *Digitaria ammophila* (silky umbrella grass), and two exotic ones, *Anthephora pubescens* (wool grass) and *Cenchrus ciliaris* cv. Biloela (buffel grass), were tested.

Digitaria and the two exotic grasses reacted similarly to applied phosphorus while *Cenchrus* utilized soil nitrogen more readily than the others.

Phosphorus produced marked growth responses, increased the nitrogen and phosphorus contents of the plants, reduced the time between emergence and tillering and reduced root/shoot ratios. Nitrogen fertilizer produced no significant responses and actually retarded very early seedling growth. There were no nitrogen × phosphorus interactions.

Introduction

A gross deficiency of phosphorus in mulga (*Acacia aneura*) soils for maximum plant growth has been clearly documented (Cowie 1967). This deficiency is extremely acute for buffel grass (*Cenchrus ciliaris*) in the seedling stage (Christie 1975). Experience has shown that under field conditions buffel grass is extremely difficult to establish on mulga soils (Wilson 1961), growing only under the canopy of particular tree species where the soil pH is nearer to neutral and fertility generally is higher. Poplar box trees (*Eucalyptus populnea*) are the best-known example of this (Ebersohn and Lucas 1965). Many grass species native to mulga soils, as well as some exotic grasses, do not appear to share the same preference for this microsite. Thus there can be some speculation as to the importance of improved nutrition of species other than *C. ciliaris* during the establishment phase.

Total nitrogen and available phosphorus are higher in the surface soil under box trees than in the nearby mulga soil (Christie 1975), so nitrogen could also be important to seedling growth, especially if strong nitrogen × phosphorus interactions occur. The nitrogen nutrition of seedlings growing in mulga soil has not been adequately assessed to date and little is known about the nutritional requirements of most native grasses in western Queensland. This experiment was conducted to assess the importance of nitrogen and phosphorus to seedling growth of a number of grasses on mulga soil, including some native species.

Materials and Methods

The soil was collected from the 0–15-cm zone under an open mulga forest on the Experimental Reserve near Charleville. It was the acid form of a sandy red earth and similar to that described by Dawson and Ahern (1973). It had the following chemical composition: pH (1/5 suspension in water) 4·4; total nitrogen (Kjeldahl digest) 0·09%; nitrate nitrogen (1/5 suspension read by nitrate electrode) 4 ppm; total phosphorus (modification of Beckwith and Little (1963) and Murphy and Riley (1962)) 150 ppm; acid-extractable phosphorus (Kerr and von Stieglitz 1938) 8 ppm. A test of the soil after the trial for mineralizable nitrogen according to the method of Waring and Bremner (1964) gave the following results: nitrate nitrogen 8·1 ppm; ammonium nitrogen 36·1 ppm; mineralizable nitrogen 0. After being sieved through a 2-mm mesh it was potted immediately into pots 20 cm in diameter each lined with a Polythene bag. Each pot was filled with a known weight of air-dry soil (about 7 kg) and subsequently brought to field capacity (13% w/w moisture) by the addition of deionized water. In all, the trial contained 288 pots—4 species × 3 phosphorus levels × 3 nitrogen levels × 2 ages of harvest × 4 replications—laid out in a randomized block in a plant house sheeted with clear polyvinyl chloride (Beale 1969).

The grasses used were *Monachather paradoxa* Steud. (mulga oats), *Digitaria ammophila* (F. Muell.) (silky umbrella grass), *Anthephora pubescens* Nees (CPI 43713)* (wool grass) and *Cenchrus ciliaris* L. cv. Biloela (buffel grass). The first two are native to mulga soils in the area while the last two are exotic but, once established, capable of high dry matter yields on these soils (O'Donnell *et al.* 1973). Caryopses of each species were used for planting except in the case of *Digitaria*, where seeds (i.e. caryopsis plus lemma and palea) were sown. They were soaked in deionized water in the laboratory, beginning on 18 February 1972 until germination commenced, and then three groups of four seeds were planted per pot. Seedlings were thinned to three per pot prior to the nutrients being applied.

Nutrients were applied in solution (100 ml) to the surface of the soil at the time when the second leaf of most seedlings of a species was emerging. Phosphorus (as sodium dihydrogen phosphate) was applied at rates equivalent to 0 (P_0), 125 (P_{125}) and 250 (P_{250}) kg superphosphate/ha. Nitrogen (as ammonium nitrate) was applied at rates equivalent to 0 (N_0), 16·8 (N_1) and 33·6 (N_2) kg nitrogen/ha. The actual amount of nutrient added per pot for 125 kg superphosphate equiv./ha was 46·75 mg phosphorus and for 16·8 kg nitrogen/ha it was 65·23 mg nitrogen. No further applications of nutrient were made during the experiment. Pots were watered to field capacity daily with deionized water.

Differences in germination rate between species resulted in the nutrients being applied on different dates. *Cenchrus* and *Anthephora* were fertilized 5 days after imbibition began, *Digitaria* 7 days after and *Monachather* 8 days after. The stages of harvest were (*a*) four fully expanded leaves and (*b*) 12 (exotic) or 15 (native) fully expanded leaves. Any distinct lamina with a ligule was classed as a leaf and a leaf was considered to be fully expanded when its ligule was clear of the sheathing leaf base of the previous leaf. The harvest stages chosen were based on an earlier seedling morphology trial which showed:

(i) A lag phase in seedling growth between the three- and six-leaf stage.

(ii) A rapid growth phase after tillering.

---

[*] Commonwealth of Australia Plant Introduction number.

per plant while *C. ciliaris* had the least (Table 4). The increase in plant nitrogen and phosphorus over that in the seeds was very great for *D. ammophila* and comparatively small for the other species (Table 4). Addition of phosphorus increased these changes.

Table 4. Effect of phosphorus fertilizer on the amounts of nitrogen and phosphorus in four grass species at the four-leaf stage

Figures for a particular nutrient which are followed by the same letter do not differ significantly from one another ($P < 0 \cdot 05$)

Species	Initial seed content		Four-leaf stage			
			P_0		P_{250}	
	N (mg)	P (μg)	N (mg)	P (μg)	N (mg)	P (μg)
M. paradoxa	0·283	16·4	5·9ab (21)*	379b (23)	8·06a (28)	753a (46)
D. ammophila	0·025	3·8	3·12bc (125)	196bc (52)	4·54bc (182)	708a (186)
A. pubescens	0·133	21·6	4·94bc (37)	202bc (9)	5·34b (40)	489ab (23)
C. ciliaris	0·116	15·2	2·31c (20)	102c (7)	3·29bc (28)	347b (23)

* Figures in parenthesis indicate the proportional increase in the plant content of nitrogen and phosphorus over the initial seed content.

In the absence of fertilizer the average rates of uptake of nitrogen and phosphorus by the native species on a whole-plant basis were much greater than by the exotics during this early growth stage (Table 5). Yet once the critical phosphorus deficiency was relieved, the rates of phosphorus and nitrogen uptake were comparable, although at the top phosphorus level *C. ciliaris* appeared to be more efficient at taking up nitrogen than the other species.

Table 5. Effect of phosphorus fertilizer on the average rate of nutrient uptake between germination and the four-leaf stage in four grass species

Species	Nutrient uptake (μg/mg whole plant/day)					
	P_0		P_{125}		P_{250}	
	N	P	N	P	N	P
M. paradoxa	2·7	0·17	2·8	0·20	3·7	0·35
D. ammophila	2·2	0·14	4·5	0·44	5·1	0·79
A. pubescens	1·5	0·06	3·2	0·24	4·6	0·41
C. ciliaris	1·7	0·06	4·9	0·37	7·3	0·77

At the four-leaf growth stage the phosphorus concentration of the exotic grasses had been reduced to 14% of the original seed concentrations, yet *M. paradoxa* tissues still had 72% of the original level and *A. ammophila* 23% in the absence of fertilizer. The addition of a phosphorus fertilizer considerably reduced this decline.

The addition of phosphorus significantly reduced the time to tillering in all species, the largest individual difference being between P_0 and P_{125}. Earlier tillering in *D. ammophila* and *A. pubescens* was partly due to fewer leaves being present at the time of tillering. However, the increased earliness of tillering was due mainly to a greater rate of leaf production (Table 1). Fertilizer nitrogen had no effect on tillering.

Harvest 2

The effect of phosphorus recorded on early seedling growth rates was continued through to harvest 2 (pre-flowering). Again nitrogen had no effect on growth rates, and the major effect of phosphorus was at the lower of the two levels of application, except for *M. paradoxa* (Fig. 2). These graphs do not show the designated harvest size in some cases because they could not be validly extended once any plants in a given treatment had been harvested.

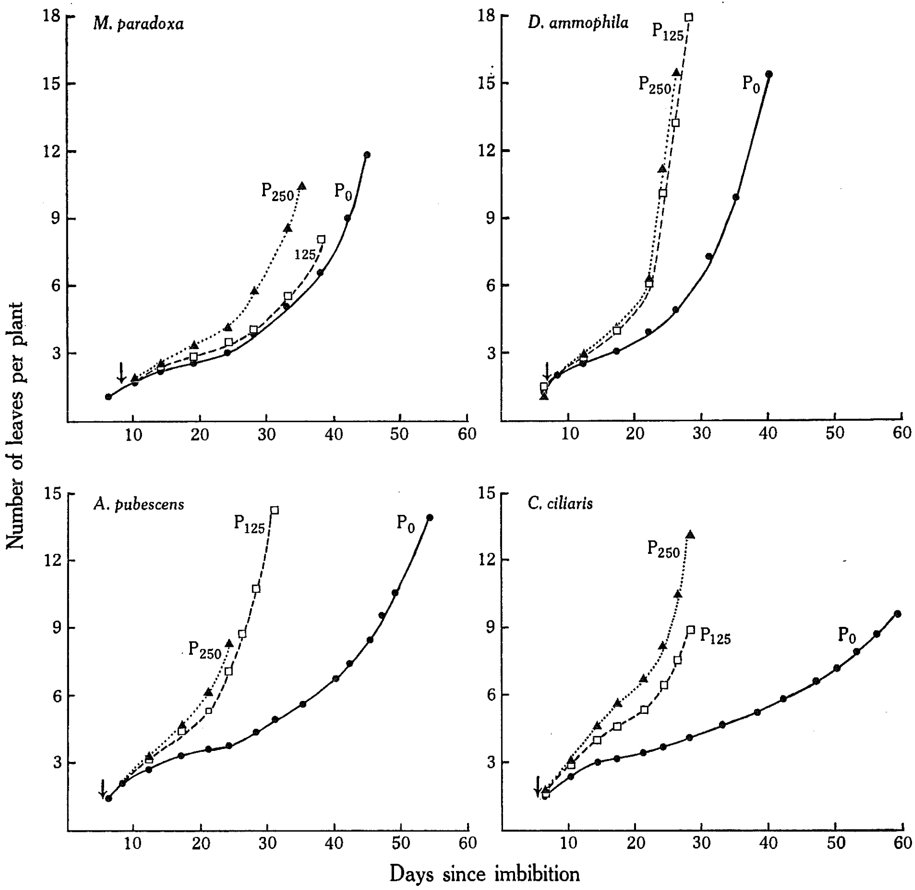

Fig. 2. Seedling growth response to applied phosphorus by four grasses growing in mulga soil. Arrows indicate when fertilizer was applied.

The only species to show a significant increase in shoot yield from the addition of phosphorus was *C. ciliaris*, this increase being due mainly to an overall increase in leaf and stem size. By contrast, nitrogen applications significantly ($P < 0{\cdot}05$) depressed shoot yield, averaged over all species, from 1·891 g to 1·604 g per pot. At the time of harvest the average single-plant yield for *M. paradoxa* was about 271 mg, for *D. ammophila* 385 mg, for *A. pubescens* 710 mg and for *C. ciliaris* 933 mg.

As at the first harvest, the application of phosphorus reduced root/shoot ratios and had a highly significant effect on the levels of phosphorus and nitrogen in the plants, particularly phosphorus in the shoots (Table 2). Species differences were also highly significant, the native species having higher concentrations than the exotics.

Fertilizer nitrogen, applied very early in the plant's life, had a highly significant effect ($P < 0{\cdot}01$) in increasing the percentage of nitrogen in the tops at harvest 2. The level of significance achieved was mainly due to the increase in *C. ciliaris* from an average of 2·1% nitrogen where no fertilizer nitrogen was applied to 2·53% at the N_2 level.

Discussion

The outstanding feature of this experiment was the response by all species to applied phosphorus. This response manifested itself particularly in the growth rate of the seedlings (Table 1; Fig. 2) and in the concentrations of phosphorus and nitrogen in the tissues of the plant (Tables 2 and 3). This pattern of response was expected from the two exotic species in the light of earlier studies by Cowie (1967) and Christie (1975).

However, both these earlier studies were conducted with only exotic species as test plants and with omission techniques to quantify their importance. Thus nutrient interactions, e.g. nitrogen and phosphorus, could have exaggerated their phosphorus responses. In addition, Christie mixed his phosphorus evenly through the potted soil while both authors mixed lime with the soil at high rates which radically altered the pH and probably micronutrient availability.

Seedlings of *M. paradoxa* did not respond nearly as decisively as those of the other species. Being well adapted to the phosphorus-deficient mulga soils, this species could therefore be suspected of lacking any great ability to utilize high levels of phosphorus (Rorison 1968). An inability to utilize high levels of phosphorus has been shown in *Thyridolepis mitchelliana* (Nees) S. T. Blake which is also a native of mulga soils (Christie and Moorby 1975). In nutrient culture, *T. mitchelliana* was unable to respond to high levels of phosphorus while *C. ciliaris* made increased growth with increasing levels of phosphorus up to quite high concentrations.

The marked response to applied phosphorus by *D. ammophila* was particularly interesting (Fig. 2). Its growth response was maximal at phosphorus levels equivalent to only 125 kg superphosphate/ha and it also showed a tendency to consume luxury amounts of phosphorus at the P_{250} level. This accumulation of phosphorus in *Digitaria* was not caused by a soil nitrogen deficiency, because it was not reduced by applied nitrogen. The two exotic species responded similarly to applied phosphorus, both utilizing the highest level (P_{250}) to advantage over the P_{125} level. They also showed little tendency toward luxury consumption of applied nutrients.

The first species to reach the two- to three-leaf stage was *C. ciliaris*, but in the absence of additional phosphorus it then fell steadily behind until it was a smaller plant than even the slow-growing *M. paradoxa* at 32 days of age. However, the addition of superphosphate at 125 kg/ha enabled it to maintain its initial size advantage. The magnitude of the growth response to phosphorus fertilizer corresponds with present ratings for ease of establishment of these species on mulga soils, i.e. *C. ciliaris* is the hardest to establish and *M. paradoxa* the easiest (Silcock, unpublished data).

At harvest 1 the two exotic species had considerably lower concentrations of phosphorus in the shoots than the natives when no fertilizer phosphorus was applied (Table 2). This seems to be the growth stage at which they require extra phosphorus most, even though the amount may be comparatively small (about 90 μg maximum per plant). Nitrogen seemed to be fairly readily available to all species even in the absence of adequate phosphorus, though a significant improvement in plant levels did occur in species other than *M. paradoxa* when phosphorus was added. High tissue concentrations of phosphorus and nitrogen in *M. paradoxa* were associated with the smallest response to phosphorus fertilizer. Within a species there was a general correlation between the concentration of phosphorus in the shoots and the growth rate (Table 2 cf. Table 1).

Most of the added phosphate would have been held or adsorbed in an available chemical form in the top 2·5 cm of soil (Silcock, unpublished data). There it would have been inaccessible to most roots as well as having its effectiveness reduced whenever the surface soil was dry. Thus it appears that the small, early seedling root system was able to capitalize on the increased phosphate intermittently available to it in the surface soil, and to translocate it efficiently throughout the plant. In fact, the amount of extra phosphorus in the pot may not be as important as its concentration or 'availability' adjacent to the plant's surface seminal roots.

The significant effect of nitrogen, applied at the two-leaf stage, on the dry matter yield and nitrogen concentration of the shoots at the second harvest only was unusual. In most grasses extra nitrogen increases shoot yield (Grunes *et al.* 1958). The slight early setback caused by nitrogen (Fig. 1) could have been due to the release of ammonia on breakdown of the ammonium nitrate under the summer conditions (Stephen and Waid 1963). But at the pre-flowering stage in a pot, nitrogen deficiency would normally be anticipated (Boatwright and Haas 1961) and a positive response to nitrogen expected. The limited soil volume should have accentuated any mineral deficiency (Cornforth 1968), and the response in shoot nitrogen percentage to applied nitrogen at harvest 2 would indicate that nitrogen was marginally deficient at this stage. Thus the significant decline in yield ($P < 0·05$) may have been fortuitous.

Nitrogen × phosphorus interactions are commonly reported in grass nutrition studies (Wilson and Haydock 1971), usually because the seedlings respond initially to phosphorus fertilizer, and as the plants mature the response to nitrogen increases. Total soil nitrogen was low, in keeping with mulga soils generally (Dawson and Ahern 1973), and laboratory tests showed that little mineralizable nitrogen was present. The level of available phosphorus was also low, so the greater mobility and the higher concentration of the mineral nitrogen, as shown by the soil analysis at the end of the trial, seem to be the best explanation for the lack of a plant growth response to nitrogen fertilizer. A lack of response by seedlings to nitrogen fertilizer has also been reported by Campbell (1973) with temperate pasture species in a field situation.

The rate of phosphorus uptake is probably the crucial factor restricting the growth of exotic grasses on mulga soils (Christie 1974). The seed of the exotic species contained more phosphate than *D. ammophila*, yet they suffered an 86% decline in average phosphorus concentration by the time they had four fully expanded leaves if no phosphate fertilizer was supplied. The native species varied in their decline but in the case of *M. paradoxa* it was only 28% and for *D. ammophila* it was 77%. These declines were inversely proportional to the response of seedlings to applied phosphorus (Table 1) and appear to be a good measure of the adequacy of the seedlings' nutritional status.

On unfertilized mulga soil the native grasses adjusted their phosphorus uptake to suit their growth requirements far better than the exotics. At harvest 1, *M. paradoxa* had absorbed 23 times its original seed capital of phosphorus and the more demanding *D. ammophila* had taken up 52 times its original phosphorus capital (Table 4). By comparison, *C. ciliaris* and *A. pubescens* seedlings contained only seven and nine times, respectively, the amounts their seed originally held. When phosphorus was more readily available (P_{250}), the two exotics responded by absorbing 23 times their original seed supply while the natives absorbed the extra phosphorus in even greater amounts.

Phosphorus fertilizer would appear to offer a solution to the problem of slow seedling development on mulga soils. It would markedly reduce the time to tillering for many potentially productive exotic grasses that are difficult to establish normally. Although no definite correlation has been recorded between tillering and successful establishment amongst the native species in the field, early-tillering plants usually flower early (Silcock 1975) and thus infuse seed of a sown species into the ecosystem more rapidly. Early tillering is also desirable as it influences the earliness with which axillary growing points become physiologically capable of expanding in the event of the death of the main shoot or root axis. Proliferation of tillers (and the accompanying root system) of grasses in the semiarid mulga country would sometimes be a more desirable feature of pasture species than dry matter yield. Thus the use of phosphate fertilizers to increase early seedling development of sown grasses on mulga soils appears promising, provided that an economical method of fertilizer application can be devised.

Acknowledgments

Special thanks go to Mrs Lynn Williams for her competent technical assistance throughout the running of this trial. Appreciation is also expressed to Dr Eric Craswell, who arranged for the mineralizable nitrogen determinations. Many other officers within the Agriculture and Agricultural Chemistry Branches of the Queensland Department of Primary Industries provided guidance and advice during the experiment, and for this we are very grateful.

The financial support for this work provided by the Wool Research Trust Fund is also gratefully acknowledged.

References

Beale, I. F. (1969). Construction of a frost-free plant house. *Qd. J. Agric. Anim. Sci.* **26**, 553–63.

Beckwith, R. S., and Little, I. P. (1963). Rapid method for the estimation of total phosphorus in soils. *J. Sci. Fd Agric.* **14**, 15–19.

Boatwright, G. O., and Haas, H. J. (1961). Development and composition of spring wheat as influenced by nitrogen and phosphorus fertilization. *Agron. J.* **53**, 33–6.

Campbell, M. H. (1973). Factors responsible for losses during germination, radicle-entry, establishment, and survival of surface-sown pasture species. Ph.D. Thesis, Univ. of New England.

Christie, E. K. (1974). Physiological responses of the semi-arid grasses *Thyridolepis* and *Astrebla* compared with *Cenchrus.* Ph.D. Thesis, Macquarie Univ.

Christie, E. K. (1975). A study of phosphorus nutrition and water supply on the early growth and survival of buffel grass grown on a sandy red earth from south-west Queensland. *Aust. J. Exp. Agric. Anim. Husb.* **15**, 239–49.

Christie, E. K., and Moorby, J. (1975). Physiological responses of semiarid grasses. I. The influence of phosphorus supply on growth and phosphorus absorption. *Aust. J. Agric. Res.* **26**, 423–36.

Cornforth, I. S. (1968). Relationships between soil volume used by roots and nutrition accessibility. *J. Soil Sci.* **19**, 291–301.

Cowie, A. M. (1967). Edaphic and environmental factors in relation to land use at "Gowrie" station, Charleville. M.Agr.Sc. Thesis, Univ. of Queensland.

Dawson, N. M., and Ahern, C. R. (1973). Soils and landscapes of mulga lands with special reference to south-western Queensland. *Trop. Grassl.* **7**, 23–34.

Ebersohn, J. P., and Lucas, P. (1965). Trees and soil nutrients in south-western Queensland. *Qd. J. Agric. Anim. Sci.* **22**, 431–5.

Grunes, D. L., Viets, F. G. Jnr., and Shih, S. H. (1958). Proportionate uptake of soil and fertilizer phosphorus by plants as affected by nitrogen fertilization. I. Growth chamber experiment. *Soil Sci. Soc. Am. Proc.* **22**, 43–8.

Kerr, H. W., and von Stieglitz, C. R. (1938). The laboratory determination of soil fertility. Tech. Commun. Qd. Bur. Sugar Exp. Stns. No. 9.

Murphy, J., and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural water. *Anal. Chim. Acta* **27**, 31–6.

O'Donnell, J. F., O'Farrell, R., and Hyde, K. W. (1973). Plant introduction and reseeding in the mulga zone. *Trop. Grassl.* **7**, 105–10.

Rorison, I. H. (1968). The response to phosphorus of ecologically distinct plant species. I. Growth rates and phosphorus absorption. *New Phytol.* **67**, 913–23.

Silcock, R. G. (1975). Factors influencing the establishment of perennial grasses on the lateritic red earths (mulga soils) of south-western Queensland. M.Sc. Thesis, Univ. of New England.

Stephen, R. C., and Waid, J. S. (1963). Pot experiments on urea as a fertilizer. I. A comparison of responses by various plants. *Plant Soil* **18**, 309–16.

Waring, S. A., and Bremner, P. M. (1964). Ammonium production in soil under waterlogged conditions as an index of nitrogen availability. *Nature* (*Lond.*) **201**, 951–2.

Wilson, R. G. (1961). Sowing pastures in south-west Queensland. *Qd. Agric. J.* **87**, 214–25.

Wilson, J. R., and Haydock, K. P. (1971). The comparative response of tropical and temperate grasses to varying levels of nitrogen and phosphorus nutrition. *Aust. J. Agric. Res.* **22**, 573–87.

Manuscript received 18 December 1975