

Seed Coating and Localized Application of Phosphate for Improving Seedling Growth of Grasses on Acid, Sandy Red Earths

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Abstract

The seedling growth of tropical grasses on acidic, sandy red earths was improved greatly by the application of small amounts of phosphate fertilizers in close proximity to the seed. Fertilizer had to be applied within 5 cm of the seed of *Anthephora pubescens* to have any effect. Many phosphorus sources stimulated seedling growth of *Cenchrus ciliaris* when applied as coatings to the fascicle (the propagule containing the grain). Water-soluble orthophosphates proved the best phosphorus sources for the purpose. Optimum rates of coating ranged up to 2 mg phosphorus per fascicle (10 mg monosodium phosphate), depending on the availability of surface soil moisture.

Valuable grasses such as *C. ciliaris* could be introduced into millions of hectares of native pastures on infertile, sandy soils in north-eastern Australia, at reasonable cost, if a suitable commercial coating process can be developed.

Introduction

Large areas of North-west, Central and South-west Queensland have mean annual rainfalls of >450 mm but are currently unsuited to cropping and support only low-quality native pastures. Where soil fertility is high, buffel grass pastures have been easily established. Once established, buffel persists well on most other soil types too, and provides a more stable and productive pasture than the native ones (Paull and Lee 1978). Thus graziers owning large areas of native pastures on the less fertile soils have been trying for years to introduce exotic pasture grasses, particularly buffel grass. Some success has been achieved on the deep, sandy Cypress pine soils (Uc 1.2) but the red-brown earths or mulga soils (Gn 2.1, Northcote 1971) have not been successfully exploited to date.

The dominant nutrient deficiency limiting seedling growth of many grasses on mulga soils is phosphorus (Christie 1975; Silcock *et al.* 1976). Species of *Cenchrus*, *Digitaria*, *Anthephora* and *Schmidtia* are particularly responsive to phosphorus in the seedling stage (Silcock 1980). The biggest limitation to the implementation of the current establishment technology has been the cost of broadcasting superphosphate on land which currently has a low value (\$6 per hectare (Holmes 1981)) combined with the high risk of seedling failures due to drought. Banding fertilizer with the seed would probably be quite successful (Wagner 1956), require less fertilizer and not stimulate the growth of competing weeds, but this technique is not feasible because of the rough terrain and large quantities of fallen timber. Thus pelleting fertilizer around the seed seemed the only option left if exotic grasses were to be widely established in mulga country.

Theoretical considerations indicate that:

- (i) The fertilizer should not have a great capacity for moisture retention as this might induce premature germination of the seed after small falls of rain.
- (ii) Uptake of 80–90 μg of fertilizer phosphorus per seedling is required (re-calculated from the data of Silcock *et al.* 1976).
- (iii) Phosphate fertilizer would probably be physically immobilized upon mixing with wet mulga soil during the first fall of rain (Lawton and Vomocil 1954).
- (iv) Most soluble fertilizers reduce germination if placed in contact with seeds (Carter 1967).

World-wide experience in the use of pellets and coatings to improve grass seedling establishment in dryland pastures has been discouraging (Chadwick *et al.* 1969; Hirota 1972; Dowling 1978). Where fertilizer coatings were used successfully to improve seedling establishment, the results were generally attributed to the physical effects of the coat and not to the fertilizer (Vartha and Clifford 1973; Scott 1975). The irregular shape and hairiness of many grass propagules presents an added difficulty to the implementation of the coating technology currently used on legume and horticultural seeds.

This paper reports on studies designed to find (a) if coating grass seeds with phosphorus fertilizers is a feasible way of improving seedling growth on mulga soils, and (b), if (a) is feasible, what fertilizers are most successful and at what quantities per seed are optimal growth responses achieved. The experiments have been grouped into three logical parts (A, B and C) each with its relevant methodology, results and discussion. *Anthephora pubescens* was the test plant used initially. It is just as responsive to phosphorus in the seedling stage as buffel grass, and tillers earlier and more prolifically in pots (Silcock *et al.* 1976). It is therefore a more sensitive test plant than buffel for growth characteristics other than forage yield.

Part A: Timing and Proximity of Fertilizer to the Seed

Materials and Methods

Experiment 1: Optimum Time for Fertilizer Application

Fifty-six plastic-lined pots were filled with 7 kg of air-dry (0.83% moisture) sandy, red-earth (mulga soil) collected from 0.5 cm depth beneath a canopy of mature mulga trees near Charleville. The soil was sieved through a 2-mm sieve and packed to an average bulk density of 1.57 g/cm³ in the pots, and had the following chemical characteristics: pH 5.7, 7 ppm BSES acid-extractable phosphorus and 0.4 m.e./100 g extractable potassium. The pots were grouped into a randomized block in a plant house, and all were watered up to field capacity (10.5% moisture) with rainwater on 23 December 1974. Later that day, 100 ml of solution of $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ (93.6 mg phosphorus) was spread over the soil surface of each of seven pots (treatment 1). This represented a phosphorus application rate equivalent to 250 kg superphosphate/ha. This procedure was repeated on seven other unfertilized pots on five more occasions at the following times:

- Treatment 1, fertilized 21 days before sowing;
- 2, fertilized 7 days before sowing;
- 3, fertilized at sowing;
- 4, fertilized at seedling emergence;
- 5, fertilized at leaf 2 emergence;
- 6, fertilized at leaf 3 emergence;
- 7, not fertilized;
- 8, not fertilized.

All pots were left unwatered between the applications for treatments 1, 2 and 3.

On 13 January 1975, three caryopses (i.e. grains) of *Anthephora pubescens* CPI 43713 were planted close together in the centre of every pot, about 5 mm below the soil surface. The soil surface of all pots was then kept moist with periodic light sprayings of rainwater until the seedlings were well-emerged (3 days). Thereafter, all pots were brought daily to field capacity with a single watering. Fertilizer for treatments 4, 5 and 6 was applied (as before) to unfertilized pots as seedlings reached the developmental stages previously indicated. Seedlings were thinned to one per pot 7 days after sowing. Plants in treatment 7 were harvested on 30 January 1975 along with those in treatments 1–6 (17 days after sowing), while plants in treatment 8 were harvested on 14 February 1975 when most plants had as many main shoot leaves as the largest plants in treatments 1–5 at their harvest (seven leaves). This treatment allowed comparisons to be made of plant weight, tiller (i.e. axillary shoot) number and tiller sites of unfertilized plants compared with fertilized ones with the same number of main shoot leaves, i.e. at a similar physiological stage of development.

During seedling growth, the following records were kept for each seedling:

(i) date of emergence of each main shoot leaf, (ii) date of appearance of tillers 1 and 2, and (iii) leaf axil in which the tillers appeared.

At harvest the following data were collected: number of root axes at the crown, total number of leaves visible, and oven-dry weight of shoots.

The data were analysed by the analysis of variance technique.

Experiment 2: Proximity of Fertilizer to the Seed

Fifty-four pots were filled with 7 kg of air-dry, sieved mulga soil as in experiment 1, and watered to field capacity (10.5% moisture), and the soil surface carefully flattened. When the surface 1 cm of soil was quite dry, two caryopses of *A. pubescens* were planted 5 mm below the soil surface in the centre of each pot (surface 20 cm diameter). After planting, nine phosphate-fertilizer treatments (described in Table 1) were applied.

Treatments 2, 3, 4 and 6 are equivalent to 19.1 kg phosphorus ha⁻¹ over the treated area, a rate within the range normally recommended for establishing grass seedlings on mulga soils (Christie 1975). Treatment 9 (9.6 mg phosphorus) required about as much solid NaH₂PO₄·2H₂O (48 mg) as could be placed in a small heap, and was a convenient multiple of treatment 4. Treatment 7 needed

Table 1. Experiment 2: fertilizer rates and placement in relation to the centrally sown *A. pubescens* seeds

The phosphorus source for all treatments was NaH₂PO₄·2H₂O

Treat- ment number	Total phosphorus applied per pot (mg)	Method of fertilizer application	Zone of application relative to the pot centre
1	Nil	—	—
2	60.0	100 ml of solution	20 cm diam. circle
3	15.0	25 ml of solution	10 cm diam. circle
4	2.4	4 ml of solution	4 cm diam. circle
5	0.6	1 ml of solution	1 cm diam. circle
6	45.0	75 ml of solution	Outside a central 10 cm diam. circle
7	0.6	Solid crystals	Central spot
8	2.4	Solid crystals	Central spot
9	9.6	Solid crystals	Central spot

a quarter of the phosphate used in treatments 4 and 8, and probably contained the minimum extra phosphorus (90 µg) required for optimal seedling growth (assuming 15% is absorbed by the plant (Mitchell 1957)). Treatment 5 was comparable with treatment 7, except in the way the fertilizer was applied, and treatments 4 and 8 are similarly comparable.

Fertilizer solutions were restricted to their prescribed areas by metal rings slightly pressed into the soil. Solid fertilizers were tipped into as compact a pile as possible on the soil surface, usually < 3 mm diameter, and then very gently watered in by a fine spray of water. All pots were brought to field capacity shortly after the fertilizer had been applied.

given plant spacing is much less than if it were broadcast evenly. For example, if seed was sown on a 10-cm grid and could be coated with double superphosphate, the results of experiment 2 indicate that only 15 kg of fertilizer would be needed per ha compared with about 120 kg if aerially spread.

Although applied phosphate did not move far laterally, it did apparently move downwards a small way into the soil, far enough for the roots of a seedling sown at 5 mm depth to capture some of the phosphate. Whether the uptake was via the seminal root, the subcoleoptilar internode or lateral roots developed from it, or by nodal roots extending from the crown is not known. However, the habit of this tropical, panicoid grass (Ellis 1977) of elevating the coleoptilar node to the soil surface (Hyder 1974) may be important in the utilization of surface-applied phosphate fertilizer. Many temperate grasses such as the cereals do not normally elevate the coleoptilar node and thus do not develop roots early in the surface soil above the seed. Thus they respond best to phosphorus fertilizer applied directly below the seed rather than broadcast above or mixed with the seed (Allen *et al.* 1954; Nyborg and Hennig 1969).

The need for a small amount of phosphate fertilizer for satisfactory growth of certain grasses on mulga soil is clearly shown. The minimum needed is, however, apparently much greater than 0.6 mg phosphorus (treatments 5 and 7). The efficiency of phosphate fertilizer recovery was much lower than 15% as suggested in the methodology, and was probably less than 4% (treatment 8). A low recovery rate from phosphate fertilizers is, however, not uncommon in cereals under conditions of moisture stress (Mitchell 1957). Experiments to determine the feasibility of coating the seed with adequate phosphate fertilizer, without causing a reduction in germination, are reported in Parts B and C.

Part B: Preliminary Coating Trials

Experiment 3: laboratory tests of coating methods and substances

Materials and Methods

A range of high-phosphorus substances, including reagent-grade chemicals, food-grade phosphates and commercial fertilizers, were ground up by using a mortar and pestle, and their coating suitability tested as either dry powders, suspensions, or concentrated solutions if water soluble. Buffel grass (*C. ciliaris*) was used as the test species as seed was more readily available than for *A. pubescens*, and any promising results would have immediate field relevance to huge areas of land. Detergents (Teepol or Comprox) were essential additives to ensure adequate wetting of the bristly buffel grass fascicles*. Freshly coated seeds were dried for up to 15 days over silica gel in desiccators without any reduction in seed viability.

For germination tests, seeds were always sown at 5-mm depth in dry, finely sieved mulga soil 1.5 cm deep in aluminium germination trays. Germination tests on paper were considered unrealistic and likely to prejudice the results of the more ionic fertilizers. The soil was then brought to field capacity with a fine spray of rainwater and the trays covered with Perspex lids and left on the laboratory bench (temperature range, 20–30°C). Counts of emerging seedlings were made daily for 10 days. In one of the concluding germination trials, buffel fascicles were individually dipped into a 3% Methofas glue (mixed with two drops of Teepol per 50 ml of solution), then into a finely ground powder of fertilizer and then placed in a desiccator to dry for 3 days. Forty fascicles were sown per treatment. The results are presented (Table 3) as an indication of the effect of the coatings on seedling emergence and for comparison with later pot trials with the same fertilizers.

* The fascicle is the bristle-covered dispersal unit of *Cenchrus ciliaris* L. which may contain up to five caryopses (i.e. grains) each enclosed in its own lemma, palea and glumes (Tothill and Hacker 1973).

Results and Discussion

The ranking of germination suppression in this experiment was consistent with most other tests. Differences between tests were reasonably ascribed to variations in the amount of coating adhering in each trial. However, the apparent enhancement of early germination by the insoluble calcium phosphates (Table 3) was repeatable. These two fertilizers never suppressed germination of buffel grass caryopses. All the other chemicals tested markedly reduced germination of caryopses on at least one occasion, with commercial superphosphate, double superphosphate and monoammonium phosphate (MAP) being particularly toxic and almost completely inhibiting seedling emergence. Table 3 shows that germination rate and total germination were reduced by most coatings at the heavy rates used.

Table 3. Percentage seedling emergence from buffel grass fascicles coated with various phosphate fertilizers and germinated in moist mulga soil

See text for details of coating methods. Coatings are listed in their approximate order of solubility in water

Coating material	Mean coat weight (mg)	% P	Solubility rating at 25°C	Percentage emergence	
				3 days	7 days
Control	0	—	—	37	90
Methofas glue	0.1	0.0	Low	35	67
Sodium hexametaphosphate (Tech. grade)	23.1	29.6	Very High	0	43
NaH ₂ PO ₄ ·2H ₂ O (A.R. grade)	11.7	19.9	Very High	3	55
NH ₄ H ₂ PO ₄ (A.R. grade)	21.3	27.0	High	0	58
Calgon (commercial grade)	13.9	24.1	High	0	18
Na ₂ HPO ₄ (A.R. grade)	11.7	21.8	Moderate	0	55
KH ₂ PO ₄ (A.R. grade)	16.3	22.8	Moderate	0	77
Monoammonium phosphate (feed grade)	16.9	20.5	Partly	0	80
Double superphosphate (fertilizer)	20.7	19.2	Partly	7	70
Superphosphate (fertilizer)	20.4	9.2	Partly	7	70
CaHPO ₄ ·2H ₂ O (A.R. grade)	5.4	18.0	Insoluble	30	75
CaHPO ₄ (A.R. grade)	11.7	22.8	Insoluble	62	85

A subsequent germination test was made with the same chemicals applied as suspensions or as highly concentrated solutions and at lower rates (3.7–12.0 mg per fascicle). This time there was little reduction in germination rate because of coating and no consistent effect on total germination, except a large reduction again by commercial Calgon (sodium hexametaphosphate, a water softener) (see Table 3). Other important conclusions from this early work were:

- (i) Dry powders are more difficult than solutions or suspensions to apply evenly and with any weight precision to buffel fascicles.
- (ii) Greater quantities of coat can normally be applied by using a glue plus finely ground fertilizer than by using concentrated solutions. Only NaH₂PO₄·2H₂O and sodium hexametaphosphate solutions could achieve coatings of much greater than 10 mg.
- (iii) The very soluble sources are most easily applied as concentrated solutions, the completely insoluble ones as slurries and the commercial phosphate

fertilizers (a mixture of soluble and insoluble substances) by wetting the fascicles in glue and then rolling them in finely ground, dry fertilizer.

- (iv) Pyrophosphates are quite unsuitable phosphorus sources as they seriously damage soil structure adjacent to the pellet.

Experiment 4: suitable phosphorus sources for seedling growth

Materials and Methods

A pot trial was conducted in a glasshouse to compare 10 phosphorus sources as seed coatings for stimulating seedling growth of Gayndah buffel grass. The substances used, their relative solubility in water and mean amount of coating applied are shown in Table 4. Citraphos is calcined, C-grade Christmas Island rock phosphate (Palmer *et al.* 1979). Buffel fascicles of similar size (3–4 mg) and conformation were used and all the fertilizers were thoroughly ground with a mortar and pestle before being applied. Fascicles were individually coated as described in experiment 3.

Table 4. Experiment 4: phosphorus fertilizers used to coat Gayndah buffel fascicles, their phosphorus content, coat weight, coat : seed ratio and treatment code
Mean fascicle weight was 3.37 mg

Fertilizer	Code	Solubility in water	Coat weight (mg)	Weight of P in coat (mg)	Coat:seed ratio
Nil	CON	—	0.0	—	—
CaHPO ₄ (A.R. grade)	CAI	Insoluble	7.6	1.74	2.3
CaH ₄ (PO ₄) ₂ (Tech. grade)	CAS	Moderate	10.4	2.57	3.1
Citraphos	CIT	Slightly	8.0	1.21	2.4
Superphosphate	SUP	Partly	8.4	0.83	2.5
Double superphosphate	D/S	Moderate	12.0	2.31	3.6
Monoammonium phosphate (fertilizer grade)	MAP	Moderate	11.5	2.35	3.4
Sodium hexametaphosphate (Tech. grade)	SHP	High	14.2	4.21	4.2
NH ₄ H ₂ PO ₄ (A.R. grade)	NH4	High	9.9	2.66	2.9
KH ₂ PO ₄ (A.R. grade)	KH2	High	10.3	2.34	3.0
NaH ₂ PO ₄ .2H ₂ O (A.R. grade)	NAP	High	5.7	1.12	1.7

The seeds were planted, pedicel end downwards, at shallow depth into dry, mulga soil in pots lined with a plastic bag. The longest bristles were still visible above the soil surface. Each pot contained 17 seeds, 12 with a particular coating plus 5 uncoated ones, sown in the pattern shown in Fig. 2. The uncoated seeds were to test for lateral availability of phosphorus from adjacent pellets. In all, there were three blocks of 11 pots, each pot containing one treatment.

After planting, the pots were watered regularly with a fine, pressurized spray for 72 h so that the surface soil remained moist and the moisture content of all the soil had reached field capacity after this time. At each watering a pot received about 100 ml of rainwater. Thereafter watering was twice daily, by gently flooding, until 7 days after sowing when a once-daily, morning watering took over. Multiple emergences from one fascicle were thinned to one plant 5 days after sowing. Plants were inspected twice daily and the following data recorded: time to coleoptile emergence, time of leaf 3 emergence, time to full expansion of leaf 3, time to full expansion of leaf 5, length of leaf 5 (L5).

Plants were cut off below the crown once L5 had fully expanded and the trial was terminated 41 days after sowing. By this time all plants showing any obvious fertilizer response had L5 fully expanded. All the remainder had at least three leaves, but were unlikely to reach the five-leaf stage for many weeks. The results were tested by the analysis of variance technique, and means were separated by using Duncan's Multiple Range Test.

Experiment 5: phosphorus source $\times$ rate trial**Materials and Methods**

A second pot experiment was conducted in the glasshouse using four fertilizer coatings which had produced a range of responses from buffel seedlings in experiment 4. Each fertilizer was applied at a relatively high and at a low rate to fascicles of Gayndah buffel (Table 5). Low rates were applied in a liquid medium to allow reasonable control over the quantity of coating applied. However, despite this precaution, $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ in solution was applied relatively heavily (Table 5). Slurries were used where the compound was relatively insoluble. High coat weights were produced by using powdered fertilizer and glue as described for experiment 4.

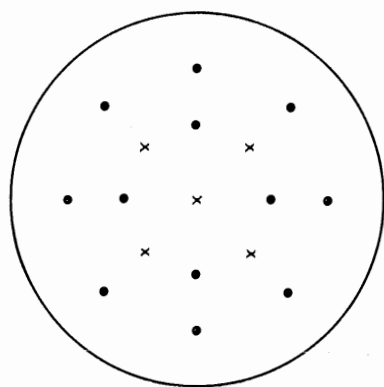


Fig. 2. Experiment 4: sowing layout of buffel grass seeds within each pot.
● Fascicle coated with fertilizer,
× uncoated fascicle.

Table 5. Experiment 5: phosphorus fertilizers, coating rates and methods used to coat buffel grass fascicles

Fertilizer	Code	Method of application	Mean dry weight of coat (mg)
Nil	CON	—	0.0
Double superphosphate	DSL	Glue + powder	22.6
Double superphosphate	DSS	Slurry	2.5
CaHPO_4 (A.R. grade)	CAL	Glue + Powder	21.8
CaHPO_4 (A. R. grade)	CAS	Slurry	2.2
$\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ (A.R. grade)	NAL	Glue + powder	20.0
$\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ (A.R. grade)	NAS	Solution	11.4
$\text{NH}_4\text{H}_2\text{PO}_4$ (A.R. grade)	NH4L	Glue + powder	15.5
$\text{NH}_4\text{H}_2\text{PO}_4$ (A.R. grade)	NH4S	Solution	3.2

The soil was the same as for experiment 4, and sowing and watering were conducted in the same way. The only differences were that larger pots holding 11.2 kg of air-dry soil were used, 20 seeds were sown per pot, and uncoated seeds were not sown amongst coated ones. Altogether there were 45 pots, five blocks of nine pots, with one treatment per pot.

The following data were recorded for each seedling: time to seedling emergence, time to full expansion (i.e. ligule visible) of leaves 3 and 5, time to first tiller appearance and the subtending leaf number.

When leaf 5 was fully expanded, its length was measured, and the shoot was removed, oven-dried and weighed. All samples were analysed for nitrogen and phosphorus by a micro-Kjeldahl digestion followed by titration against boric acid for nitrogen content, and spectrophotometric absorption at 660 nm, after complexing with molybdate, for phosphorus.

Apart from the data on emerging seedling numbers, all data were analysed by using a subset of 11 plants from each pot. This was done to overcome calculation problems caused by unrealistically large numbers of missing values in most treatments owing to a proportion of the fascicles having no caryopsis. Eleven was the minimum number of plants to survive in any pot and the 11 used from each pot were the first 11 to emerge and survive. The analysis of variance technique was used to test for significance, each coating being regarded as an unrelated treatment. Means were separated by Duncan's Multiple Range Test.

Table 6. Experiment 4: effect of various phosphate fertilizer coatings on the emergence and growth of buffel grass seedlings in pots of mulga soil

Values within a column followed by the same superscript are not significantly ($P < 0.05$) different (Duncan's Multiple Range Test)

Coating ^A	% emergence		Days from sowing to leaf 3 appearance	Days to full expansion of leaf 3	% of emerging seedlings with 5 fully expanded leaves 41 days after sowing
	65 h	113 h			
CON	47.2 ^b	86.1 ^b	12.8 ^d	30.2 ^d	0.0 ^a
CAI	55.6 ^b	94.4 ^b	11.4 ^c	21.3 ^c	8.8 ^a
CAS	25.0 ^{ab}	94.4 ^b	10.8 ^b	15.1 ^{ab}	100.0 ^b
CIT	52.8 ^b	100.0 ^b	13.2 ^d	32.4 ^d	0.0 ^a
SUP	13.9 ^{ab}	91.7 ^b	11.4 ^c	16.7 ^{ab}	87.5 ^b
D/S	5.6 ^{ab}	80.6 ^b	11.5 ^c	16.3 ^{ab}	100.0 ^b
MAP	25.1 ^{ab}	88.9 ^b	9.3 ^a	13.2 ^a	100.0 ^b
SHP	0.0 ^a	19.4 ^a	11.8 ^c	17.2 ^b	95.6 ^b
NH4	33.3 ^b	83.3 ^b	9.8 ^a	13.7 ^a	100.0 ^b
KH2	27.8 ^{ab}	86.1 ^b	10.9 ^b	16.0 ^{ab}	100.0 ^b
NAP	38.9 ^b	88.9 ^b	10.4 ^b	14.6 ^{ab}	96.9 ^b

^A See Table 4 for explanation of the treatment code.

Results

Experiment 4

Sodium hexametaphosphate (SHP) badly flocculated the clay in the soil and within a week the infiltration rate of the surface soil in these pots was severely reduced. No other coating had any apparent effect on soil structure. Emergence was slowed significantly by SHP, double superphosphate and single superphosphate (Table 6) and, as in earlier studies, the insoluble CaHPO_4 tended to enhance early emergence. However, population differences had largely disappeared after 113 h, except for SHP. After 12 days, fertilizer effects were clearly evident. Leaf 3 appeared earlier in treatments with very soluble phosphorus sources than in treatments using insoluble sources such as CaHPO_4 and Citraphos (Table 6). This trend continued as the plants grew larger, irrespective of earlier germination setbacks. Note particularly the difference between the two calcium phosphates, CaHPO_4 and $\text{CaH}_4(\text{PO}_4)_2$. Only 9% of the uncoated seedlings showed any signs of having access to phosphorus from adjacent coated seeds, the majority of these being from treatments KH_2PO_4 and $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$.

Experiment 5

Seedling emergence was first noticed after 64 h and was fastest from the uncoated seeds. After 72 h it was apparent that some coatings, in particular double super-

phosphate (DSL) and ammonium phosphate (NH₄L), when heavily applied, delayed emergence (Table 7). Except for NH₄L and DSL, twice-daily watering of the pots resulted in the emergence of similar numbers of seedlings for all treatments after

Table 7. Experiment 5: effect of different seed coatings on the emergence of buffel grass from c. 5 mm depth

Values followed by the same superscript in a particular column are not significantly ($P < 0.05$) different (Duncan's Multiple Range Test)

Coating ^A	Percentage emergence			Mean time (h) to seedling emergence of the first 11 seedlings
	72 h	96 h	7 days	
CON	43 ^c	75 ^c	83 ^b	75 ^a
DSL	5 ^a	31 ^a	67 ^a	102 ^d
DSS	25 ^b	67 ^c	81 ^b	83 ^b
CAL	31 ^{bc}	66 ^c	83 ^b	78 ^{ab}
CAS	34 ^{bc}	70 ^c	87 ^b	77 ^a
NAL	24 ^b	63 ^c	82 ^b	81 ^b
NAS	17 ^{ab}	57 ^{bc}	81 ^b	86 ^b
NH ₄ L	4 ^a	48 ^b	72 ^{ab}	94 ^c
NH ₄ S	44 ^c	75 ^c	86 ^b	75 ^a

^A See Table 5 for explanation of the treatment code.

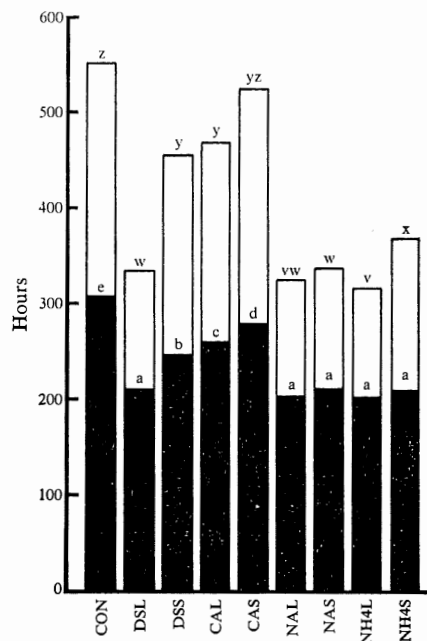


Fig. 3. Experiment 5: effect of nine different phosphate fertilizer coatings (described in Table 5) applied to fascicles of buffel grass on the time from seedling emergence to full expansion of leaf 3 (shaded columns), and the time between full expansion of leaves 3 and 5 (open tops of columns). Columns surmounted by the same letter are not significantly different ($P < 0.05$).

7 days. Thereafter, until L3 fully expanded, seedling growth was enhanced by all coatings (Fig. 3), with DSS and the insoluble CAL and CAS being the least effective.

After leaf 3 had expanded, the large coatings of soluble phosphate, namely NH₄L, NAL, NAS and DSL, were the most effective in stimulating seedling growth and early tillering (Table 8). The early effectiveness of NH₄S was lost after leaf 3 expanded,

resulting in a decreased rate of leaf appearance and reduced tillering. Dry matter yield and length of leaf 5 were affected by coatings in a similar way to rate of later leaf production. The mean shoot dry weight of NAL plants with five fully expanded leaves was three times that of control plants (Table 8). Uptake of phosphorus

Table 8. Experiment 5: the effect of the application of various phosphate coatings to buffel grass fascicles on tillering, shoot yield and phosphorus uptake by the seedlings

Values followed by the same superscript are not significantly ($P < 0.05$) different (Duncan's Multiple Range Test)

Coating ^A	Percentage of tillered plants 18 days after sowing	Dry matter yield of shoots (mg)	Phosphorus content of shoots (μ g)	Difference in P yield (μ g) relative to the concentration in CON plants
CON	0 ^a	24.0 ^a	44 ^a	0
DSL	33 ^c	68.3 ^{de}	205 ^{cd}	+80
DSS	0 ^a	38.7 ^b	63 ^{ab}	-8
CAL	0 ^a	34.5 ^b	61 ^{ab}	-1
CAS	0 ^a	29.8 ^{ab}	52 ^a	-3
NAL	47 ^d	76.2 ^e	243 ^d	+104
NAS	34 ^c	64.3 ^d	188 ^c	+71
NH4L	43 ^d	72.3 ^{de}	269 ^d	+137
NH4S	10 ^b	53.0 ^c	95 ^b	-2

^A See Table 5 for explanation of treatment code.

generally reflected dry matter accumulation, but where larger coatings had been used, considerable uptake of fertilizer phosphorus occurred (Table 8). The extra phosphorus from the NH4S coat (mean of 0.87 mg phosphorus) apparently ran out for about one-quarter of the plants shortly after L3 fully expanded and those plants redistributed their internal supply to maintain a moderate growth rate. The result was phosphorus concentrations in the shoots no higher in these slower growers than those of unfertilized plants. However, the slower growing NH4S seedlings (mean 43.6 mg dry matter and 76.3 μ g shoot phosphorus) were still much faster growing and larger than those in DSS, CAL and CAS, yet significantly ($P < 0.05$) smaller than the others in their pots (mean 64.6 mg dry matter and 118.5 μ g phosphorus in shoots).

Nitrogen content of the shoots of NH4L plants (3.87%) was significantly ($P < 0.05$) higher than the 3.56% of NAL plants, but this difference represents only 10% of the extra nitrogen added to the pots by the ammonium fertilizer.

Discussion

Generally orthophosphates are more effective sources of phosphorus for plants than are metaphosphates and pyrophosphates (Jolibois *et al.* 1935), and soluble orthophosphates are better than insoluble orthophosphates (Allen *et al.* 1954). However, soil reaction and plant species can markedly influence the relative effectiveness of phosphorus fertilizers (Hausenbuiller and Weaver 1960), with many less-soluble forms being more effective on acid soils than on alkaline soils (Salter and Barnes 1935; Terman *et al.* 1958). The results of both experiments agree with these overseas results, although water-insoluble phosphates such as Citraphos and CaHPO_4 were still unavailable to buffel seedlings on the acid soils used (pH 5.0). Of the

water-soluble phosphates used, monoammonium phosphate was usually the most effective. This has also been the case on other soil types where plants were grown to a greater size (Dion *et al.* 1949; Mortvedt and Terman 1978).

In contrast to most world experience, soluble fertilizers in close contact with fascicles of buffel grass, were only toxic to germinating seedlings when applied at high rates. Studies by Sayre and Clarke (1935) on beans, Sadler (1980) on flax, Carter (1967) on a range of crops, and Nyborg and Hennig (1969) on barley, flax and rapeseed indicate that any fertilizer, especially nitrogen fertilizers, mixed with seed at relatively high rates severely reduces seedling emergence. Cereals, which are closely related to pasture grasses, were not as sensitive as most of the other crops tested (Carter 1967; Nyborg and Hennig 1969). Younger and Gilmore (1978) have also reported that buffel grass did not have its emergence from clay soils severely reduced by heavy (11:1) seed coatings of superphosphate. Thus our results are not entirely uncharacteristic, especially as the caryopsis in the buffel fascicle is not in direct contact with the fertilizer coat. The glumes, lemma and palea could conceivably have acted as semipermeable membranes, allowing moisture through but not most of the osmotically active salts in the coat. In addition, highly soluble phosphates would probably move further in soil solution before binding to soil particles (Rogers *et al.* 1953), and this would help to dilute the fertilizer around the emerging radicle. Nonetheless, many radicles and later nodal roots had a distinct bend in them to avoid close association with the fertilizer coat.

The extra phosphorus needed to produce a good growth rate by buffel seedlings under the conditions of experiment 5 could be reckoned at 40–65 μg per seedling, allowing for an extra 20% for the root system (based on the data from Silcock *et al.* 1976). This is lower than the estimate of 80–90 μg made before these experiments were conducted. The average percentage phosphorus in the shoots at harvest in the unfertilized and ineffective fertilizer treatments varied between 0.16 and 0.18%, while for the four best coatings it ranged between 0.29 and 0.37%. The mean for NH_4S was 0.18%, which is well below the 0.26% tentatively suggested by Christie (1975) as the optimal tissue concentration at the pre-flowering stage on this soil.

Overall, the initial results from coating buffel grass seed with phosphate fertilizers were most encouraging, with the highly soluble orthophosphates meeting most of the theoretical requirements envisaged before the trials began. Some lateral spread of soluble fertilizers may occur but, in practice, seedlings have to obtain their extra phosphorus requirements from their own coating. Provided the fertilizer is water soluble, the cation carrier seems unimportant. Monosodium and monoammonium orthophosphates are readily available commercially, in bulk, at moderate prices. Thus they offer the best practical source of coating material for further experiments. Monosodium phosphate was chosen for the next experiment because (i) much more concentrated phosphorus solutions can be made from it, and (ii) any possible confounding effects due to ammonium ions are avoided. The trials aimed to determine the optimum amount of coating required by an individual fascicle to produce the desired enhancement of buffel seedling growth on mulga soils.

Part C: Coating Rates

Materials and Methods

Two pot experiments (experiments 6 and 7) were conducted using identical techniques, except that the first experiment used more coated seeds and a much less severe moisture regimen than the

second. Solutions of A.R. grade $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ were made up, ranging from one-quarter saturated to fully saturated at room temperature (*c.* 0.78 mg/ml). By dipping buffel fascicles into the various solutions we were able to achieve a range of coatings between 0 and 30 mg per fascicle (0.6 mg phosphorus per fascicle). In experiment 6, 154 seeds and 13 pots were used, while in experiment 7, 120 seeds and 10 pots were used. In the first experiment (experiment 6), the glasshouse was covered with shadecloth and the daily water allocation of about 160 ml was 30% more than in experiment 7. As a result, the soil surface remained visibly wet for a longer period each day. The pots were 20 cm diameter and held 7.5 kg of air-dry mulga soil. The 12 seeds per pot were sown just below the soil surface into dry soil in a pattern similar to that in Fig. 2. Each seed had a known weight of fertilizer coated on it, and they were stratified by weight so that each pot contained six seeds of two adjacent weight classes. In this way an aberrant or damaged pot would not completely eliminate results along any section of the response curve, yet widely differing coating rates were not used in the same pot, in case of accidental lateral washing of fertilizer.

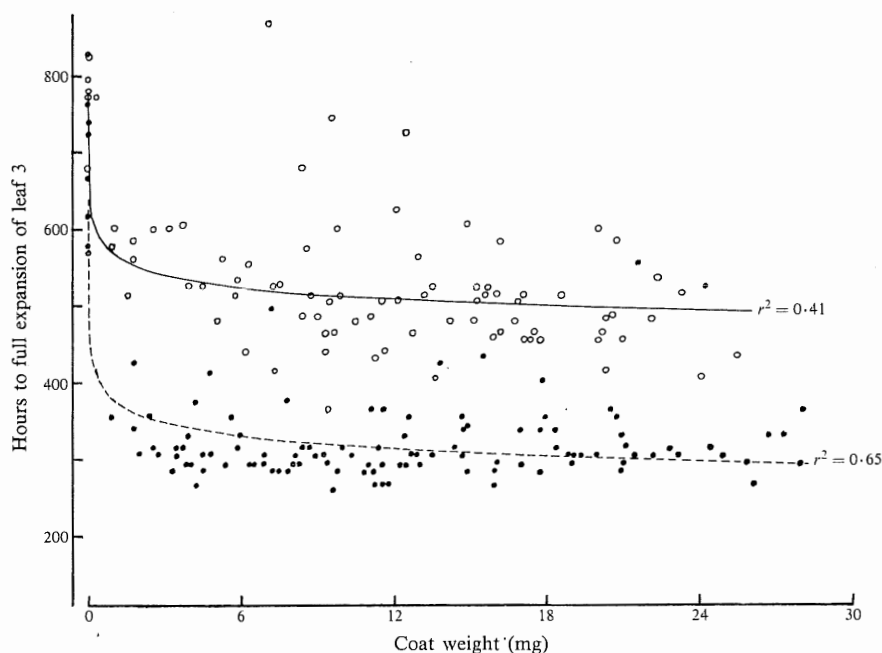


Fig. 4. Response of buffel grass seedlings to different rates of phosphate fertilizer coating on the fascicle, as measured by the time taken to expand three leaves. Response curves are fitted power curves. ● Experiment 6, ○ experiment 7.

The pots were randomly placed in a block and watered regularly with a fine spray for 6 days after sowing to simulate protracted, light rainfall. By this time the soil was at field capacity and thereafter pots were surface-watered each morning. Data recorded for each seed included: time to coleoptile emergence; time to emergence and full expansion of leaves 3, 4 and (where feasible) 5; and lengths of these leaves. The results were plotted against weight of coating, and regression lines were fitted.

Results and Discussion

Rate of seedling emergence was unaffected by the range of coatings used. The fertilizer coatings had their greatest effect during the expansion of leaf 3, as expected, and thereafter growth rate was largely unaffected by the amount of fertilizer, except for uncoated seed. Data are presented for both trials showing the time between

sowing and full expansion of leaf 3 (Fig. 4). Lines of best fit have also been calculated. In both cases, large amounts of coating (> 20 mg) were no more effective in enhancing seedling growth than were moderate rates (10 mg). In the well-watered pots of experiment 6, any coating seemed to be fully effective for producing rapid buffel seedling growth. However, in the drier trial (experiment 7), rates below about 9 mg of coat were not quite as effective. Availability of soil moisture around the seed appears to influence the minimum weight of coating needed to produce maximum seedling growth rate.

Because these pots trials were watered via the soil surface, the soil surrounding the fertilizer was wetted once daily. Uptake of phosphate by surface roots would probably only occur while this zone was wet. Hence uptake would have occurred over a longer period each day in experiment 6 and thus have allowed small amounts of fertilizer to be more effective. In the field, where the surface soil dried out rapidly, greater amounts of seed coating would probably be needed for optimal seedling growth. Coatings of about 10 mg of a 20% phosphorus fertilizer, such as mono-sodium phosphate, will probably be needed for field tests. This represents a seed:coat ratio of just over 1:3—a realistic objective. At such rates, the necessary efficiency of phosphorus recovery is only 2–4.5% (assuming 40–90 μg phosphorus is needed). This is low considering the proximity of the seed to the fertilizer, but the time scale is only short.

General Discussion

There would appear to be a good chance of applying adequate coatings of phosphorus fertilizer to seeds to enhance seedling growth of tropical grasses on the sandy red-earths of South-west Queensland without significant detriment to seed germination. Our success has probably been greater than in other parts of the world for a number of reasons. Firstly, no attempt was made to retain extra moisture around the seed, other than that which was naturally available in the surface soil for seed germination. The coating tends to delay germination, so that seeds germinate only when favourable soil moisture exists for a prolonged period. We have evidence that some coated seeds, which initially fail to germinate, can retain their viability and emerge when the soil is wetted a second time. This delay could be an advantage in a semi-arid area where good establishment rains are scarce despite the number of falls which will germinate seeds (Silcock 1973). Delayed germination may be especially beneficial to buffel grass because it tends to emerge after comparatively small falls of rain. The resulting seedlings die very quickly under the conditions in South-west Queensland.

Secondly, the tropical conditions under which buffel grass and other panicoid grasses grow best, are conducive to extremely rapid seedling growth under good moisture conditions. However, low soil fertility can seriously limit seedling growth rate under such conditions, more so than fertility might affect seedling growth of temperate grasses in their normal growing conditions (i.e. during spring). Thus the demand for nutrients can theoretically be greater in tropical grass seedlings than in temperate ones, especially for immobile elements like soil phosphate. The added phosphorus primarily affects rate of cell division and expansion of meristems but consequently influences leaf area, shoot dry matter and rate of tillering. Earlier tillering, at lower nodes (experiment 1), and the accompanying formation of adventi-

tious roots may be very important for successful establishment in the field (Silcock 1975). Wilson *et al.* (1976) have shown the importance of adventitious roots in minimizing moisture stress in seedlings with large leaf areas. Christie (1975) stated that it is moisture stress which ultimately kills phosphorus-deficient buffel seedlings on mulga soils. Thus phosphate coatings could theoretically be more successful on these xeric, infertile soils than on most other types.

Thirdly, by working with panicoid grasses which elevate the crown from sowing depth up to the soil surface (Hyder 1974), we may also be giving the early seedling root system a better chance than that of temperate species, of exploiting surface-applied phosphate.

One potential problem with broadcast seed is movement of the ungerminated seed away from where its coat washes off, say in a small storm. The magnitude of this problem can be assessed only under field conditions, but we do not expect the problem to be great if other requirements for successfully establishing pastures, such as slight seed burial and soil disturbance, are met.

All the trials to date have been on seeds coated individually under laboratory conditions. If this research is to have practical application, a way must be found of applying suitable fertilizer to the seeds in bulk. The glues and hardeners needed must not affect germination. Coating hairy seeds like buffel grass with insoluble substances such as lime and gypsum is possible (Norton 1969). Applying soluble fertilizers at a consistent, calibrated rate may prove much more difficult on a large scale. Collaborative studies are now being undertaken with a firm which specializes in coating seeds.

There may be additional benefits from sowing fertilizer-coated buffel seed which may offset the extra cost of the coating process. If more reliable establishment can be achieved, recommended sowing rates (2 kg/ha) for mulga soils could be reduced, maybe by half. At recent seed prices, this could save over \$4 per hectare. If seed was aerially sown, the heavier coated seeds could be distributed much more accurately. If ground-broadcast, the coated seed could be cast in much wider swathes than ordinary buffel grass seed, thus saving some sowing costs. The coatings would also, in theory, make theft by ants more difficult, although insecticides could be incorporated in the coating process.

Our estimates show that millions of hectares of infertile, acid, sandy to sandy loam soils in north-eastern Australia could benefit from the successful infusion of a significant amount of buffel grass into areas where it currently cannot be reliably grown.

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