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Phosphorus seed coating increases phosphorus uptake, early growth and yield of pearl millet (*Pennisetum glaucum* (L.) R. Br.) grown on an acid sandy soil in Niger, West Africa

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Abstract

In pot and field experiments conducted in 1990 and 1991 on an acid sandy, phosphorus (P) deficient soil in Niger, West Africa, the effect of seed coating on seedling emergence, early growth and grain yield of pearl millet (*Pennisetum glaucum* (L.) R. Br.) was studied. Seeds of pearl millet were coated with different rates (0; 0.5; 1.0; 2.0; 5.0; 10.0 mg P seed^{-1}) and types of P fertilizers (single superphosphate, ammonium dihydrogen phosphate; monocalcium phosphate, sodium dihydrogen phosphate and sodium triphosphate). Seedling emergence was generally reduced at coating rates higher than 0.5 mg P seed^{-1} and prevented with single superphosphate and sodium triphosphate at rates higher than 5 mg P seed^{-1}. No correlation was found between the pH and osmomolity of the coatings and final emergence of millet seedlings. The most favourable effect on plant growth and P content was achieved with ammonium dihydrogen phosphate (AHP) as seed coating. This was attributed to the enhancement effect of ammonium on P uptake. Compared to the untreated control dry matter production at 20 days after planting (DAP) was increased by 280%, P content per plant by 330%, total biomass at maturity by 30% and grain yield by 45%. Although seed coating with AHP may be harmful to seedlings emergence, it represents a suitable method to enhance early growth and increase yield of pearl millet.

Introduction

In West Africa pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the most important food crop [12] and its production is limited by inherent low soil fertility. One of the major constraints to millet production is phosphorus (P) deficiency at early growth stages of the crop [5, 22].

Deficiency of nutrients during early plant growth can reduce yield, since various yield-determining components are developed in this stage. Cowie and Asher [6] showed that maximum grain number in sorghum was determined at early growth stage and was reduced when the seedlings suffered from nitrogen deficiency. In tomatoes, yield was reduced to about 50% if P deficiency occurred at the seedling stage [28]. Vigorous early growth, due to sufficient seed reserves, can counteract stress conditions [32]. This is important particularly in the Sahelian region, where plant establishment is often impaired by drought and sand blast, occurring regularly prior to the rainfall events [3].

In small seeded species such as subterranean clover, seed reserves were exhausted after ten days [23]. In oats, most of the P reserves from the seeds were translocated to the developing roots and shoot during the first eight days after germination [16].

Pearl millet which has very small seeds (7–

10 mg seed^{-1}) and low P reserves (about 20 μg P seed^{-1}), should require an external supply of P soon after emergence. If sown in the traditional way at rates of 200,000 seeds ha^{-1}, the seed reserves would only be 3.8 g P ha^{-1}. This is very low compared with a demand of about 20 g P ha^{-1} for producing 5 kg ha^{-1} dry matter within the first 20 days.

In millet production, using P surface broadcast or point placement application technique [5], young seedlings were supplied insufficiently with P.

Although seed coating is commonly used in cereals, such as maize [42], barley [1], wheat and oats [37] no information is available whether seed coating is a suitable method of meeting early P demand and improving growth of pearl millet. The present work examines the effect of seed coatings with different P fertilizers and P rates on emergence, early growth, and yield of pearl millet on an acid sandy soil in Niger.

Material and methods

Pot experiment

A pot experiment was conducted in a growth chamber to compare the suitability of different P fertilizers for seed coating of pearl millet. The P fertilizers used were (i) single superphosphate ($Ca(H_2PO_4)_2 + 2CaSO_4$; SSP), (ii) ammonium dihydrogen phosphate ($NH_4H_2PO_4$; AHP), (iii) monocalcium phosphate ($Ca(H_2PO_4)_2 + H_2O$; MCP), (iv) sodium dihydrogen phosphate ($NaH_2PO_4 + 2H_2O$; SHP) and (v) sodium triphosphate ($Na_5P_3O_{10}$; STP). With the exception of SSP, reagent-grade chemicals were used (Fluka, Chemie AG). Each fertilizer was applied at rates of 0.5; 1.0; 2.0; 5.0; and 10 mg P seed^{-1}, which was equivalent to 0.1; 0.2; 0.4; 1.0; and 2.0 kg P ha^{-1} (assuming that millet is sown at 2.0×10^5 seeds ha^{-1}). The seed coating procedure was performed by Saat- und Erntetechnik GmbH, Eschwege, Germany, in a rotation pan using bentonite as coating substance.

For the pot experiment top soil (0–30 cm; Psammentic Paleustalf) was used from the experimental site at the ICRISAT Sahelian Center at Sadoré, Niger (climate and soil properties see below). The pots (plastic trays) were filled with 12 kg air-dried soil and watered to field capacity. For each treatment 50 seeds of pearl millet (cv. CIVT) were planted at a depth of 10 mm and covered with a plastic foil to prevent water loss. Inert coated seeds (0 mg P seed^{-1}) and uncoated seeds were sown additionally as control, to separate physical and chemical treatment effects of the coating.

With the exception of the nutrients applied with the P seed coatings no further fertilization took place. Plants were grown under controlled climatic conditions at 30°C/25°C day/night temperature with 14 h day length. The pots were watered daily to maintain moisture at field capacity. Emergence was counted daily and plants were harvested 16 days after planting. Shoots were dried at 65°C for dry weight determination. The pH of the coatings was determined after shaking 5 g of coated seeds with 15 ml of distilled water for 30 min. In the same solution, the osmomolity of the coatings was determined using and osmometer (Type: Digital, Knauer KG, Germany).

Field experiments

During the rainy seasons of 1990 and 1991, field experiments were conducted at the ICRISAT Sahelian Center (ISC) at Sadoré, 45 km southeast of Niamey, Niger, West Africa (13° 15′ N latitude, 2° 18′ E longitude). In this area mean annual rainfall is 560 mm with a 25% probability of receiving less than 441 mm [41], and a 36°C average daily maximum temperature on a yearly basis.

The soil at the ICRISAT Center is derived from eolian sand deposits, and classified as sandy Psammentic Paleustalf: sandy, siliceous, isohyperthermic [44]. The top soil (0–15 cm) has 91% sand and 9% clay and silt, a pH (H_2O; 1:1) of 4.9, CEC of 1.3 meq 100 g^{-1} soil, base saturation of 42%, organic matter content of 0.17% and available P (Bray I) of 2.6 mg kg^{-1} soil. The field capacity for water is 0.14 m^3 m^{-3} [30].

Pearl millet (cv. CIVT) was planted manually in pockets spaced 1 m × 1 m on plots of 12 m^2 (12 m × 1 m) in 1990 and 45 m^2 (5 m × 9 m) in 1991. Plots were laid out completely randomized with 6 replications. Each pocket received 20 seeds.

In 1990 the treatments were (i) seeds not coated; (ii) seeds inert coated (0 mg P seed^{-1}); (iii) seeds coated with monocalcium phosphate (MCP); (iv) seeds coated with ammonium dihydrogen phosphate (AHP). Phosphorus was applied at rates of 0.5; 1.0; 2.0 and 5.0 mg P seed^{-1}, equivalent to 0.1; 0.2; 0.4 and 1.0 kg P ha^{-1}.

Since MCP proved unfavourable for plant growth in 1990, in 1991 P was applied only as AHP. Treatments in 1991 were (i) seeds uncoated and (ii) seeds coated with 0.5 mg P seed^{-1} as AHP. Plant height was determined every 10 days by measuring the distance from the ground to the tip of the longest leaf. To monitor the reproductive phase the percentage panicles flowering was counted in 1991 from 60 days after planting (DAP) until maturity. For determination of dry matter accumulation in 1990 plants of a 6 m^2 area were harvested only before tillering (40 DAP). In 1991 plants were harvested at the five-leaf stage (20 DAP), at tillering (40 DAP) and at maturity (90 DAP). At the five-leaf stage the stand was thinned to three plants per pocket and seedlings, which were in excess, were harvested. At tillering and at maturity plants of an area of 9 m^2 were harvested and divided into shoot, panicle and seeds. The plant material was dried at 65°C to constant weight.

Prior to chemical analysis the plant material was ground. Concentration of N in the shoot dry matter was determined using a Macro-N-Analyzer (Heraeus). Phosphorus was determined colorimetrically using the vanado-molybdate method [14] after ashing plant dry matter at 450°C overnight.

The results of the field experiments were statistically analyzed using ANOVA procedures. The LSD mean separation test at a significant level of 5% was calculated by the Student-Newman-Keuls Test and values are presented in the result section as vertical bars.

Results

Pot experiment

In the pot experiment, dependent on the type and rate of applied fertilizer, seed coating affected percent emergence of millet. At a rate of 10 mg P seed^{-1} emergence was prevented completely, irrespective of the P fertilizer used (data not presented). Seed coatings with SSP and STP reduced emergence by more than 50% at a rate of 0.5 mg P seed^{-1} and completely at a rate of 5.0 mg P seed^{-1} (Fig. 1). Seed coatings with 0.5 mg P seed^{-1} did not impair emergence when P was applied as SHP and only slightly when applied as AHP and MCP. However, at a rate of 5.0 mg P seed^{-1} as AHP, MCP and especially as SHP, emergence was reduced (Fig. 1).

The effects on emergence by 1.0 mg and 2.0 mg P seed^{-1} were between the above mentioned P rates of 0.5 mg and 5.0 mg P seed^{-1}. Data for the emergence of uncoated seeds are not presented, because they were similar to the inert (0 mg P seed^{-1}) coated seeds.

Shoot dry weight after 16 days of growth was also affected by the type and the rate of P fertilizer. Seed coatings with increasing rate of P enhanced shoot dry weight when applied as AHP but reduced it when applied as STP (Fig. 2). MCP and SHP had no influence on shoot dry weight at any rate. The increase in shoot dry weight by seed coating with 0.5 mg P seed^{-1} as SSP was probably due to the very low emergence (10%). Thus, emerged plants could take additional advantage of the P amounts from the coatings of ungerminated seeds.

Phosphorus concentrations in the shoot dry matter of 16-day-old seedlings from inert or uncoated seeds were very low (0.6 mg P g^{-1}) (Fig. 2). In a former study with this soil a P concentration of 3.5 mg g^{-1} in the shoot dry matter were found in vigorously growing 12-day-old seedlings [22]. Seed coating with P increased P concentrations in the shoot dry matter when P was applied as AHP, MCP or SHP, but decreased it when applied as STP (Fig. 2). The relatively low P concentration in the shoot dry matter obtained with SSP was probably due to a dilution effect, attributed to the high dry matter production (Fig. 2).

In principle, amounts of P in the shoot dry matter followed the pattern of P concentrations. Amounts were increased with increasing rates of P applied as AHP, MCP and SHP, but decreased when applied as STP (Table 1). At the lowest P rate (0.5 mg P seed^{-1}) the highest P amount was

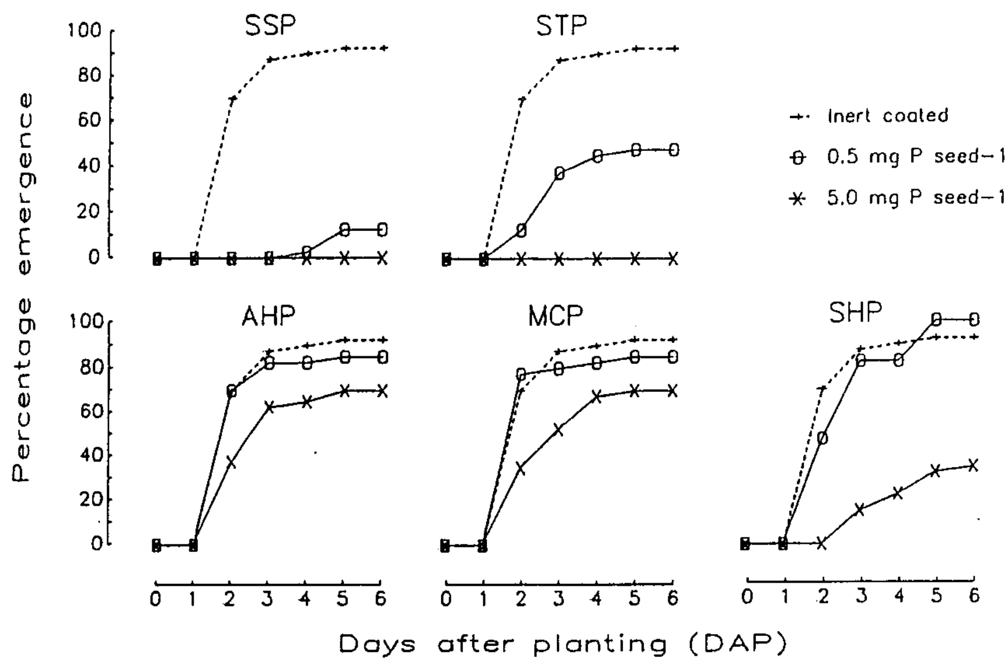

Fig. 1. Emergence of pearl millet as affected by seed coating with different rates and types of P fertilizers. SSP = Single superphosphate; STP = Sodium triphosphate; AHP = Ammonium dihydrogen phosphate; MCP = Monocalcium phosphate; SHP = Sodium dihydrogen phosphate. (Pot experiment).

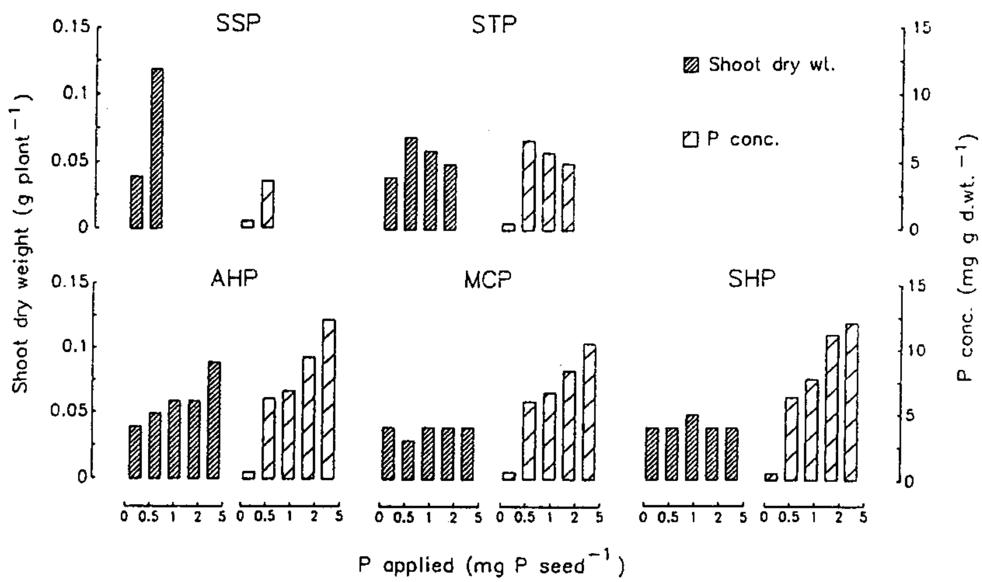

Fig. 2. Effect of type and rate of P fertilizers applied as seed coating on shoot dry weight and P concentrations in the shoot dry matter on 16-day-old pearl millet seedlings. SSP = Single superphosphate; STP = Sodium triphosphate; AHP = Ammonium dihydrogen phosphate; MCP = Monocalcium phosphate; SHP = Sodium dihydrogen phosphate. (Pot experiment).

obtained with STP, whereas at the highest P rate (5.0 mg P seed^{-1}) this was true for AHP (Fig. 3). Amounts of P in millet seedlings from inert coated seeds were similar to uncoated seeds (data not presented). At 16 DAP, P seed reserves seem to be exhausted and the seedlings depended on external P sources.

The pH and the osmomolity of the coatings, which were supposed as factors influencing the emergence of coated seeds, depended on the type and amount of P fertilizer (Table 2). As a rule the pH of the coatings increased in the order: MCP ≈ SSP < AHP ≈ SHP < inert < STP, and with the exception of STP, tended to decrease with increasing rate of applied P. Similarly the osmomolity of the coatings increased with

Table 1. Effect of increasing P rate and different types of P fertilizers applied in seed coatings on amount of P in shoots of 16-day-old seedlings of pearl millet

Treatments (mg P $seed^{-1}$)	Seed P (μg P $seed^{-1}$)		Amount of P in the shoot (μg P $plant^{-1}$)				
	reserves	reserves + coating	MCP[a]	AHP[b]	SHP[c]	STP[d]	SSP[e]
0	19	19	20	20	20	20	20
0.5	19	519	210	310	270	460	440
1.0	19	1019	260	390	390	340	
2.0	19	2019	330	560	470	260	
5.0	19	5019	440	1130	550		

[a] Monocalcium phosphate;
[b] Ammonium dihydrogen phosphate;
[c] Sodium dihydrogen phosphate;
[d] Sodium triphosphate;
[e] Single superphosphate.

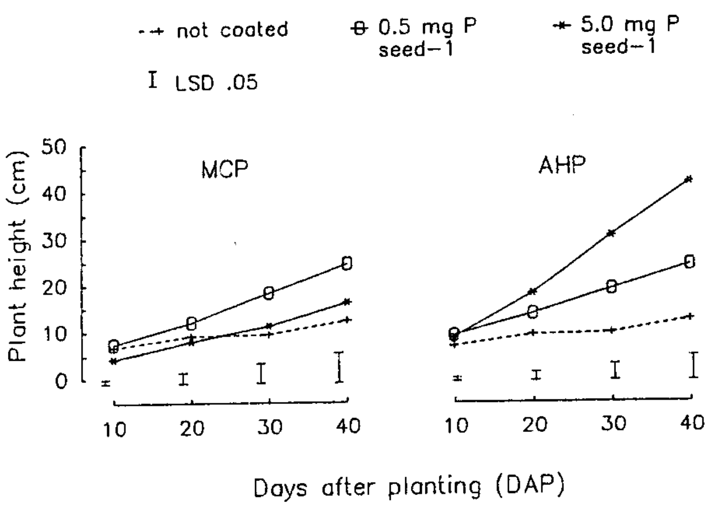

Fig. 3. Plant height of pearl millet as affected by seed coatings with different rates of monocalcium phosphate (MCP) and ammonium dihydrogen phosphate (AHP). (Field experiment, Sadoré, rainy season 1990).

increasing rates of applied P in the order: inert < SSP < MCP < STP < AHP < SHP (Table 2). However, neither the pH (r = 0.07) nor the osmotic values of the coatings (r = 0.03) correlated with emergence at 6 DAP.

Field experiments

In 1990 plant height was enhanced significantly with increasing levels of P when applied as AHP. Seed coating with MCP increased plant height only at the low P level (0.5 mg P $seed^{-1}$). The enhancement of plant height with AHP seed coating was confirmed in 1991. Although seed coating increased plant height significantly only within the first 40 DAP plant development was significantly enhanced until maturity (Fig. 4). Seed coating enhanced percentage panicles flowering 60 DAP to 35% followed by a steady decline, whereas maximum panicle formation in the untreated plants was delayed until 90 DAP. At maturity the percentage of panicles with matured seeds was greater for coated (93%) than uncoated seeds (81%).

In 1990 shoot dry weight and P uptake at 40 DAP were increased when P was applied as AHP, but were not influenced when applied as MCP (Fig. 5). The enhancement of dry matter production with AHP seed coating was confirmed in 1991. Seed coating increased shoot dry matter significantly at the five-leaf stage by nearly 300% and at tillering by 200%. At maturity, seed coating enhanced total dry matter (panicles plus seeds and shoots) by 30% and grain yield (seeds) by 45% (Fig. 6).

Improved growth of millet was correlated also under field conditions with higher P concentrations in the shoots at the five-leaf stage (20 DAP) (Fig. 7). At tillering (40 DAP) P seed coating had no effect on shoot P concentrations (Fig. 7).

Dilution by enhanced growth with P seed coatings, was presumably the cause for the insignificant effects on the P concentrations in the shoot dry matter at tillering. At the five-leaf stage only 28% of the applied P were found in the shoots, whereas at tillering the amount of P in the shoots exceeded that applied as seed coating by a factor of more than 10 (Table 3). The growth improvement of millet, especially at the five-leaf stage was probably not related to improved N nutrition. Although N was applied simultaneously with AHP the concentration of N

Table 2. Effect of increasing P rate and type of P fertilizer on the pH and the osmomolity of the coatings

Treatments (mg P seed^{-1})	pH					osmomolity (mOsmol)				
	MCP[a]	AHP[b]	SHP[c]	STP[d]	SSP[e]	MCP[a]	AHP[b]	SHP[c]	STP[d]	SSP[e]
0			5.76					177		
0.5	3.87	4.99	5.01	6.54	3.83	397	587	680	513	297
1.0	3.09	4.83	4.71	7.20	3.34	563	817	920	600	467
2.0	2.65	4.60	4.39	7.55	3.03	863	1160	1460	1007	520
5.0	2.29	4.18	4.38	7.62	2.79	1330	2163	1617	920	607
10.0	2.16					1667				

[a] Monocalcium phosphate;
[b] Ammonium dihydrogen phosphate;
[c] Sodium dihydrogen phosphate;
[d] Sodium triphosphate;
[e] Single superphosphate.

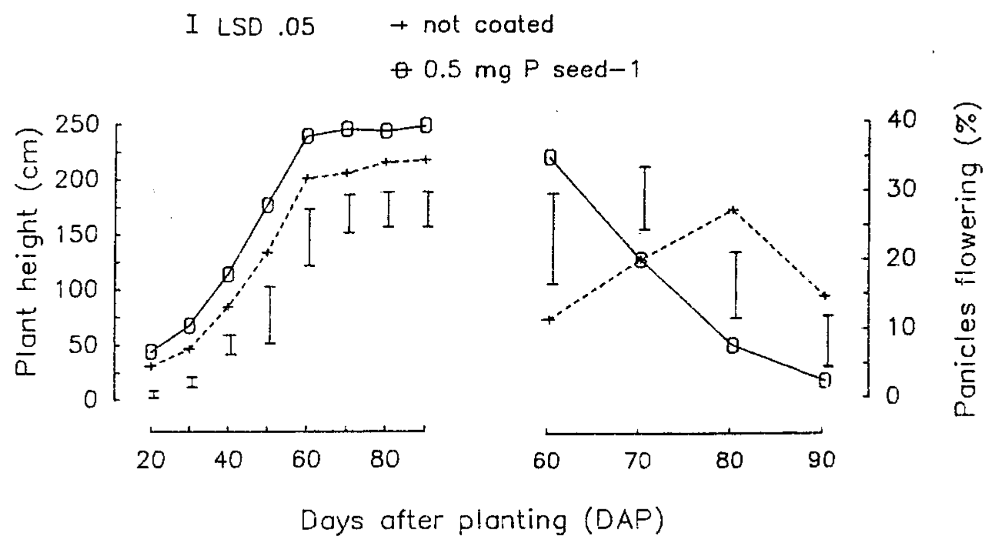

Fig. 4. Plant height and reproductive growth of pearl millet as affected by seed coating with ammonium dihydrogen phosphate (AHP). (Field experiment, Sadoré, rainy season 1991).

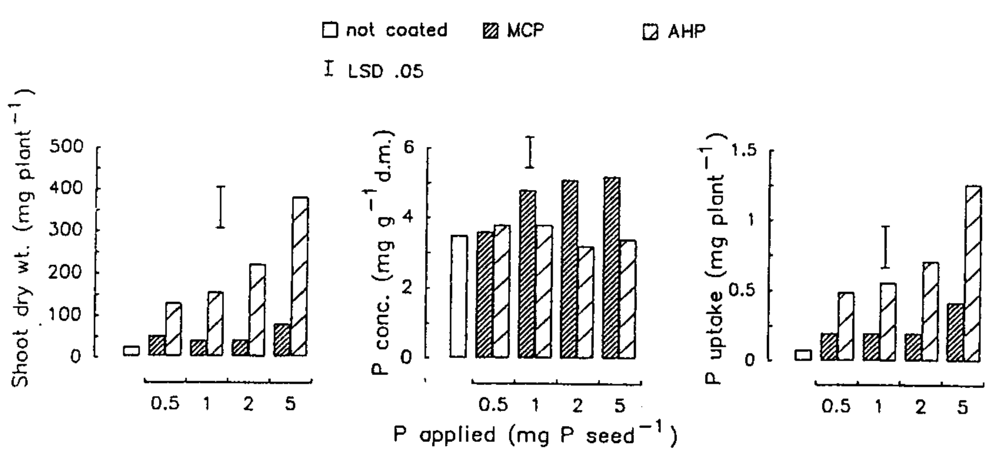

Fig. 5. Effect of increasing P rate of monocalcium phosphate (MCP) and ammonium dihydrogen phosphate (AHP) applied as seed coating on shoot dry weight, shoot P concentrations and amounts of P in shoots of pearl millet before tillering (40 DAP). (Field experiment, Sadoré, rainy season 1990).

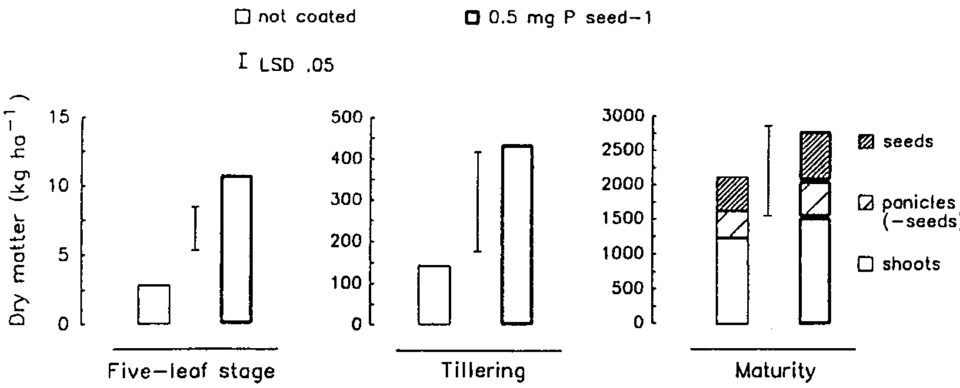

Fig. 6. Dry matter production of pearl millet at the five-leaf stage (20 DAP), at tillering (40 DAP) and at maturity (90 DAP) as affected by seed coating with ammonium dihydrogen phosphate (AHP). (Field experiment, Sadoré, rainy season 1991).

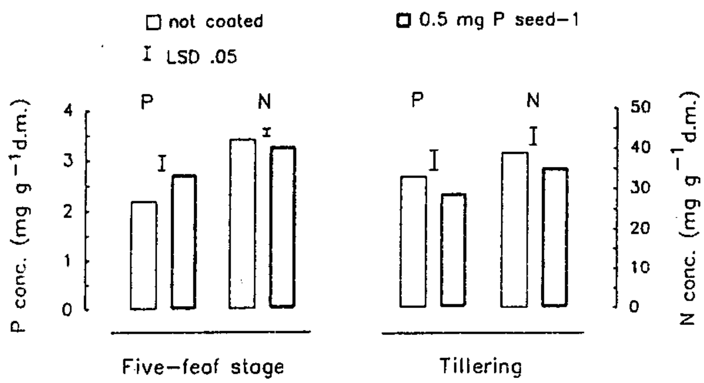

Fig. 7. Effect of seed coating with ammonium dihydrogen phosphate (AHP) on the concentrations of P and N in the shoot dry matter of pearl millet at the five-leaf stage (20 DAP) and at tillering (40 DAP). (Field experiment, Sadoré, rainy season 1991).

in the shoot dry matter, which was already in the sufficiency range (>32 mg N g^{-1} dry matter; [7]), was not influenced by seed coating (Fig. 7).

Table 3. Amount of P in the shoots of pearl millet as affected by seed coating with ammonium dihydrogen phosphate (AHP) at the five-leaf stage (20 DAP) and at tillering (40 DAP). (Sadoré, rainy season 1991)

Treatments	P supply[1] (g ha^{-1})	P in shoots (g ha^{-1})	
		Five-leaf stage	Tillering
not coated	6	7[a]	379[a]
coated (0.5 mg P $seed^{-1}$)	106	30[b]	1027[a]
LSD (.05)		9	658

[1] P supply via seed reserves (6 g P ha^{-1}) and seed coatings (100 g P ha^{-1});
[a,b] Means with the same letter do not differ significantly using an LSD (.05).

Discussion

Seed coating improved early growth and amount of P in pearl millet, once deleterious effects on emergence were avoided. The tolerance of cereals compared to cruciferes and legumes [2, 38] to higher concentrations of soluble fertilizers during emergence was attributed to the enclosure of the caryopsis by glumes, lemma and palea [15, 37, 40]. These structures were considered as a barrier to restrict movement of solutes from the outer lemma and palea to the caryopsis [27]. In contrast to oats and barley, which are insensitive to fertilizer seed coating [2], glumes are missing in seeds of pearl millet [19]. This explains the susceptibility of pearl millet during emergence to damage caused by P seed coating.

Similar emergence rates of inert coated seeds and uncoated seeds indicate that the dominant effect of the P coating was related to its chemical composition. The solubility of a fertilizer [38], its pH [35, 34, 38] and its osmotic value, expressed by the salt index [31] are regarded generally as responsible factors for damage during emergence. Since readily soluble P fertilizers can reduce emergence [36], low soluble fertilizers were recommended for seed coating [9]. However, in the present study STP also reduced emergence (Fig. 1), although polyphosphates are known as slow-release P fertilizer [8]. The lack of any relationship between the pH, osmomolity and final emergence of millet is in agreement with Scott *et al.* [37], who found no relationship between emergence of oats and wheat and the pH of the nutrient coatings or the salt index of the fertilizer used. Although SSP is known as a "safe" fertilizer due to its low salt index [31], it proved to be the most harmful one for seed coating with respect to emergence, both in millet (Fig. 1) and in buffel-grass [40]. Gutty [15] speculated that the harmful effect of SSP on seedling emergence could be attributed to the formation of HF from components of SSP, such as free acid (0.6% H_2SO_4) and CaF_2.

Within the first 16 DAP millet growth was affected particularly by the type of P fertilizer (Fig. 2). Plant height (Fig. 3) and dry matter production (Figs 5 and 6) were increased when P was applied as AHP. In contrast to results obtained with lucerne and phalaris [38], wheat [39] and chickpea [9], millet growth could not be improved by seed coating with MCP; the reasons for that are not known. In the pot experiment (Fig. 2) as well as under field conditions (Fig. 7) improved millet growth within the first 20 DAP was related to increased P concentrations in the shoot dry matter, particularly when P was applied as AHP.

For emergence seed coating with sparingly soluble fertilizer generally have been found to be less risky than readily soluble fertilizer [34]. At later growth stages the reverse is true [38]. Sparingly soluble fertilizer such as lime-reverted SSP [18, 36] or slow-release fertilizer such as isobutylidine diurea [36] were found to be unsuitable in supplying nutrients to seedlings.

In millet, enhanced P uptake was related also to the chemical composition of fertilizer used. Highest P uptake from seed coating was achieved when P was applied together with N as AHP (Fig. 5, Table 1). Hathcock *et al.* [17] showed that seed coatings with P and N in combination enhanced growth of tall fescue and Kentucky bluegrass more than seed coatings containing N or P only.

Enhancement effects of N on P uptake has been shown for maize [11] and wheat [24], particularly when N was applied as ammonium [25]. The enhancement effect of NH_4^+ on P uptake was attributed to a stimulation of anion uptake in response to cation (NH_4^+) uptake [4]. In the acid sandy soil used in the experiment with millet rhizosphere acidification by NH_4^+–N is not likely to be an explanation for enhanced P uptake by AHP, but probably the stimulation of NH_4^+–N on root growth [26].

High P supply is particularly important for seedling growth. In the soil solutions P requirement for maximum growth of *Desmodium aparines* (Link) was greater at the seedling stage than at later growth stages [13]. In wheat, maximum P concentrations in the shoot dry matter were found at 25 DAP [29] and highest P requirement up to the end of tillering [43]. The high P demand at early growth stages may be due to the development of yield-determining structures [2]. In millet, for example, panicle meristems are already initiated at 20 DAP, the floret primordia are formed at 28 DAP and all floral parts are developed at 30 DAP [19]. The acceleration of vegetative and prolongation of generative growth in millet by P seed coating (Fig. 4) could be attributed to the improved P supply and P uptake at early growth stage. Enhanced P uptake at early growing stages has also been explained as causal factors for increased flower bud production in pepper [10], flower number and pod set in soybean [33] and the number of grains in barley [20] and oats [21].

In conclusion, the results suggest that P seed coating at low rates of P as AHP may stimulate early growth for developing higher yields on soils low in available P. However, further work is necessary to develop practical methods to avoid deleterious effects of fertilizer seed coatings on emergence. Additional application of polyvinyl acetate or sucrose [42] to the coatings may be a possibility to improve the emergence of fertilizer coated seeds.

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References

1. Abdou FM and El-Kobbia T (1976) Effect of seed pretreatment with phosphorus on the yield and phosphorus uptake by barley. Agrochimica 20: 29–36
2. Ascher JS, Scott JM and Jessop RS (1987) Tolerance of a range of crop species to seed coatings with monocalcium phosphate. Proc 4th Aust Soc of Agron, Melbourne, 239 p

3. Banzhaf J (1988) Auswirkungen von Windschutzstreifen aus Brachlandvegetation auf Wachstum und Ertragsbildung von Perlhirse (*Pennisetum americanum* (L.) Leeke) und Cowpea (*Vigna uniculata* (L.) Walp.) im südlichen Sahel Westafrikas. PhD thesis, University of Hohenheim, Germany
4. Blair GJ, Miller MH and Mitchell WA (1970) Nitrate and ammonium as sources of nitrogen for corn and their influence on the uptake of other ions. Agron J 62: 530–532
5. Christianson CB, Bationo A and Baethgen WE (1990) The effect of soil tillage and fertilizer use on pearl millet yields in Niger. Plant Soil 123: 51–58
6. Cowie AM and Asher CJ (1986) Effects of nitrogen stress at particular growth stages on yield and grain nitrogen concentration in hybrid grain sorghum. In: Foale MA and Henzell RG (eds) Australian Sorghum Conference, pp 6.79–6.89. Qld. Agric. College, Lawes: Gatton
7. Dey G, Dhillon NS and Sidhu AS (1980) Plant analysis for nitrogen to maximize maize (*Zea mays* L.) and pearl millet (*Pennisetum typhoides*) yields. J Ind Soc Soil Sci 28: 412–414
8. Dick RP and Tabatabai MA (1987) Polyphosphates as sources of phosphorus for plants. Fert Res 12: 107–118
9. Dinkelaker B (1990) Genotypische Unterschiede in der Phosphateffizienz von Kichererbse (*Cicer arietinum* L.) Ph D thesis, University of Hohenheim, Germany
10. Dodd J, Krikum J and Haas J (1983) Relative effectiveness of indigenous populations of vesicular-arbuscular mycorrhizal fungi from four sites in Negev. Isr J Bot 32: 10–21
11. Engelstad OP and Allen SE (1971) Effect of form and proximity of added N on crop uptake of P. Soil Sci 112: 330–337
12. FAO (1986) 1986 FAO production yearbook. Food and Agriculture organization of the United Nations, Rome
13. Fox RL, Nishimoto RK, Thompson JR and de la Pena RS (1974) Comparative external phosphorus requirements of plants growing in tropical soils. Trans 10th Int Congr Soil Sci 4: 232–239
14. Gericke S and Kurmies B (1952) Die kolorimetrische Phosphorsäurebestimmung mit Ammonium-Vanadat-Molybdat und ihre Anwendung in der Pflanzenanalyse. Z Pflanzenernähr Düng Bodenkd 59: 235–247
15. Guttay JR (1957) The effect of fertilizer on the germination of wheat and oats. Mich Agric Exp Stn Q Bull 40: 193–202
16. Hall JR and Hodges TK (1966) Phosphorus metabolism of germinating oat seeds. Plant Physiol 41: 1459–1464
17. Hathcock AL, Dernoeden PH, Turner TR and McIntosh MS (1984) Tall fescue and Kentucky bluegrass response to fertilizer and lime seed coatings. Agron J 76: 879–882
18. Hay RJM (1973) The effect of coating and pelleting on germination and establishment of some grasses. Ph D thesis, University of Canterbury, Lincoln College, NZ
19. ICRISAT (1981) Research bull No. 6. In: Maiti RK and Bidinger FR (eds) Growth and development of the pearl millet plant. ICRISAT Patancheru
20. Jensen A (1982) Influence of four vesicular-arbuscular mycorrhizal fungi on nutrient uptake and growth in barley (*Hordeum vulgare*). New Phytol 90: 45–50
21. Koide RT, Li M, Lewis J and Irby C (1988) Role of mycorrhizal infection in the growth and reproduction of wild vs. cultivated plants. I. Wild vs. cultivated oats. Oecologia 77: 537–543
22. Kretzschmar RM, Hafner H, Bationo A and Marschner H (1991) Long- and short-term effects of crop residues on aluminum toxicity, phosphorus availability and growth of pearl millet in an acid sandy soil. Plant Soil 136: 215–223
23. Krigel L (1967) The early requirement for plant nutrients by subterraneum clover seedlings (*Trifolium subterraneum*). Aust J Agric Res 18: 879–886
24. Leikam DF, Murphy LS, Kissel DE, Whitney DA and Moser HC (1983) Effects of nitrogen and phosphorus application method and nitrogen source on winter wheat grain yield and leaf tissue phosphorus. Soil Sci Soc Am J 47: 530–535
25. Leonce FS and Miller MH (1966) A physiological effect of nitrogen on phosphorus absorption by corn. Agron J 58: 245–249
26. Marschner H, Roemheld V, Horst WJ and Martin P (1986) Root-induced changes in the rhizosphere: Importance for the mineral nutrition of plants. Z Pflanzenernähr Bodenkd 149: 441–456
27. McWilliam JR and Phillips PJ (1971) Effect of osmotic and matric potentials on the availability of water for seed germination. Aust J Biol Sci 24: 423–431
28. Menary RC (1967) Studies in the phosphorus nutrition of the tomato (*Lycopersicon esculentum* Hill) Ph D Thesis. University of Queensland, Brisbane
29. Ningping L and Barber SA (1985) Phosphorus uptake rate and growth characteristics of wheat roots. J Plant Nutr 8: 449–456
30. Payne WA, Lascano RJ, Hossner LR, Wendt CW and Onken AB (1991) Pearl millet growth as affected by phosphorus and water. Agron J 83: 942–948
31. Rader LF, White LM and Whittaker CW (1943) The salt index – a measure of the effect of fertilizers on the concentration of the soil solution. Soil Sci 55: 201–218
32. Read DWL (1983) Residual phosphorus increase the P content of wheat. Better Crops 67: 26–27
33. Schenk NC and Smith GS (1982) Response of six species of vesicular-arbuscular mycorrhizal fungi and their effects on soybean at four soil temperatures. New Phytol 92: 193–201
34. Scott D (1975) Effect of seed coating on establishment. N Z J Agric Res 18: 59–67
35. Scott D and Hay RJ (1974) Some physical and nutritional effects of seed coating. Proc 12th Int Grassld Congr Moscow. Iglovikov VG and Movsisyants AP (eds) Vol I, Part II, pp 523–531
36. Scott JM, Mitchel CJ and Blair GJ (1985) Effect of nutrient seed coating on the emergence and early growth of perennial ryegrass. Aust J Agric Res 36: 221–231
37. Scott JM, Jessop RS, Steer RJ and McLachlan GD (1987) Effect of nutrient seed coating on the emergence of wheat and oats. Fert Res 14: 205–217
38. Scott JM and Blair GJ (1988) Phosphorus seed coatings

for pasture species. I. Effect of source and rate of phosphorus on emergence and early growth of phalaris (*Phalaris aquatica* L.) and lucerne (*Medicago sativa* L.). Aust J Agric Res 38: 437–445

39. Scott JM, Hill CB and Jessop RS (1991) Growth chamber study of phosphorus applied as drilled granules or as seed coatings to wheat sown in soils differing in P-sorption capacity. Fert Res 29: 281–287
40. Silcock RG and Smith FT (1982) Seed coating and localized application of phosphate for improving seedlings growth of grasses on acid, sandy red earths. Aust J Agric Res 33: 785–802
41. Sivakumar WVK (1986) Climate of Niamey. Agroclimatology Progress Report Report 1, ICRISAT Sahelian Center, Niamey, Niger
42. Smid AE and Bates TE (1971) Response of corn to small amounts of fertilizer placed with the seed: V. Seed coating compared with banding. Agron J 63: 380–384
43. Sutton PJ, Peterson GA and Sander DH (1983) Dry matter production in tops and roots of winter wheat as affected by phosphorus availability during various growth stages. Agron J 75: 657–663
44. West LT, Wilding LP, Landeck JK and Calhoun FG (1984) Soil survey of the ICRISAT Sahelian Center, Niger, West Africa. Soil and Crop Sciences Department/TropSoils, Texas A&M University System, College Station Texas