Agronomic Evaluations of MAP and DAP[1]

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The old issue of MAP vs DAP has resurfaced. Although the renewed interest in this issue stems from manufacturing considerations, it would seem appropriate at this point to review our current understanding of agronomic characteristics of these two materials. One of the last reviews done on this subject was part of a review of P sources written by Larry Murphy and presented at the 1979 North Central Extension Industry Soil Fertility Workshop entitled "MAP, DAP, Poly and Rock". The amount of new research conducted since that review is not extensive, however, some has been performed and the intent of this paper will be to incorporate the new information with the old.

Theoretical Considerations

The fundamental chemical differences potentially of agronomic importance between MAP and DAP are caused by the characteristics reported in Table 1. The characteristics of monocalcium phosphate (MCP), which is the P form in single and triple superphosphate, are shown for reference. The high pH resulting from DAP hydrolysis and the elevated ammonium level relative to MAP create the potential for agronomic differences via the following mechanisms:

1. Ammonia formation from DAP. The ammonia present at any given level of ammonium is determined by pH. At a pH of 8.28, the ammonia/ammonium ratio is 0.1 while at 7.28 it is only 0.01. One can easily understand the concern for DAP since both the ammonium level and the pH are at least initially much higher than for MAP. The ammonia formed could cause seed germination problems, seedling injury, or possibly interfere with root development in a P band.

2. Soil-fertilizer reaction product differences. Since the chemical environment of dissolving fertilizer granules of MAP and DAP differ, the minerals formed as the soil and fertilize react could differ in solubility and result in either short term or long term effects on P availability to plants. These effects could be caused by alteration of P concentrations in fertilizer bands, differences in band volume due to varying mobility, or by differences in P forms present in the soil solution. The lower initial pH of MAP would favor formation of $H_2PO_4^-$ over $HPO_4^=$. Since hydroponic studies show $H_2PO_4^-$ to be taken up more rapidly by plants, this could enhance MAP performance (Fig. 1). Alteration of the sequence of minerals formed could also impact the long term availability of the fertilizer P by delaying or enhancing P fixation reactions. Band pH differences could effect the availability of micronutrient cations which usually increases as pH decreases.

3. Impurities in MAP. Since lower grade phosphate rock can be used to make MAP, MAP can contain more impurities than DAP. The impact of these impurities on agronomic effectiveness is another theoretical concern.

The remaining sections of this paper will review the literature that addresses these theoretical concerns.

Ammonia Related Concerns

Jackson et al., summarized findings of Pairintra (1973) by stating that spring wheat seedling injury in Montana from ammonium phosphate fertiizers increased in the order ammonium polyphosphate < MAP < DAP < urea ammonium phosphate. Damage from all fertilizers increased as calcium carbonate in the soil increased. Other Montana researchers have reported on MAP and DAP effects on small grain emergence and yield. Smith et al. (1973) concluded that DAP produced more stand damage of wheat on calcareous soils when compared at equivalent N rates. They also reported lower yields for DAP when sources were compared at constant N rates. However, comparison at the same P level of at least some of their data indicates the sources gave the same yield response and the apparently lower yields with DAP were caused by the lower rate of P applied.

Later studies by Christensen et al. (1977) on irrigated barley grown on soils ranging in $CaCO_3$ content from 0.4 to 15.1% again showed greater stand damage for DAP compared to MAP at the same N level (Fig.2). No yield differences were measured between sources in one year while in another year that was more conducive to ammonia damage, DAP treatments averaged 2.3 bu/a less than MAP across 6 locations and 4 N levels (Table 2). They concluded that damage from banding ammonium phosphates with barley seed could be minimized by not exceeding 20 lb N/A for 12 inch rows when soil moisture is excellent at the time of seeding.

Kansas researchers compared the winter wheat germination and seedling damage potential of MAP and DAP banded with the seed across four site years where yields were measured (Table 3). Soils were slightly acid to neutral in pH and ranged from medium to very high in soil test P. Since the objective was to measure injury potential, P was broadcast on all treatments to bring the total applied up to 50 lbs/a except where more than that went on in the band. Nitrogen was also equalized at 75 lbs/a with a broadcast application. Inspite of potential P response at several of the sites favoring MAP when treatments are compared at equal N rates, no difference was detected between the two sources across the four locations.

Field studies comparing seed placed MAP and DAP at a P_2O_5 rate of 20 lbs/a were conducted on two calcareous soils in North Dakota (Dahnke and Swenson, 1981). Neither durum or barley differed in their response to the P sources. Phosphorus increased yield at the site seeded to durum but not at the site seeded to barley which had a higher P soil test level.

Stevenson and Bates (1968) studied the effects of N:P atom ratio of ammonium phosphates on the emergence of wheat from an Oneida clay loam and a Fox sandy loam. Both soils were adjusted to pH's of 5.4 amd 7.4. Fertilizers were compared at a constant N rate of 60 lbs/A which resulted in 300 lbs P_2O_5 /A from MAP and 150 lbs P_2O_5/A from DAP in a 7" band spacing. Soil pH had no effect on emergence in either soil nor did N:P ratio in the clay loam soil. However, in the sandy loam soil, early emergence was markedly lower for DAP.

The emergence of winter wheat when DAP, MAP, OSP, and CSP were banded with the seed was determined where moisture and temperature were controlled (Baker et al. 1970). The Oklahoma researchers used a Norge loam and a Meno sand for the growth chamber studies (pH not reported). Some of their results for the loam soil are presented in Figure 3. Detrimental effects of of a given fertilizer treatment on emergence increased as temperature increased from 15 to 25C and as moisture tension (stress) increased form 1 to 3 bars. As expected, the detrimental effects were much greater on the sandy soil. MAP and DAP produced more injury than the other sources, especially under warm dry conditions, but were similar to each other. Under cool moist conditions for the loam soil, rates of 20 and 40 kg P/ha (40 and 80 lbs P_2O_5/A) as MAP or DAP delayed emergence but did not effect final stand (7" rows).

Nyborg and Lopetinsky (1972) studied germination and emergence effects on rape in Alberta when DAP, MAP and TSP were placed with the seed at a rate of 20 lbs P_2O_5/A in a greenhouse experiment. They concluded that MAP and TSP were essentially equall in effects on rape, while DAP delayed emergence and decreased the the number of surviving seedlings.

North Dakota researchers compared MAP, DAP, and urea urea phosphate (UUP) using three spread types on a pneuamatic seeder where the seed and fertilizer are applied together (Deibert et al., 1985). The study was conducted on a Bearden silty clay soil with a pH of 7.9. Spread type A was the maximum spread and was achieved with a 12" sweep and deflector. Spread type B had a 6" spread while spread type C had no spread and was accomplished using a spear point providing approximately a 1" band. Spring wheat stand reductions are shown in Figure 4. With the maximum spread, no difference was measured in stand between MAP and DAP at 39 lbs P_2O_5/a regardless of the urea rate applied. Spread B and C resulted in greater stand reductions due to urea but differences between MAP and DAP were minor.

An assumption sometimes made is that due to the hydrolysis of DAP in soils, the N in DAP should be treated like urea N when determining the maximum rate for placement with the seed. Research conducted by Creamer and Fox (1980) indicate that such a recommendation may be an over-reaction to the ammonia hazard of DAP at least for acid or near neutral soils. They measured a pH of 9.1 for urea at a rate of 89 lbs N/a applied at a row spacing of 30" while the same conditions with DAP produced a pH of only 7.3 (Table 4). Also, pH was elevated substantially to a distance of 2" for urea while the effect for DAP extended only to approximately 1". The authors pointed out that at a pH of 9.1, 40% of the total ammoniacal N would be present as ammonia while at 7.3 free amonia is only 1.4%. One needs to also consider that the DAP rate used in this comparison would contain 121 lbs P_2O_5/a, much higher than would normally be placed in a band. The authors concluded that the ammonia toxicity potential for DAP is much lower than urea under equivalent conditions and that there is little or no danger of nitrite toxicity developing around banded DAP.

Ammonia injury to corn from banded MAP and DAP was studied in the laboratory by Allred and Ohlrogge (1964) on a Oaktown fine sand and a Fincastle silt loam . The rates used were equivalent to 254 lbs P_2O_5/A for MAP and 212 lbs P_2O_5/A for DAP in 30" rows. At these very high rates, root development near MAP bands was more pronounced than near DAP bands. After 10 days, roots were living in the salt zones of MAP bands in both soils while no roots were observed within any of the DAP bands although roots were closer to the DAP bands in the silt loam than in the sand. A distinct ammonia odor was noticed at the termination of the experiment (10 days) around the DAP bands in the sandy soil while no such odor was detected in the silt loam. Ammonia resulting from DAP hydrolysis rapidly permeated the soil pore space to distances as great as 3" from the band.

Harapiak and Beaton (1986) used urea and ammonium nitrate to determine if ammonia formation in a band could effect P availability as indicated by relative ^{32}P activity in barley plant material resulting from MAP dual applied with N. They measured a depressing effect of the urea (Fig. 5). The authors suggested that too much urea banded with the P source elevated ammonia levels and decreased root penetration into the band. The research of Allred and Ohlrogge and Creamer and Fox is supportive of their theory. The latter observed killed root tips from banded urea and some damage when DAP and ammonium nitrate were banded together at a rate of 121 lbs P_2O_5/a and 89 lbs N/a. However, these data suggest that the amount of ammonia potential for DAP at typical P rates is not large enough to in itself cause P availability problems due to root exclusion.

Summary. Ammonia injury of wheat and barley from DAP banded with the seed appears to be rare on neutral and acid soils. DAP injury was detected on a sandy loam soil at a rate of 150 lbs P2O5/A, much higher than would be normally used. Injury from DAP on calcareous soils is more common, however, it can generally be avoided for wheat and barley by not exceeding approximatley 20 lbs N/A on a 12" row spacing equivalent. Warm dry conditions tend to increase injury from both DAP and MAP. Yield reductions from ammonia injury are less common than emergence or stand effects. Some evidence suggests that free ammonia resulting from high fertilizer rates applied in a band, whether from DAP or urea, could temporarily delay root access to the banded P. This does not appear to be a problem at normal P source rates. Guidelines on maximum N rates for placement with the seed that consider local crop, soil, weather, and cultural factors have been developed by nearly all states and provinces .

Solubility of Soil-Fertilizer Reaction Products

One of the earliest studies on the solubility and mobility of P sources was conducted by Bouldin and Sample (1959) using fertilizer pellets containing 15 mg of P each placed in a Hartsells fine sandy loam (pH = 5.2)from Alabama or a calcareous Webster silty clay loam (pH = 8.3) from Iowa. After 3 or 5 weeks, both MAP and DAP had moved about 2.5 and 1.5 cm from the center of the pellets with the Hartsells and Webster soils respectively. In the Hartsells soil, water soluble P near the pellets was initially higher for DAP than MAP or MCP but was similar by the end of 5 weeks (Fig. 6). In the Webster soil, soluble P was markedly less for DAP than for MAP or MCP. Based on these solubility data and on greenhouse uptake studies, the authors gave the following rankings of the fertilizers as P sources. Hartsells : DAP > MAP > MCP; Webster : MCP = MAP > > DAP.

The reaction products of MAP and DAP along with other fertilizers were studied by Lindsay et al. (1962) and reported in a classic paper that lead to numerous other investigations. In their experiments, saturated solutions of the fertilizers being studied were shaken with soil for various periods of time. The MAP and DAP studies were done on a Hartsells fine sandy loam (pH=4.9) from Tennessee and on a calcareous Gila loam (pH=8.5) from Arizona. The major reaction product of MAP in the acid soil was $(NH_4)_3Al_5H_6(PO_4)_8 \cdot 18H_2O$ (taranakite) while in the calcareous soil $CaHPO_4 \cdot 2H_2O$ (DCPD) and $MgNH_4PO_4 \cdot 6H_2O$ (struvite) were the dominant products. DAP produced struvite in both soils. DAP also formed $NH_4Al_2(PO_4)_2OH \cdot 8H_2O$ and a colloidal phase in the acid soil and formed $Ca_2(NH_4)_2(HPO_4)_3 \cdot 2H_2O$ and colloidal apatite in the calcareous

soil. Therefore, they verified that the reaction products can differ between the fertilizers and that the specific products formed are influenced by soil characteristics.

Bell and Black (1970) used a different approach to study the reaction products from MAP and DAP forming in soils ranging in $CaCl_2$ pH from 6.2 to 7.8 and from 0 to 22% $CaCO_3$. They believed that field conditions were better simulated if a band of fertilizer was placed in the soil and the reaction products formed in various zones out from the band determined. The saturated fertilizer solution approach tends to overemphasize the initial characteristics of the fertilizer. Their results differed from those of Lindsay et al discussed above. After 4 weeks of incubation with MAP, DCPD was the only reaction product identified for all US soils and it persisted for the 48-week duration of the experiment.

For DAP in the zone of highest pH and P concentration immediately next to the fertilizer, $Ca(NH_4)_2(HPO_4)_2.H_2O$ occurred at 4 weeks in soils of moderate labile Ca levels. By the end of 16 weeks, this compound had been largely replaced by DPCD and/or $Ca_8H_2(PO_4)_6 \cdot 5H_2O$ (OCP) which persisted for the duration of the study. In High Ca soils OCP formed initially and no ammonium containing phosphate phase was detected. Since the solubility of OCP is lower than DCPD, its immediate formation in fertilizer bands of high Ca soils could be detrimental to initial early season P uptake. However, one could speculate that its quick formation could decrease the thermodynamic driving force for the formation of even less soluble calcium phosphates such as tricalcium phosphate or apatite and increase the long term effectiveness of the fertilizer.

The mobility of DAP, as well as triammonium pyrophospate (TPP) and ammonium polyphosphate (APP), was evaluated by Khasawneh et al. (1974) using a Hartsells fine sandy loam from Alabama with a limed pH of 6.0. The distribution profile of DAP at an equivalent rate of 174 lbs P_2O_5/A at a 30" band spacing shows movement to approximately 3.5 cm at 1 week and 5 cm after 4 weeks (Fig. 7). The researchers also pointed out that for the P sources studied, the extent of movement was influenced more by initial soil moisture content than source of P (greater the moisture content greater the movement).

Summary. Reaction product investigations do not in themselves make unequivocal statements about likely agronomic performance differences between MAP and DAP. They do suggest that in near neutral and acid soils differences due to reaction products are not likely. In calcareous soils, greater immediate availability is indicated for MAP, while long term differences are harder to predict. If colloidal apatite forms from DAP as indicated by Lindsay et al., effectiveness of DAP would be less than MAP. However, if OCP is the primary phosphate forming as reported by Bell and Black, DAP may actually have greater long term availability than MAP.

Plant Availability Comparisons

Beaton and Read (1963) evaluated the effects of soil-fertilizer reaction period temperature and moisture on short term P uptake from a calcareous Saskatchewan soil (pH = 7.7, CaCO3 = 6.6%) treated with several pelleted P sources. After one week of incubation in their growth chamber study, uptake by oats was greater from MAP than from DAP, however, after seven weeks of incubation differences between MAP and DAP were minor (Fig. 8). The advantage of MAP over DAP increased as the temperature of the soil-fertilizer incubation period increased. The investigators attributed the difference in uptake to the assumed formation of reaction products such as colloidal apatite, octacalcium

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phosphate, and struvite by DAP which would be less available in this soil than the DCPD formed by MAP.

Amer at al.(1980) evaluated in a greenhouse study the solubility and plant availability of DAP and monocalcium phosphate (MCP) on two soils from Egypt, a silty clay alluvium containing 4.1% CaCO3 and a silt loam desert soil containing 39.0% CaCO3. At a rate of 227 lbs P2O5/A, MCP and DAP gave similar P uptake for both soils but at the 454 lb rate MCP resulted in more P in the plant than DAP. The authors attributed the difference to P immobilization induced by ammonia volatilization from DAP at the high rate.

Lu et al. (1987) compared DAP to single superphosphate (SSP) plus urea in a short term greenhouse study of a Vernon clay subsoil from Texas (pH = 8.0, CaCO3 = 20%). Rates included varied from 123 to 981 lbs P2O5/A. The DAP treatments were inferior to the SSP treatemnts in P uptake and Olsen P whether the fertilizer was broadcast, deep banded or incorporated. Soil test levels for the incorporated placement were substantially lower for DAP especially at the higher rates (Table 5).

Zagorodnyi et al. (1970) compared MAP and DAP on irrigated soils of the west central USSR and concluded that under the conditions of their experiments, MAP and DAP were equal in their ability to supply P for a number of crops. Other USSR investigators have drawn the same conclusions in a number of reports published from 1968 to 1976 (Murphy,1979).

MAP and DAP were compared in a starter band (2" below, 2" beside the row) for corn for three years in Michigan on a Charity clay at a rate of 200 lbs of material per acre (Yerokun and Christenson, 1989). No differences between MAP and DAP were found in the concentration of N, P, Ca, Mg, Zn, or Mn in whole plants at the 4-leaf stage or in ear leaves. Also, no yield differences were detected.

Soil solution P concentration (C_{li}) and diffusable P (C_{si}) were measured by Ernani and Barber (1989) in a Raub silt loam at pH 5.6 where MAP and DAP had been incubated moist for 30 days at a rate of 100 mg/kg soil. Values of C_{li} and C_{si} did not differ for the two sources. The researchers used the Barber uptake model to predict plant P uptake during the 30 day period and again found no differences between sources.

Summary. Growth chamber studies tend to support the predictions from the reaction product studies. In calcareous soils, especially at very high P rates, P availability from DAP has been less than MAP or MCP. However, in field comparisons with lower P rates, studies discussed in this section as well as those from the ammonia section tend to show similar plant availability for MAP and DAP.

Micronutrient Effects

Hossner and Richards (1968), working with a soil at pH 7.0, observed no difference in Mn uptake between DAP and MAP when no Mn was added to the P band, however, when 25 ppm Mn was added, both MAP and DAP increased Mn uptake but MAP had a greater effect than DAP.

Randall et al. (1975) compared the effects of MAP and DAP on soil Mn availability to soybeans on a Sebewa loam at pH 6.1 and, unlike Hossner and Richards, noted that DAP was more effective than MAP in correcting Mn deficiency. The higher pH, higher P rate (50 ppm P), and shorter growth period of the Hossner and Richards study might explain the difference in outcome.

Voth and Christenson (1980) conducted several experiments evaluating the effects of fertilizer sources on Mn availability. They conducted an incubation study using a Tappan loam soil and measured pH and DTPA extractable Mn in bands where MAP or DAP, KCl, and Urea had been applied (Table 6). After 3 weeks, sufficient nitrification had taken place to significantly depress pH in the band for both treatments below that of the check. In this study MAP and DAP did not differ in reaction zone pH at 3, 5, or 7 weeks of incubation. Mn was elevated for both sources throughout the incubation including DAP at the 3-week sampling. In other work by the researchers, sugar beet and soybean field studies at sites testing near a pH of 8.0 showed that tissue Mn concentrations were higher 5 to 6 weeks after planting when $MnSO_4$ was band applied with MAP than when applied with DAP at a rate of 50 lbs P_2O_5/a (Christenson, 1981).

Summary. **Band application of either MAP or DAP generally increases Mn availability to crops. Whether one source is better than the other at increasing Mn appears to be unresolved.**

MAP Impurities

The greater level of impurities in MAP compared to DAP has lead to recent investigations on the impact of MAP impurities on agronomic properties. Sikora et al.(1989b) studied the water-insoluble fractions of three MAP (11-52-0) fertilizers. The fertilizers were produced from North Carolina, Florida, and Idaho phosphate rock. In greenhouse comparisons, they found that the water-insoluble fractions were inferior P fertilizers, however, no difference was found between the total P fertilizers nor did they differ in bioavailability from reagent grade MAP (Fig. 9).

The investigators also characterized the impurities present in the three MAP fertilizers (Fig. 10). In a later paper, the solubility products of the five impurities identified were determined (Sikora et al.,1989a). The order of P solubility at pH 6.5 was $AlNH_4HPO_4F_2$ > MCP > $MgNH_4PO_4$ = $FeNH_4(HPO_4)_2$ > $MgAl(NH_4)_2H(PO_4)_2F_2$ > variscite > = strengite > DCPD = DCP > hydroxyapatite. This sequence indicates that the impurity compounds in MAP are more soluble than the compounds that normally form in soils such as DCPD, DCP, Variscite, and strengite. Therefore, the impurity compounds may not be as adequate a source of P as MAP or MCP but, they will supply P to plants over time as the P reverts to less soluble soil compounds.

Mullins and Sikora (1989) in a field study evaluated 9 MAP sources that varied from 81 to 97% water-soluble P. Their findings were similar to the greenhouse investigations since   no meaningful differences in yield or P uptake between the sources were detected.

Summary. It does not appear that MAP impurities pose any agronomic problem.

Conclusions

There is considerable theoretical and emperical evidence that suggests the performance of a P source depends on the conditions under which it is used. These conditions have been discussed in their appropriate sections. Differences actually measured in the field are typically less than what theoretical considerations suggest. Generally, the potential problems with DAP appear to be avoidable with slight adjustments in management. Today's planting and fertilizing equipment provides a number of alternatives to traditional banding with the seed and has decreased the severity of DAP concerns.

Availability of MAP and DAP, under the field conditions in which they are normally used, appears to be similar. As indicated by Murphy in 1979, more information on the residual effects of various P materials, including MAP and DAP, over long time spans could be useful data. The impact of organic matter on long term source differences might also be of value.

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Table 1. Characteristics of saturated solutions of three phosphate fertilizers at 25°C (Lindsay et al., 1962).

Fertilizer	pH	P	Accompanying Cation	
		moles/liter		
Monocalcium phosphate (MCP) $Ca(H_2PO_4)_2 \cdot H_2O$	1.48	3.98	Ca	1.44
Monoammonium phosphate (MAP) $NH_4 H_2PO_4$	3.47	2.87	NH_4	2.87
Diammonium phosphate (DAP)	7.98	3.82	NH_4	7.64

Table 2. MAP produced slightly higher irrigated barley yields then DAP one year in Montana but gave the same yields in another year (Christensen et al., 1977).

Source	1974 1/	1975 2/
MAP	51.9	59.2
DAP	53.3	56.9
LSD.05	NS	2.0

1/ Average of 3 locations and 10, 20, and 30 lb N rates.

2/ Average of 6 locations and 10, 20, 30 and 40 lb N rates.

Table 3. Yield of winter wheat in Kansas as affected by seed placed MAP and DAP P sources (Moore et al., 1979; Lundquist et al., 1980).

P Source [1]	P Carrier Rate [2] N	P₂O₅	Site 79A	79SC	79SW	80SW	Avg.
		lb/A	----------------bu/A----------------				
Check	0	0	50	48	38	24	40
MAP	9	45	56	55	34	38	46
	18	90	57	59	33	36	46
	27	135	59	59	35	36	47
DAP	9	23	60	60	35	33	47
	18	46	59	60	39	33	48
	27	69	58	57	35	37	47
LSD.05			NS	8	NS	9	
MAP	Avg.	Avg.	57	58	34	36	46
DAP	Avg.	Avg.	59	59	36	35	47

[1] MAP = 11-55-0; DAP = 18-46-0.
[2] N was equalized for all treatments by topdressing 75 lbs N 1A. P was brought up to a total of 50 lbs P₂O₅/A with a broadcast application except where more than 50 was applied in the band.

Table 4. Comparisons of pH values produced by DAP and used at a rate of 89 lbs N/A in 36 inch row spacing in a Hagerstown silt loam (Creamer and Fox, 1980).

Material	Days after application	Zone 1 0 to 1"	Zone 2 1 - 2"	Zone 3 2 - 3"
Urea	7	9.1	8.7	7.0
	12	9.1	8.7	7.2
DAP	7	7.3	6.9	6.8
	12	7.3	6.9	6.8
	LSD.05	0.12		

Initial soil pH = 6.8; soil moisture = -1/3 bar, 22% H₂O.

Table 5. Olsen P in soil treated with DAP or urea + SSP
for the incorporated placement (Lu et al., 1987).

| Fertilizers | Equivalent Rates, lbs P_2O_5/A | | | |
	123	245	491	981
	------------------P, ppm------------------			
DAP	5.2	6.7	12.3	27.0
Urea + SPP	8.3	17.2	28.6	55.3
LSD.05	13.35		Check = 1.5	

Table 6. Effect of P sources on pH and DTPA Mn levels in the
contiguous soil after 3, 5, and 7 weeks of incubation
(Veith and Christenson, 1980).

| Fertilizer source | 3 weeks | | 5 weeks | | 7 weeks | |
	pH	Mn	pH	Mn	pH	Mn
		ppm		ppm		pmm
Control	7.5c*	2.2a	7.6c	2.4b	7.7c	1.9b
DAP-Urea-KCl	7.3b	10.6c	7.2ab	3.5c	7.3ab	2.3c
MAP-Urea-KCl	7.3b	9.4c	7.2ab	3.1c	7.3ab	1.8b

* Column means followed by same letter are not different at the 5%
level using Duncan's Multiple Range Test.

Fertilizer rate = 60, 59, 60 lbs N, P_2O_5, K_2O/Acre based on
28 inch row spacing. Soil sampled as a 4-cm cube centered on
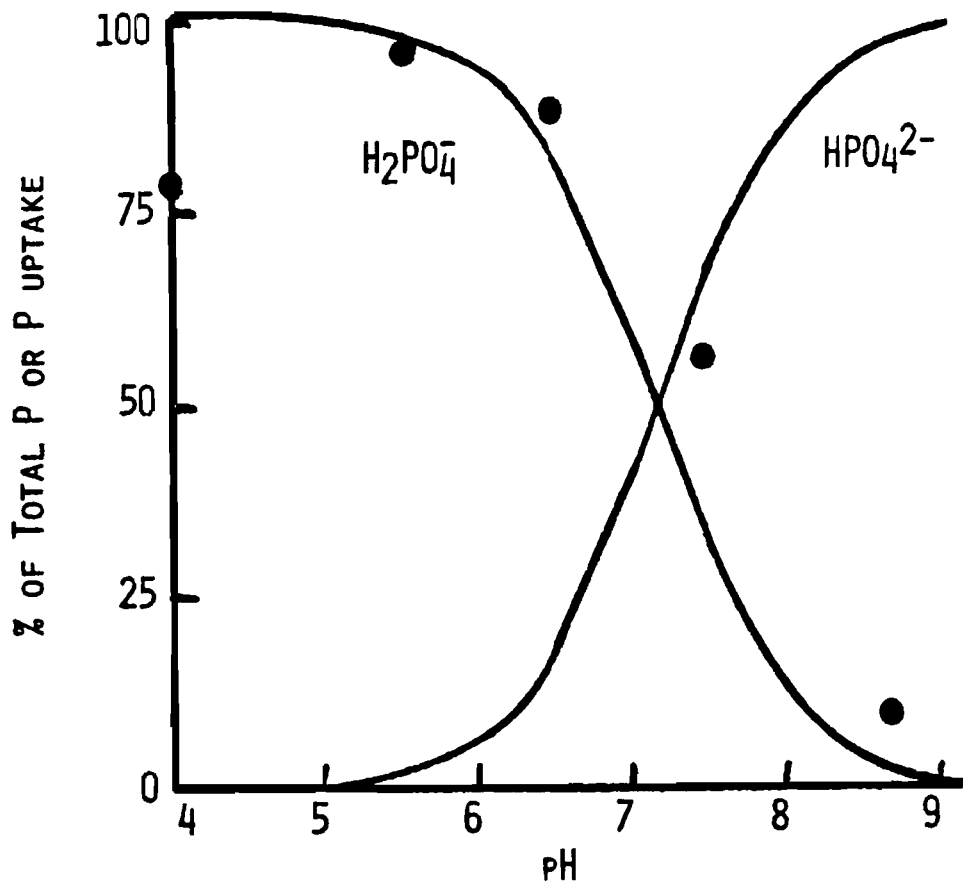band.

Fig. 1. Influence fo pH on solution orthophosphate form and relative uptake of P^{32} from a nutrient solution by field bean shoots (Hendrix, 1967).

MAP $\dot{Y}= 56\ 0\cdot1\ 026N - .0298\ N^2$

DAP $\dot{Y}= 60\ 8\cdot0\ 892N - 0398\ N^2$
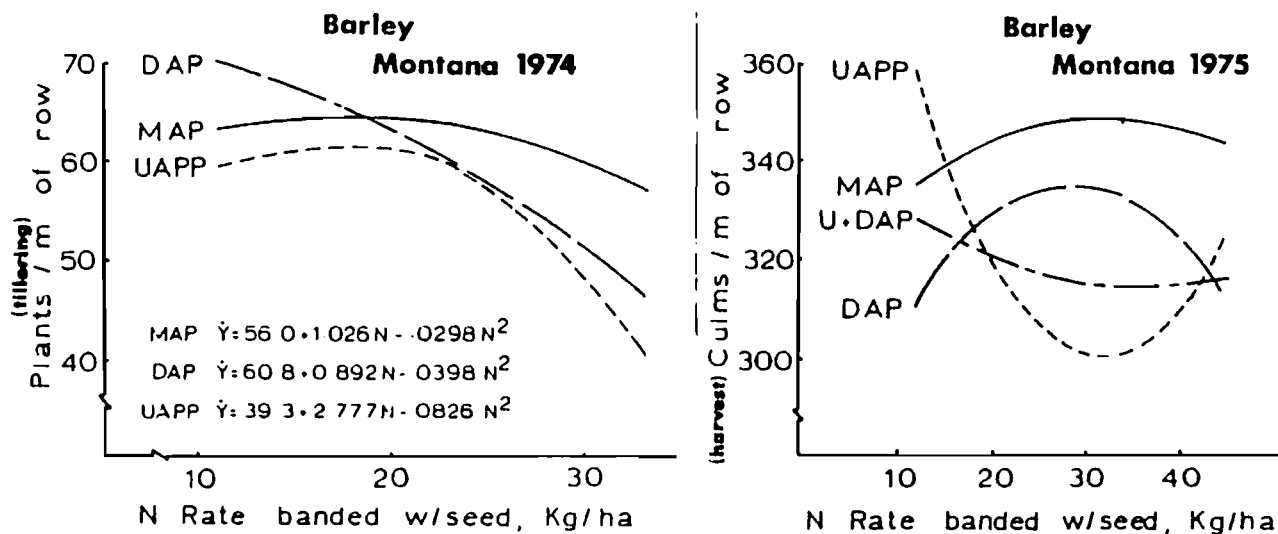
UAPP $\dot{Y}= 39\ 3\cdot2\ 777N - 0826\ N^2$

Fig. 2. Pre-harvest stand counts and number of culms of barley were significantly influenced by rate and type of ammonium phosphate fertilizers in these Montana studies (Christensen et al. 1977).
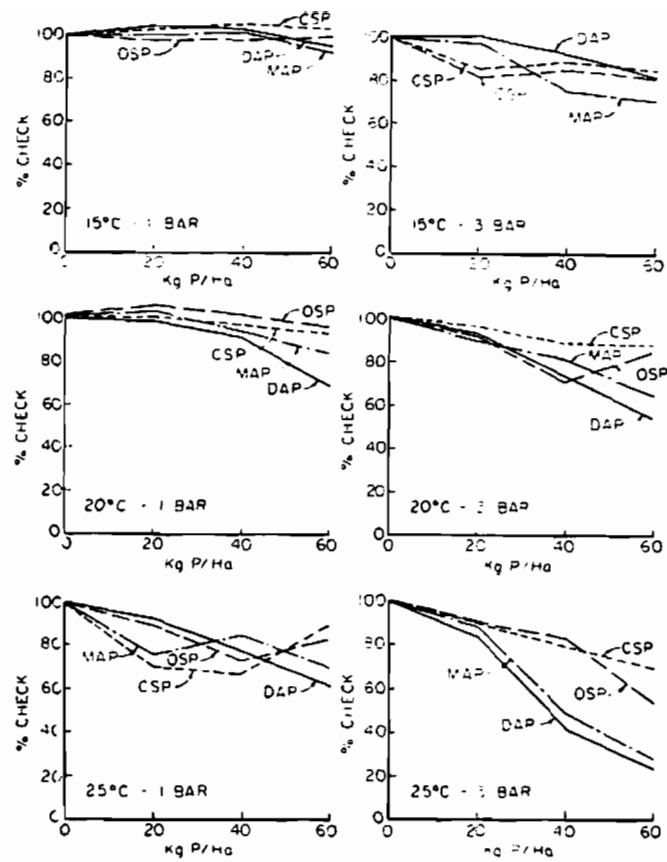
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Fig. 3. The effect of DAP, MAP, OSP, and CSP on the
emergence of wheat seedlings at various temperatures
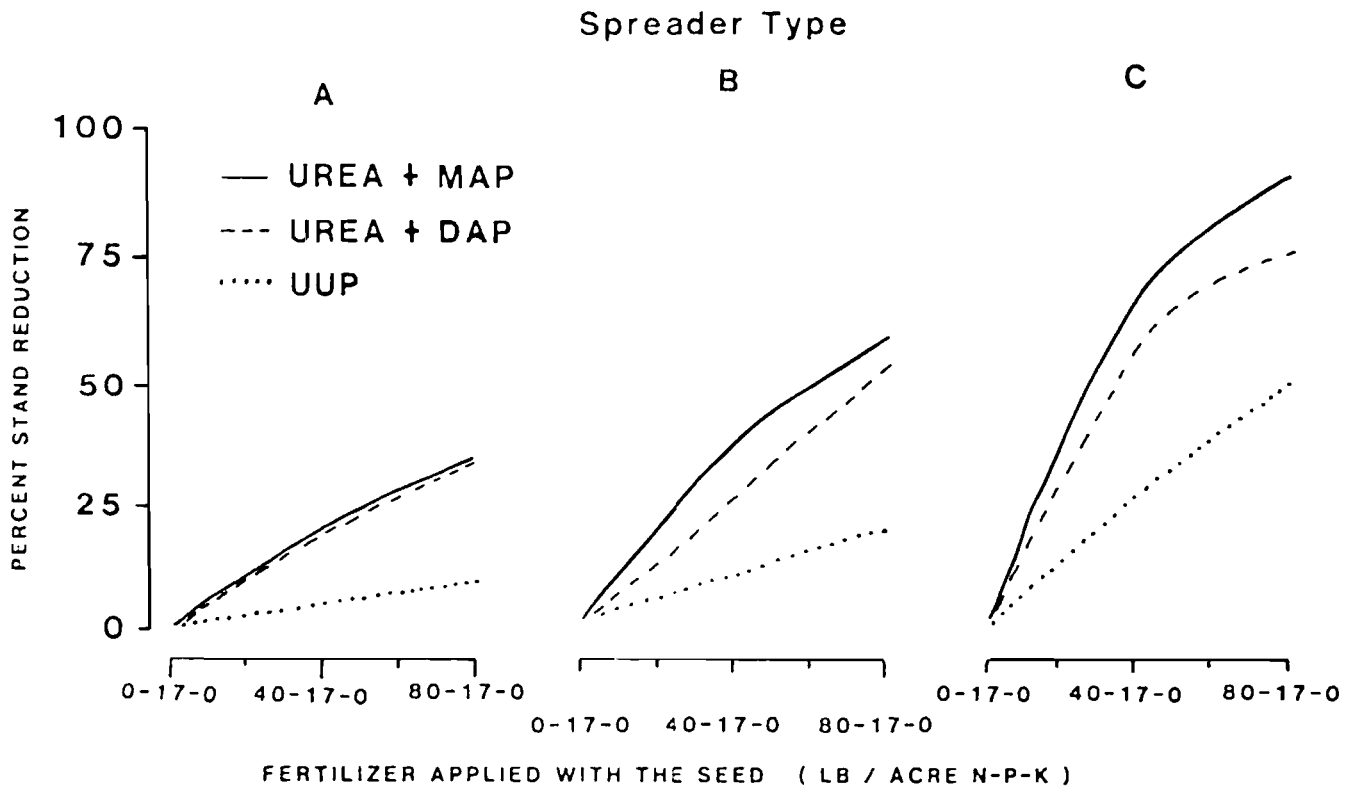and soil moistures (Baker et al.,1970).

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Spreader Type

Fig. 4. Spring wheat stand reduction as influenced by N and P source and rate for three spreader types (Deibert et al.,1985).
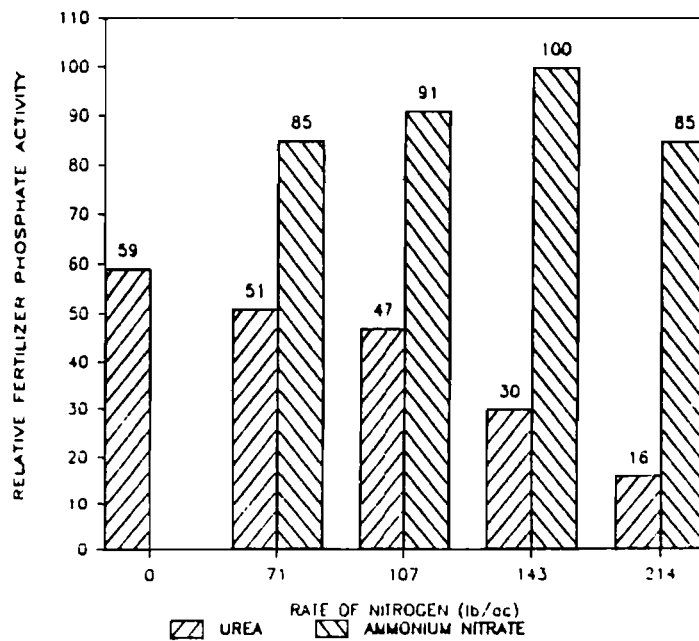

Fig. 5. Influence of rate and source of N applied in dual N-P bands on relative ^{32}P activity in barley plant material, P as MAP at 33 lbs P_2O_5/A (Harapiak, 1985).
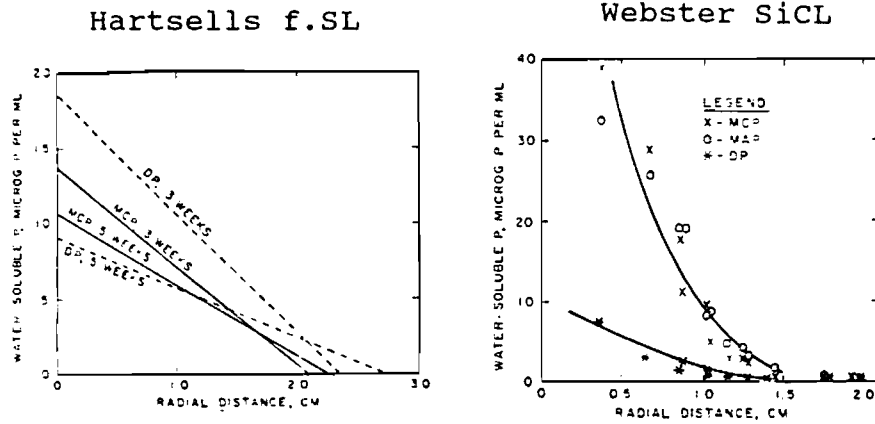
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Hartsells f.SL   Webster SiCL

Fig. 6. Water soluble P of soil samples near pellets of
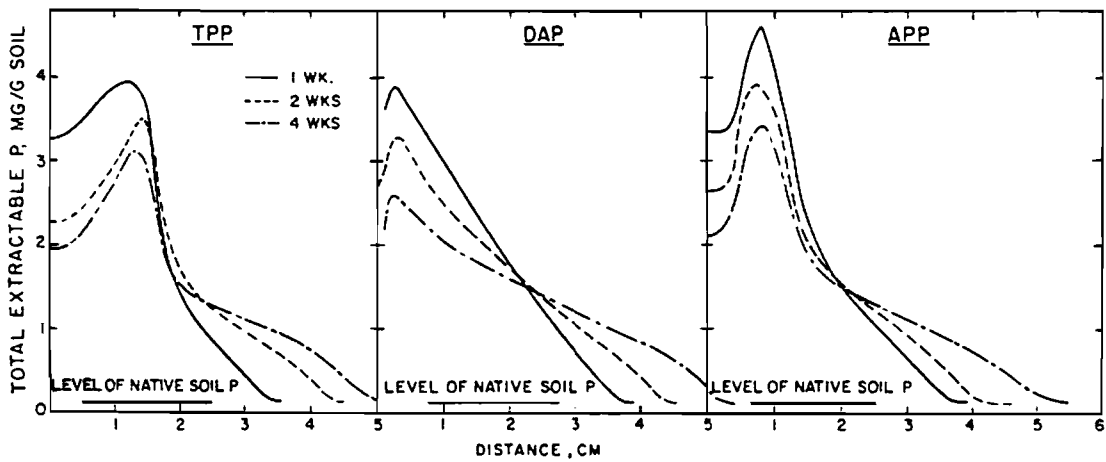fertilizer placed in soil (Bouldin and Sample, 1959).

Fig. 7. Phosphorus distribution profiles in columns treated
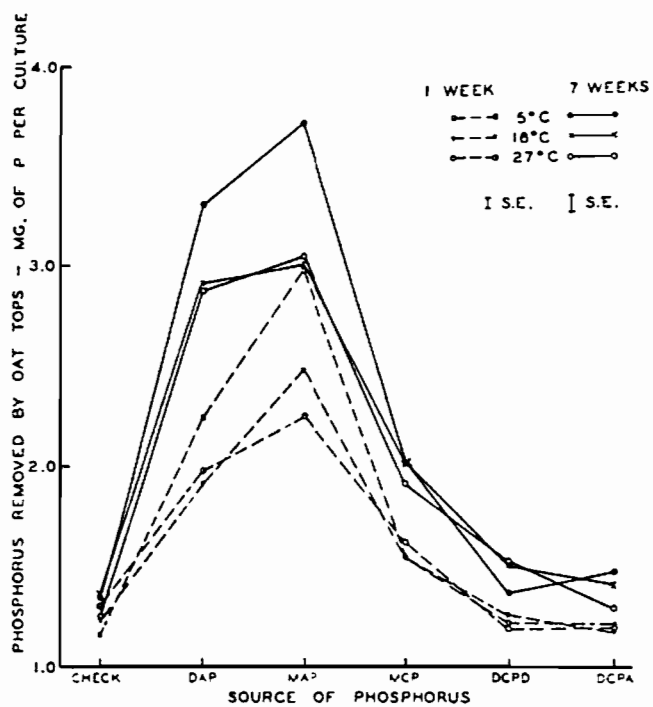with TPP, DAP, or APP (Khasawneh et al., 1974).

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Fig. 8. Influence of phosphate source and temperature during the initial soil-fertilizer reaction period on subsequent P uptake by oat tops (Beaton abd Read, 1963).
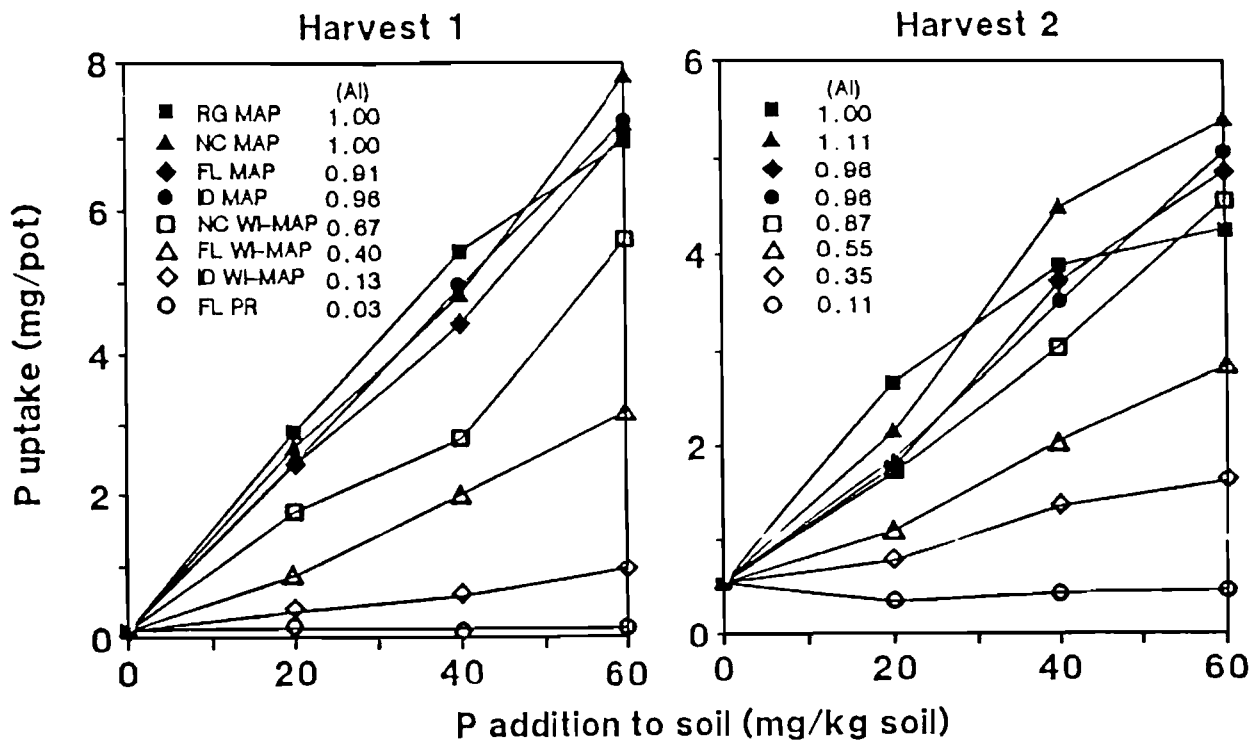
Harvest 1

	(AI)
■ RG MAP	1.00
▲ NC MAP	1.00
◆ FL MAP	0.91
● ID MAP	0.96
□ NC WI-MAP	0.67
△ FL WI-MAP	0.40
◇ ID WI-MAP	0.13
○ FL PR	0.03

Harvest 2

	(AI)
■	1.00
▲	1.11
◆	0.96
●	0.96
□	0.87
△	0.55
◇	0.35
○	0.11

P uptake (mg/pot)

P addition to soil (mg/kg soil)

Figure 9. Phosphorus uptake of sorghum-sudangrass in two consecutive harvests as affected by 3 MAP sources, 3 WI-MAP fractions, reagent grade $NH_4H_2PO_4$ (RG MAP), and a FL PR. AI = availability index. (Sikora et al.,1989b)

% P OF TOTAL P IN WI FRACTION AS PRESENT IN IMPURITY COMPOUND

WI-MAP SOURCE

NC   FL   ID

$AlNH_4HPO_4F_2$ $FeNH_4(HPO_4)_2$ $MgNH_4PO_4$
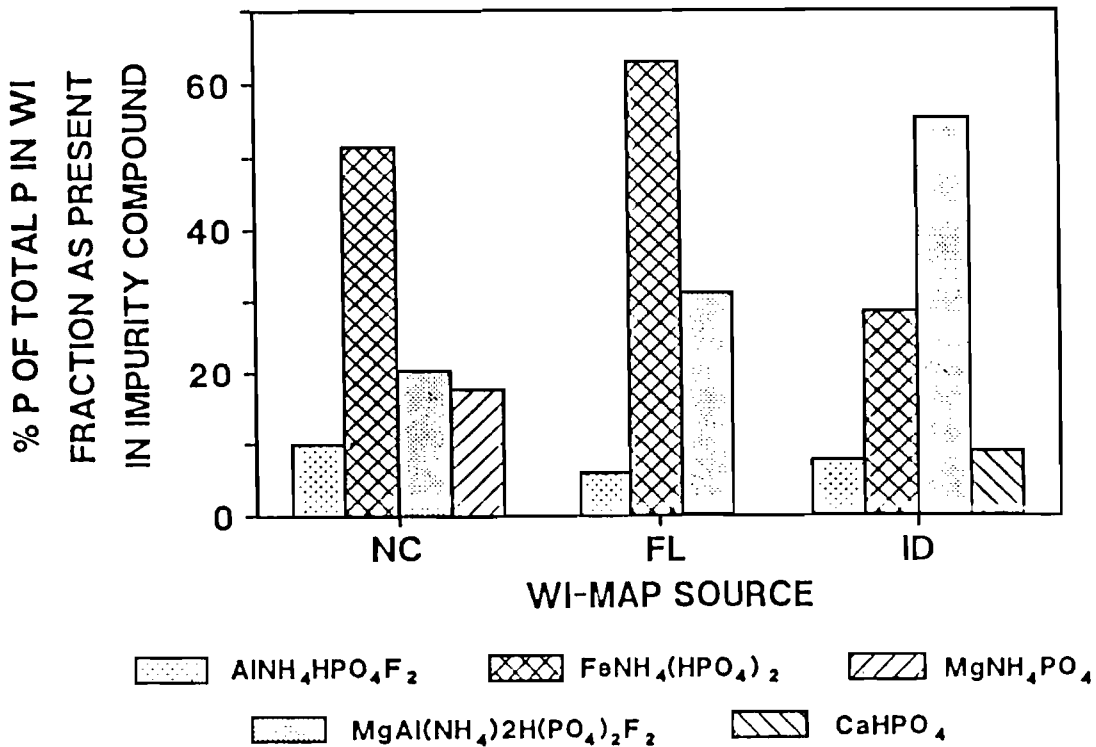
$MgAl(NH_4)2H(PO_4)_2F_2$ $CaHPO_4$

Figure 10. Phosphorus distribution in compounds present in WI fractions of MAP. Values calculated from compound distributions shown in Table 4. (Sikora et al.,1989a)

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PROCEEDINGS OF THE NINETEENTH

NORTH CENTRAL EXTENSION - INDUSTRY SOIL FERTILITY CONFERENCE

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Volume 5

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