ANNUAL REPORT TO SUPPORTING INSTITUTIONS

1990 GROWING SEASON

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I. Introduction

Experiments were conducted in the laboratory, greenhouse, and field during 1990, in many areas of soil fertility and management. Field experiments were conducted to evaluate the effectiveness of *Penicillum bilaji* (PB-50) inoculation of wheat seed as a phosphorus fertilizer substitute and greenhouse studies were performed to evaluate possible varietal interactions with P fertilization and PB-50 inoculation. Field studies were conducted to evaluate the relative effectiveness of several potential nitrification inhibitors under field conditions. Experiments have been initiated to determine if availability of banded polyphosphate fertilizers are increased by inclusion of ATS in the fertilizer band. Field studies were conducted to evaluate ATS as an herbicide extender when used with 2,4-D or EPTC.

II. PB-50 field studies.

A. Project orientation

Research has been conducted by Dr. R. Kucey of Agriculture Canada since the early 1980's on the nature of phosphorus-solubilizing organisms on root surfaces. This research has led to the isolation of a strain of *Penicillium bilaji* which grows rapidly in the root rhizosphere of several crop species. This organism apparently releases organic acids during its metabolism and seed inoculation with this strain has led to significant increases in P uptake by crops in both greenhouse and field studies in Canada. This strain has been released for sale with the trade name "PB-50". The purpose of this study was to determine if inoculation of wheat seed with PB-50 would increase P availability under North Dakota growing conditions.

Such an inoculant would be of great value to North Dakota growers if inoculation led to increases in P uptake early in the season. Farmers in North Dakota often use drill-applied P to obtain a "starter" effect, but would prefer to use faster broadcast and incorporation methods. Thus, the measurement of PB-50 inoculation effects on early plant P uptake and growth parameters was a high priority of this study.

B. Materials and Methods

A simple four-treatment trial with four replications was installed at four sites in North Dakota. Treatments consisted of two levels of drill P (0 vs 15 kg P/ha as triple superphosphate) multiplied by two levels of PB-50 inoculation (seed not inoculated vs seed inoculated according to manufacturer's recommendation). The seed was inoculated the day of seeding, and samples were sent to the manufacturer to confirm active inoculation. 'Stoa' wheat was used and seeded at 1.25 to 1.5 bu/A. Two sites were in southwestern ND (Hettinger and Dickinson), one site was in northeastern ND (Langdon), and one site was centrally located (Carrington). The Dickinson site was planted on summerfallow, the rest on land cropped the previous year.

Early growth parameters included stand, plant above-ground dry weight, main stem (MS) leaf development rate by the Haun scale, and tiller initiation. Common root rot (CRR) severity was measured at physiological maturity by the standard 1-4 scale of Ledingham, where 1=clean, 2=slight, 3=moderate, and 4=severe CRR. Common root rot measurements were performed courtesy of Dr. Bob Stack, Department of Plant Pathology, NDSU. Other measurements (height, head density, etc.) were taken as was common practice at each individual experiment station.

C. Results

Dickinson

This site was low in available P and had a near neutral pH (Olsen P=10 lb/A, pH=6.7). Most early growth parameters (plant dry matter, MS Haun stage, and tiller initiation) were significantly increased by application of phosphorus fertilizer (Table 1). Inoculation with PB-50 had little effect on these parameters, except for plant dry matter at the first sampling, where PB-50 gave a small but significant increase. None of the plant dry matter or tillering parameters were influenced by PB-50 at the second sampling.

Application of phosphorus fertilizer gave a yield increase of about 8 bu/A at Dickinson (Table 5). Inoculation with PB-50 gave a yield increase of about 4.5 bu/A. It is difficult to explain this yield increase, as there was little effect of PB-50 on the early growth parameters usually associated with P response. It is possible that the PB-50 increased P uptake by the wheat, but not early in the season. Plant analysis should answer these questions. It is certain, however, that the PB-50 did not reduce root disease (Table 5). The addition of P fertilizer increased CRR somewhat, and there was no influence on PB-50 on root disease either in the absence or presence of P fertilization.

Hettinger

This site had an Olsen soil test of 12 lb/A, and a pH of 6.5. Phosphorus fertilizer increased most of the early growth parameters of the wheat (Table 2). Seed treatment with PB-50 had no influence on these parameters.

This site was planted on stubble ground, not on fallow, and suffered damaging drought stress late in the season. Thus, there was little effect of the treatments on grain yield (Table 6).

Yields did tend to be a bit higher when treated with PB-50, and the effect was significant at the 0.2 level.

The head count at harvest was significantly higher with P fertilization, but PB-50 had no influence. This agrees with the data presented earlier that showed significant increases in tillering with P fertilization. Test weight was reduced and grain protein increased with P fertilization. This was possibly due to the stimulation of tillering, which could have led to greater drought stress later in the season, which would lead to more shrivelled grain with a higher protein content.

Crop height at harvest tended to be increased with P fertilization, but the effect was not significant. Common root rot tended to be increased by P fertilization.

Langdon

Almost all early growth parameters were improved by addition of P fertilizer (Table 3). The soil test data from Langdon is missing, but the samples will be rerun. The initial P test was similar to the other sites.

Grain yields tended to be improved with addition of P fertilizer, but the effect was not significant (Table 7). Test weight was improved significantly with addition of P fertilizer, which contradicts our observations at Hettinger. Inoculation with PB-50 had no influence on these parameters.

Severity of CRR was significantly increased by P fertilization, which agrees with the other two sites. Inoculation with PB-50 tended to reduce CRR, but the effect was not significant.

Carrington

The Carrington site had an Olsen test of 11 lb/A, and a pH of 7.7. The application of P had a significant effect on early growth at the first sampling (Table 4). The application of P tended to increase plant dry matter and tiller initiation at the second sampling, but these effects were not significant. The grain yield information has not been delivered to me by the Carrington station as of this date.

In general, drill application of P fertilizer improved early growth and development of wheat at all sites. This agrees with the general observation that most of the response to P fertilization occurs early in the season. Seed inoculation with PB-50 had little or no influence on these early growth parameters. We must conclude that, unfortunately, PB-50 inoculation does not seem to give a "starter" effect on early wheat growth.

PB-50 inoculation significantly improved wheat yields at one site (Dickinson). The reason for this response is not clear. Early growth parameters such as tillering were not improved and common root rot was not suppressed. Plant analysis should tell us if inoculation with PB-50 improved P uptake later in the season.

This research does not disprove the potential for such inoculant to reduce P fertilizer need. The results with this organism in Canada have been encouraging. Perhaps the organism is out of its range of adaptation in North Dakota soils.

III. PB-50 greenhouse study

A. Project orientation

We were puzzled why PB-50 inoculation gave a positive response to grain yield at Dickinson, but not at the other sites. We felt that a possible explanation was that the variety we selected (Stoa) was perhaps not a "friendly" variety towards this organism. To examine this theory, we collected soil from the Hettinger site (response to P fertilizer but not to PB-50) and from the Dickinson site (response to both P fertilizer and PB-50) for a greenhouse study. We are only halfway through this greenhouse study, having conducted the study with the Hettinger soil only.

B. Materials and Methods

The greenhouse experiment consisted of six popular but widely differing spring wheat varieties (Amidon, Butte 86, Grandin, Len, Marshall, and Stoa) by three treatments. Two kg of soil was placed in plastic pots. The treatments consisted of a control (no P or PB-50 treatment), seed treatment with PB-50, and soil treatment with 50 mg P/pot. Nitrogen was applied to each pot at 150 mg/pot. The fertilizer sources were urea and diammonium phosphate. About 200 g of soil was removed from each pot, and the fertilizer solutions were added in 300 mL of water. Ten seeds were sown, covered with the 200 g of soil, and the pots brought to field capacity with deionized water. After emergence the pots were thinned to 5 plants/pot. The experiment had 5 replicates.

About 40 days after seeding the experiment was terminated. Main stem development was determined by the Haun system. Tiller initiation was determined by the Klepper method. The number of main stem leaves were determined. All of the varieties tested normally produce 8-leaf plants. The plants were excised at the soil surface, dried, weighed, and ground for chemical analysis. Total P analyses have not been completed at this writing.

C. Results

The results of the trial are listed in Table 8. In general there was no influence of PB-50 inoculation on any of the parameters tested. However, there were strong effects of P fertilization and dramatic P x variety interactions. Some of these interactions have not been documented before, to my knowledge.

Overall main stem Haun stage varied dramatically by variety. Len was the least developed variety, with an average Haun stage of 7.1 at experiment termination. Plant dissection was often necessary to determine number of main stem leaves with this variety. Butte 86 was the most developed variety, with an average Haun stage of 9.6 at experiment termination.

Main stem Haun stage was, averaged across variety, improved about 0.6 leaf by phosphorus fertilization (from 7.9 to 8.5). This is in agreement with our field studies and with other studies that show a general advancement of maturity with phosphorus fertilization. Main stem development of one variety, Marshall, was not significantly advanced by P fertilization.

Tiller initiation in the absence of P fertilizer differed considerably from variety to variety. Butte 86 failed to produce any tillers in the absence of P fertilization. Grandin and Stoa also tillered poorly without added P. Amidon and Len produced about 1.0 and 0.8 tiller per plant in the absence of P fertilization. Marshall apparently tolerated the P stress much better, producing 1.6 tillers per plant in the absence of P fertilization.

P fertilization stimulated tillering at the T1, T2, and T3 positions by all varieties. P fertilization also greatly stimulated T0 (coleoptile tiller) initiation by the variety Amidon. We have previously notice in the field that this variety is more vigorous in producing T0 tillers.

The total number of tillers produced in the presence of P fertilization varied by variety as well, ranging from 1.6 for Butte 86 to 3.0 for Amidon.

Phosphorus fertilization has long been known to influence wheat tillering, but we did not expect such large variety x P interactions for tiller initiation.

Leaf habit was dramatically influenced by P deficiency. Two varieties, Amidon and Marshall, produced virtually all 8-leaf plants whether P was added or not. Butte 86 and Grandin produced almost all 7-leaf plants in the absence of P fertilization and almost all 8-leaf plants when fertilized with P. Len and Stoa were intermediate, producing some 7-leaf plants in the absence of P fertilization, but producing all 8-leaf plants in the presence of P fertilization.

All of the effects of P on plant development were reasonably consistent across variety. Butte 86 and Grandin seemed to be the varieties most sensitive to P deficiency. Both tillering and leaf habit were dramatically influenced. Tillering of Stoa was dramatically influenced by P fertilization, but leaf habit less so. Len and Amidon tillered better in the absence of P than the aforementioned varieties, but leaf habit was not dramatically changed. Marshall seemed to suffer the least P stress, as P fertilization gave only a modest improvement in tillering and little or and leaf habit change. P fertilization advanced main stem Haun stage for all varieties except Marshall, again suggesting that Marshall was suffering the least P stress in the absence of P fertilization.

Based on the crop development data, it seems that the sensitivities of these varieties to P stress on this soil were Butte 86=Grandin>Stoa>Len>Amidon>Marshall.

The dry matter yield data (Table 9), gives some support to the previous paragraph. The relative yield of the various varieties [100 x (control yld/yld with P)] was calculated. The relative yield of Marshall (85%) was considerably higher than for the other varieties, again indicating that perhaps this variety had a superior ability to withstand P stress in this greenhouse experiment.

If the repeating this study with the Dickinson soil confirms these dramatic variety x P interactions, further greenhouse and field studies would be justified. Current P management schemes for wheat do not account for possible P x variety interactions such as observed in this trial.

IV. Field nitrification studies

A. Project orientation

There is sustained interest in the development of slow-nitrifying fertilization systems. Research to identify fertilization programs that reduce nitrate leaching potential is of high priority in most states. This year's work in this area compared the influence of ATS, dicyandiamide (DCD), and nitrapyrin (N-Serve) on the nitrification of liquid fertilizers applied under field conditions.

B. Materials and methods

Nitrification experiments were conducted at three sites in eastern North Dakota. The Embden site was conducted on a Hecla loamy sand soil. The Fargo and Davenport sites were conducted on Fargo silty clay soils. All sites were planted to spring wheat after fertilizer application.

Urea-ammonium nitrate (UAN, 28-0-0) was applied on 12-inch centers about 5 inches deep with commercially available injection equipment (John Blue). Treatments applied were: 1. No fertilizer, 2. UAN, 3. UAN+ATS, 4. UAN+DCD, 5. UAN+ATS+DCD, and 6. UAN+N-Serve. The total amount of N fertilizer (urea + ammonium + nitrate)-N applied varied slightly between treatments (95-100 kg N/ha). All fertilizers were applied at a rate of 75 kg/ha of (urea + ammonium)-N. ATS was applied at 20% of the fertilizer volume (about 20 kg S/ha). DCD was applied at 2 kg/ha of DCD-N (3 kg DCD/ha). N-Serve was included at 0.56 kg/ha. The experiments were randomized complete block designs with four replicates.

Immediately after application the fertilizer application slits were marked with flags to indicate where to take subsequent samples. The day after application, and 2, 4, and 8 weeks after application six cores per plot were taken. Only treatments 1 and 2 were sampled the day after application. The cores were 10 cm diameter by 20 cm deep and were taken so as to intersect the fertilizer band. All 6 cores were mixed and the entire mass was dried, ground, and mixed thoroughly before subsampling. The soils were analyzed for ammonium-N or (urea + ammonium)-N by steam distillation. Application dates and rainfall for the three sites are given in Table 10.

C. Results and Discussion

The Embden site was dry and cool for the first two weeks after application, and there was little apparent nitrification during this period (Table 11). Little difference was noted between the treatments. After four weeks about half of the original N application was present as ammonium in the UAN treatment. Adding ATS to the fertilizer increased the ammonium-N level from 46 to 63 ppm, which was nearly significant at the 0.10 level. Treatments receiving DCD or N-Serve contained about 80 ppm of ammonium-N. After 8 weeks there was little ammonium left in the soil, although the inclusion of N-Serve with the fertilizer led to a significant increase, from 5 to 12 ppm.

The Fargo site received consistent rainfall during the 8-week period after application (Table 10). Two weeks after application there was considerable ammonium left in all soils receiving fertilizer, and there was little difference between treatments (Table 12). After 4 weeks the UAN treatment had declined from its original level of 115 ppm to 29 ppm of ammonium-N. Adding ATS to the fertilizer increased the level of ammonium-N in the soil to 54 ppm. Treatments receiving DCD or N-Serve had about 70 ppm remaining. After 8 weeks little ammonium remained in the soil for all treatments, except those receiving N-Serve.

The Davenport site was the last site to be established and the received considerable precipitation during the first 2 weeks after application (Table 10). After two weeks the level of ammonium-N found in the UAN treatment declined from the original level of 129 ppm to 56 ppm (Table 13). Adding ATS significantly increased this to 85 ppm. About 100 ppm was found in treatments receiving DCD or N-Serve. After 4 weeks only 10 ppm of ammonium-N was found in the UAN treatment. There was a significant increase due to the inclusion of ATS, 33 ppm. About 40 ppm was found in those treatments receiving DCD. N-Serve proved to be superior to DCD at this site at 4 weeks, giving 82 ppm of ammonium-N. After 8 weeks, little ammonium remained in the soil, except for the plots receiving N-Serve, where 28 ppm of the original level of about 130 ppm remained.

The inclusion of ATS with the UAN was found to increase soil ammonium levels at all three sites. The influence of ATS was neither as strong nor as long-lasting as for specific nitrification inhibitors like N-Serve. DCD was found to be equal to N-Serve at two sites at the four week sampling. At the site with the heaviest early rainfall (Davenport), DCD was less effective than N-Serve. Only N-Serve gave measurable nitrification inhibition at 8 weeks.

Crop yields were not measured as much of the plot was used for soil sampling purposes. Agronomic problems were encountered at each site as well. Uneven emergence was obtained at the Fargo site, herbicide damage was encountered at the Davenport site, and sulfur deficiencies were evident at the Embden site. An extremely visible response to the ATS treatments was obtained at the Embden site during the stem elongation stage. However, late-season drought stress was severe at this sandy site, and yields were reduced severely.

V. ATS-herbicide studies

A. Project orientation

Recent greenhouse studies have indicated that soil application of ATS can prolong the activity of several popular herbicides. These findings were somewhat supported by field trials in 1989 which showed that weed control given by soil incorporated EPTC or 2,4-D was improved occasionally by adding 4-8 gpa of ATS to the mixture.

B. Materials and methods

Two experimental designs were employed at three locations. EPTC ('Eradicane') was incorporated at the labelled rate with 0, 5, or 10 gpa of ATS. A control treatment was also included. The second experimental design included 2,4-D incorporated with 0, 5, or 10 gpa of ATS.

Topsoil samples were taken the day after application and weekly thereafter until it was apparent by field weed growth that all benefits of the herbicide was gone. The topsoil samples were frozen and are in the process of chemical analysis for residual herbicide content and also for bioassay of residual chemical. These analyses are not completed at the time of this writing. Visual estimations of percent weed control were taken as weed growth allowed.

Rainfall was, in general, much more abundant after herbicide application in 1990 compared to 1991. Visual estimations of percent weed control showed no effect of ATS on the persistence of the chemical. Bioassays completed thus far have shown no influence of ATS on chemical persistence in 1990.

A more complete report of this research will be made to the supporting agencies when the analyses are completed. In general, the effect of ATS on herbicide persistence is spotty at best.

VI. ATS-phosphate availability studies

A. Project orientation

A recent greenhouse study by Soper and associates of the University of Manitoba indicated that the availability of phosphorus from banded liquid monoammonium phosphate was enhanced by adding ATS to the band. It has been known for decades that the acidity produced upon oxidation of reduced sulfur compounds can enhance the availability of orthophosphate fertilizers when applied to alkaline soils. The purpose of this series of studies is to determine if the availability of P from ammonium polyphosphate is improved when mixed with ATS. We cannot predict whether the effects of ATS on MAP availability will also occur with APP. At first glance, one would speculate that ATS oxidation should acidify the band and improve P availability from APP. However, we have also had some indication that addition of ATS to APP can also slow polyphosphate hydrolysis, which would (theoretically) lead to reduced P availability from APP. Given the widespread use of APP-ATS mixtures as starter fertilizers in the Corn Belt, we felt that studies were justified. These studies have just begun and should continue for several months.

B. Materials and methods

A greenhouse study has been initiated, using the topsoil from the Hettinger field location. One kg of soil was placed in a plastic pot, moistened to field capacity, and allowed to equilibrate for several hours. A 10 cm long band of liquid fertilizer was applied. Eight hundred g of soil was placed in the pot, eight barley seeds planted, 200 g of soil placed in the pot, and the upper kg of soil moistened to field capacity with a nutrient solution. The pots were watered three times weekly thereafter with deionized water to the original pot weight.

Fertilizer treatments applied in the band consisted of three droplet sizes of liquid fertilizer (0.1, 0.2, 0.4 mL) by four compositions of liquid fertilizer. The liquid fertilizer mixtures consisted of 80 mL of APP mixed with 0, 5, 10, or 20 mL of ATS and diluted to 100 mL with water. A control treatment (no banded fertilizer) was also prepared.

The nutrient solution added to each treatment was formulated with urea and sodium sulfate to give each pot a total N and S addition of 100 and 50 mg/pot, respectively.

About 40 days after planting the experiment was terminated. The plants were rated for main stem Haun stage and tiller initiation. The plants were excised at the soil surface, dried at 65^{o}C, and ground. Plant tissue analyses have not been completed at this writing. The plants will also be analyzed for total Mn (to determine if the ATS also improved Mn uptake), but these analyses are not completed at this writing. A follow-up study with a high pH soil has also been initiated and will be completed in 1-2 weeks.

C. Results and discussion

The influence of rate of APP application and level of ATS addition on barley is shown in Table 14. The data is reasonably consistent for the 0.1 mL rate of APP application, but confusing at higher rates. Application of 0.1 mL of APP increased pot yield from about 6.3 to 6.9 g/pot. Adding 5% or 10% ATS in with the APP increased pot yield to 7.2 to 7.8 g/pot. Adding 5 or 10% ATS to the APP also increased the tiller production per plant from 1.7 with APP alone up to 2.4 tillers per plant with APP plus 10% ATS. It appeared that adding 20% ATS to the 0.1 mL APP band reduced P availability, as MS Haun stage, tiller production, and pot yield was less than with lower levels of ATS addition.

The study is more confusing at higher levels of APP. There was no consistent influence of ATS at the 0.2 and 0.4 mL rate of APP.

This first modest attempt to study the influences of ATS on availability of APP must be considered to be inconclusive, particularly until the plant analyses are completed. It appears that we maximized yield with a relatively low rate of P (0.1 mL of APP) with a modest addition of ATS (10% v/v). We are repeating this study with other soils.

VII. Other studies

Microplot nitrification studies were performed along side of the large-plot nitrification studies. Treatments included a wide array of ATS-DCD ratios, to determine if there is a synergism of ATS on DCD activity, as claimed by SKW, the German manufacturer of DCD. These samples are currently being analyzed and the results should be completed within 2 or 3 weeks.

Table 1. Effect of drill-applied phosphate fertilizer and seed treatment with *P. bilaji* on early growth and tillering parameters of spring wheat. Dickinson, ND, 1990.

Treatment		First sampling			Second sampling								
P	PB-50	Stand	Haun	DM	Haun	DM	T0	T1	T2	T3	T4	ST	TPP
kg/ha		pl/2m		mg/pl		mg/pl	tillers/pl						
0	No	66	2.4	28	6.3	354	0	0.4	0.4	0.2	0	0	1.0
15	No	68	2.6	34	6.8	521	<0.1	0.8	0.9	0.3	0	0.1	2.0
0	Yes	74	2.3	29	6.3	308	0	0.5	0.3	0.1	<0.1	0.3	1.2
15	Yes	64	2.7	37	6.9	578	<0.1	0.8	0.8	0.1	0	0.1	1.9
Sig. of F													
P Fert.		NS	**	**	**	**	*	**	**	NS	NS	NS	**
PB-50 Inoc.		NS	NS	*	NS	NS	NS	NS	NS	+	NS	NS	NS
P x PB-50		+	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Std. Error		3	<0.1	1	0.1	19	<0.1	0.1	0.1	0.1	<0.1	0.1	0.2

Stand given in plants per 2 m of row. Plant dry matter given as mg/plant. Tillering data represents initiation of tillers at the T0, T1, T2, T3, T4, total subtillers and the sum of all tillering (TPP or tillers per plant). For spring wheat in our climate, the T1 and T2 positions are by far the most important contributors to yield.

+, *, ** Significant at 0.1, 0.05 and 0.01 level, respectively.

Table 2. Effect of drill-applied phosphate fertilizer and seed treatment with *P. bilaji* on early growth and tillering parameters of spring wheat. Hettinger, ND, 1990.

Treatment		First sampling			Second sampling								
P	PB-50	Stand	Haun	DM	Haun	DM	T0	T1	T2	T3	T4	ST	TPP
kg/ha		pl/2m		mg/pl		mg/pl	tillers/pl						
0	No	88	2.5	34	6.3	373	0	0.4	0.6	0.1	0	0	1.0
15	No	96	2.6	40	6.8	559	<0.1	0.8	1.0	0.1	0	<0.1	1.8
0	Yes	95	2.4	32	6.4	391	0	0.3	0.8	0.1	0	<0.1	1.2
15	Yes	92	2.7	42	6.7	579	0	0.7	0.8	0.2	0	<0.1	1.7
Sig. of F													
P Fert.		NS	**	**	**	**	NS	**	+	NS	-	NS	**
PB-50 Inoc.		NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS
P x PB-50		NS	NS	NS	NS	NS	NS	NS	NS	NS	-	NS	NS
Std. Error		6	0.1	1	0.1	21	<0.1	0.1	0.1	0.1	-	<0.1	0.2

Stand given in plants per 2 m of row. Plant dry matter given as mg/plant. Tillering data represents initiation of tillers at the T0, T1, T2, T3, T4, total subtillers and the sum of all tillering (TPP or tillers per plant). For spring wheat in our climate, the T1 and T2 positions are by far the most important contributors to yield.

+, *, ** Significant at 0.1, 0.05 and 0.01 level, respectively.

Table 3. Effect of drill-applied phosphate fertilizer and seed treatment with *P. bilaji* on early growth and tillering parameters of spring wheat. Langdon, ND, 1990.

Treatment		First sampling			Second sampling								
P	PB-50	Stand	Haun	DM	Haun	DM	T0	T1	T2	T3	T4	ST	TPP
kg/ha		pl/2m		mg/pl		mg/pl	tillers/pl						
0	No	59	2.3	26	6.5	436	0	0.4	0.9	0.8	0.1	0.3	2.5
15	No	58	2.4	28	6.9	650	<0.1	0.7	1.0	1.0	0.2	0.9	3.9
0	Yes	53	2.2	26	6.4	378	<0.1	0.4	0.8	0.8	0.1	0.2	2.2
15	Yes	63	2.4	29	6.8	645	0.1	0.9	1.0	0.9	0.1	0.5	3.5
Sig. of F													
P Fert.		NS	*	*	**	**	*	**	*	*	NS	+	**
PB-50 Inoc.		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
P x PB-50		+	NS	NS	NS	NS	NS	+	NS	NS	NS	NS	NS
Std. Error		3	0.1	1	0.1	48	<0.1	0.1	0.1	0.1	<0.1	0.2	0.3

Stand given in plants per 2 m of row. Plant dry matter given as mg/plant. Tillering data represents initiation of tillers at the T0, T1, T2, T3, T4, total subtillers and the sum of all tillering (TPP or tillers per plant). For spring wheat in our climate, the T1 and T2 positions are by far the most important contributors to yield.

+, *, ** Significant at 0.1, 0.05 and 0.01 level, respectively.

Table 6. Effect of P fertilization and PB-50 inoculation on common root rot, grain yield, and selected harvest measurements. Hettinger, ND, 1990.

Treatment		Grain yield	Test weight	Grain Protein	Heads/A	Crop Height	Common root rot
P	PB-50						
kg/ha		bu/A	lb/bu	%	(1000)	cm	
0	No	19.66	57.42	17.93	1336	66	2.68
15	No	18.10	54.48	18.55	1643	68	2.86
0	Yes	20.31	57.07	17.95	1292	68	2.63
15	Yes	20.77	54.77	18.73	1713	73	2.95
Sig. of F							
P fert.		NS	**	**	**	NS	NS
PB-50 inoc.		NS	NS	NS	NS	NS	NS
P x PB-50		NS	NS	NS	NS	NS	NS
Std. error		1.07	0.32	0.19	90	3.2	0.19

** Significant at the 0.01 level, NS=Not significant.
Common root rot rated by the Ledingham 1-4 severity scale, where 1=none, 2=slight, 3=moderate, and 4=severe common root rot.

Table 4. Effect of drill-applied phosphate fertilizer and seed treatment with *P. bilaji* on early growth and tillering parameters of spring wheat. Carrington, ND, 1990.

Treatment		First sampling		Second sampling			
P	PB-50	Haun	DM	DM	MS Tillers	ST	TPP
kg/ha			mg/pl	mg/pl	-------tillers/pl--------		
0	No	4.3	90	435	1.2	<0.1	1.3
15	No	4.6	119	533	1.5	<0.1	1.5
0	Yes	4.4	96	472	1.3	0	1.3
15	Yes	4.6	139	550	1.6	<0.1	1.6
Sig. of F							
P Fert.		*	**	NS	NS	NS	NS
PB-50 Inoc.		NS	NS	NS	NS	NS	NS
P x PB-50		NS	NS	NS	NS	NS	NS
Std. Error		0.1	10	56	0.2	<0.1	0.2

Stand measurements not taken. Plant dry matter given as mg/plant. Because of weathering of lower leaves, a second Haun rating could not be taken. Consequently the tillering data is given as the sum of the main stem tillers and the sum of the subtillers.
+, *, ** Significant at 0.1, 0.05 and 0.01 level, respectively.

Table 5. Effect of P fertilization and PB-50 inoculation on common root rot, grain yield, and selected harvest measurements. Dickinson, ND, 1990.

Treatment P	Treatment PB-50	Grain yield	Common root rot
kg/ha		bu/A	
0	No	36.02	2.25
15	No	44.00	2.52
0	Yes	41.52	2.23
15	Yes	43.43	2.58
Sig. of F			
P fert.		**	+
PB-50 inoc.		*	NS
P x PB-50		**	NS
Std. error		0.93	0.18

Common root rot measured by the 1-4 scale of Ledingham, where 1=none and 4=severe common root rot.

Table 7. Effect of P fertilization and PB-50 inoculation on common root rot, grain yield, and selected harvest measurements. Langdon, ND, 1990.

Treatment P	Treatment PB-50	Grain yield	Test weight	Crop Height	Common root rot
kg/ha		bu/A	lb/bu	cm	
0	No	77.27	57.35	92	2.45
15	No	81.70	59.75	91	2.75
0	Yes	75.24	58.26	88	2.28
15	Yes	76.52	60.07	90	2.63
Sig. of F					
P fert.		NS	**	NS	*
PB-50 inoc.		NS	NS	NS	NS
P x PB-50		NS	NS	NS	NS
Std. error		3.71	0.58	1.6	0.11

Table 8. Effects of seed inoculation with Penicillium bilaji (PB-50) and phosphorus fertilization on development of six spring wheat varieties grown in the greenhouse. Soil from the Hettinger field site.

Variety	Treat-ment	Main stem Haun+	------Tiller initiation---- TO	T1	T2	T3	Sub	TPP++	7-leaf habit+
			--% of plants with tiller--					#/plant	%
Amidon	None	7.3	0	32	68	0	0	1.0	0
Amidon	+PB-50	7.4	5	32	59	5	0	1.0	0
Amidon	+Phosphate	7.9	44	100	100	44	8	3.0	0
Butte	None	9.4	0	0	0	0	0	0.0	72
Butte	+PB-50	9.4	0	0	0	0	0	0.0	87
Butte	+Phosphate	10.1	0	52	96	8	0	1.6	4
Grandin	None	9.0	0	0	4	28	0	0.3	100
Grandin	+PB-50	8.9	0	0	0	40	0	0.4	100
Grandin	+Phosphate	9.6	4	92	92	60	24	2.7	8
Len	None	6.8	0	8	52	24	0	0.8	13
Len	+PB-50	6.9	12	8	42	20	4	0.9	13
Len	+Phosphate	7.5	4	100	92	52	0	2.5	0
Marshl.	None	7.4	0	52	96	16	0	1.6	0
Marshl.	+PB-50	6.9	4	36	66	20	0	1.3	24
Marshl.	+Phosphate	7.5	4	96	100	72	0	2.7	0
Stoa	None	7.6	8	4	16	0	0	0.3	29
Stoa	+PB-50	7.7	0	4	16	4	0	0.2	26
Stoa	+Phosphate	8.5	0	84	88	4	12	1.9	0
SE^^		0.1	3	6	6	8	4	0.1	7

+ Main stem Haun=main stem growth stage (number of main stem leaves) by the Haun scale

++ TPP=average number of tillers per plant

^ 7-leaf habit=percentage of plants producing only 7 leaves on the main stem. The normal number of main stem leaves is 8 for all the varieties tested.

^^Standard Error

For all parameters tested, the F tests for variety, treatment, and variety x treatment interaction were all highly significant.

Table 9. Dry matter yield of six spring wheat varieties as influenced by phosphorus fertilization and inoculation with PB-50.

Variety	Treatment	Plant Yield	Relative Yield[+]
		g/pot	%
Amidon	None	2.6	63
	+PB-50	2.4	
	+P	4.1	
Butte	None	2.9	68
	+PB-50	2.7	
	+P	4.2	
Grandin	None	3.1	73
	+PB-50	2.8	
	+P	4.3	
Len	None	2.2	65
	+PB-50	2.1	
	+P	3.3	
Marshall	None	2.7	85
	+PB-50	2.3	
	+P	3.2	
Stoa	None	2.4	62
	+PB-50	2.5	
	+P	3.8	

[+] 100 x (Yield without P/Yield with P)

Table 10. Application dates and precipitation from the experimental locations.

Site	Application date	Precipitation 0-2 weeks	Precipitation 2-4 weeks	Precipitation 4-8 weeks
		in		
Embden	3 May 1990	<0.1	0.7	5.7
Fargo	7 May 1990	0.8	3.2	3.5
Davenport	22 May 1990	2.6	0.6	0.7

Table 11. Effect of liquid fertilizer composition on residual ammonium in soil cores taken through fertilizer bands. Embden site, 1991.

Treatment	Time after application: 1 day	2 weeks	4 weeks	8 weeks
	ppm ammonium-N			
No fertilizer	4	3	5	3
UAN	97	99	46	5
UAN-ATS		84	63	5
UAN-DCD		105	79	6
UAN-ATS-DCD		109	85	5
UAN-N-Serve		100	78	12
LSD (0.1)		18	18	3

Table 12. Effect of liquid fertilizer composition on residual ammonium in soil cores taken through fertilizer bands. Fargo site, 1991.

Treatment	Time after application			
	1 day	2 weeks	4 weeks	8 weeks
	ppm ammonium-N			
No fertilizer	4	4	6	4
UAN	115	81	29	5
UAN-ATS		84	54	5
UAN-DCD		108	71	9
UAN-ATS-DCD		94	72	7
UAN-N-Serve		97	70	26
LSD (0.10)		18	21	3

Table 13. Effect of liquid fertilizer composition on residual ammonium in soil cores taken through fertilizer bands. Davenport site, 1991.

Treatment	Time after application			
	1 day	2 weeks	4 weeks	8 weeks
	ppm ammonium-N			
No fertilizer	4	6	2	2
UAN	129	56	10	4
UAN-ATS		85	33	3
UAN-DCD		102	43	9
UAN-ATS-DCD		96	42	9
UAN-N-Serve		114	82	28
LSD (0.10)		21	9	5

Table 14. Effect of fertilizer droplet size and addition of ATS on barley yield and development. Greenhouse study, 1990.

APP rate	ATS rate	Haun	T1	T2	T3	T4	Sub	TPP+	Yield
mL	% (v/v)		-------% of plants				----------		g/pot
None	None	9.7	15	30	80	10	0	1.4	6.27
0.1	0	10.3	10	85	75	0	0	1.7	6.93
	5	10.3	20	95	75	5	10	2.1	7.20
	10	10.5	35	95	90	15	5	2.4	7.83
	20	9.9	10	95	75	20	10	2.1	6.55
0.2	0	10.1	40	95	80	10	0	2.3	7.32
	5	10.3	10	90	90	10	15	2.2	7.14
	10	10.0	15	90	75	5	0	1.9	7.09
	20	10.4	5	80	90	15	10	2.0	7.33
0.4	0	10.5	32	100	65	16	0	2.1	7.46
	5	10.2	15	85	40	5	0	1.5	6.90
	10	10.5	15	95	80	5	0	2.0	7.14
	20	10.2	10	85	90	10	0	2.0	7.06

+TPP=number of tillers initiated per plant