Agricultural Sciences, 2014, 5, 1491-1500
Published Online December 2014 in SciRes. http://www.scirp.org/journal/as
http://dx.doi.org/10.4236/as.2014.514160

Feasibility of Rock Phosphate and Other Amendments in Preventing P Deficiency in Barley on a P-Deficient Soil in Northeastern Saskatchewan

Sukhdev S. Malhi[1,2], Cecil L. Vera[1*], Stewart A. Brandt[2]

[1]Agriculture and Agri-Food Canada, Saskatchewan, Canada
[2]Northeast Agricultural Research Foundation (NARF), Saskatchewan, Canada
Email: *cecil.vera@agr.gc.ca

Received 3 November 2014; revised 21 November 2014; accepted 1 December 2014

Abstract

In the Canadian Prairies, many soils on organic farms are low in available P, and the only alternative is to use external sources to prevent P nutrient deficiency on these soils. A 3-year (2012 to 2014) field experiment was established in spring 2012 on a P-deficient soil near Kelvington, Saskatchewan, Canada, to determine the potential of organic amendments (alfalfa pellets, compost manure, thin stillage and distiller grain dry of wheat), inorganic amendments (rock phosphate granular, rock phosphate fine, wood ash and bone meal ash) and microbial inoculants/products (JumpStart® and MYKE®PRO), applied alone or in a combination with N and/or P commercial fertilizers, in preventing P deficiency and increasing seed yield, N and P uptake of barley. Compared to unfertilized control, N only treatment did not result in any significant increase in seed yield, while application of P alone increased seed yield significantly but to a lesser degree than when both N and P fertilizers were applied together in all 3 years. Rock phosphate did not result in any seed yield benefit, even when applied along with N fertilizer. Wood ash fine increased seed yield of barley significantly only in the presence of N fertilizer, with highest seed yield in the presence of both N + P fertilizers. Seed yield of barley increased moderately with alfalfa pellets, significantly with compost manure, and considerably with distiller grain dry of wheat, but highest seed yield was obtained from thin stillage, which was essentially similar to that obtained from the N + P fertilizer combination. There was no yield benefit from JumpStart or MykePro in any year and only slight benefit from bone meal ash in 2013. The addition of N fertilizer to MykePro or bone meal ash treatments increased seed yield, but highest yield was obtained when both N and P fertilizers were added, suggesting a lack of available P for optimum seed yield. With few exceptions, the response trends of total N and P uptake in seed + straw to the amendments studied were

---

[*]Corresponding author.

How to cite this paper: Malhi, S.S., Vera, C.L. and Brandt, S.A. (2014) Feasibility of Rock Phosphate and Other Amendments in Preventing P Deficiency in Barley on a P-Deficient Soil in Northeastern Saskatchewan. *Agricultural Sciences*, **5**, 1491-1500. http://dx.doi.org/10.4236/as.2014.514160

generally similar to those of seed yield. In conclusion, the organic amendment "thin stillage" provided balanced nutrition and produced yield and nutrient uptake of barley similar to balanced N + P fertilizer treatment, and it was closely followed by "distiller grain dry of wheat", with moderate benefit from compost manure and some benefit from alfalfa pellets. In this extremely P-deficient soil, rock phosphate was not found effective in preventing P deficiency in barley, while wood ash and bone meal ash provided moderate increase in barley yield, with little yield benefit from JumpStart and MykePro, when other nutrients were not limiting in the soil.

Keywords

Cereals, Inorganic Amendments, N Uptake, Organic Amendments, P-Deficiency, Rock Phosphate, Seed Yield

1. Introduction

Because of possible high economic returns due to price premiums on organically produced food [1], organic farming is becoming popular in Canada [2] and many other countries. In organic farming, the application of synthetic chemical fertilizers, to prevent nutrient deficiencies in crops, is not allowed and alternative sources of nutrients need to be found to supply adequate amounts of nutrients in soil, essential for sustainable high crop production. In the Prairie Provinces of Canada, most soils on organic farms are deficient in plant-available N and there are many soils low in available P for optimum crop yield [3]-[5]. Previous research in Saskatchewan has indicated that long-term production of crops without adding adequate P can decrease available P in soil under organic system [6]. Other research in Montana, USA, has suggested that the depletion of available nutrients in soil on organic farms can result in poor crop yield and quality [7]. Therefore, maintaining adequate levels of available P in soil to prevent P deficiency in crops can be a serious problem for organic agriculture in the Canadian Prairies [2].

On organic farms, the deficiency of N in crops can be prevented by growing N-fixing legume crops in the rotations [8]-[10]. However, if soils are deficient in available P, the only alternative is to use external sources to prevent P nutrient deficiency. Animal manures can provide P and other nutrients [11] [12], but usually there is not enough manure to apply on all farm fields, especially in remote areas because of the high cost of transporting manure to long distances, making their use uneconomical [13]-[17]. On these soils, rock phosphate fertilizer and other amendments or microbial inoculants/products (e.g., wood ash, bone meal ash, humic acid materials and *Penicillium bilaiae*, arbuscular mycorrhizal fungi [AMF], vesicular-arbuscular mycorrhizal [VAM], MykePro) may be used to correct deficiency of P in crops. Research information on the potential of these products, particularly rock phosphate, in preventing P deficiency in crops grown on P-deficient soils is lacking under prairie soil-climatic conditions and in other parts of Canada. The objective of this study was to determine the potential of various organic and inorganic amendments/microbial inoculants or products in preventing P deficiency in barley on a P-deficient soil in northeastern Saskatchewan.

2. Materials and Methods

A 3-year field experiment was established in spring 2012 on a thin Black Chernozem (Typic Cryoboroll) loam soil near Kelvington, Saskatchewan, Canada. Soil at this site has shown severe P deficiency in alfalfa and forage yield of this crop species increased dramatically with P fertilizer application in 2011 (S. S. Malhi—personal communication). Some characteristics of soils used in these experiments are presented in **Table 1**. Precipitation in the growing season (May, June, July and August) at the nearest Environment Canada Meteorological Station (AAFC Melfort Research Farm) is given in **Table 2**. In 2012, the growing season precipitation was much above-average (especially in June and July during peak growing season), with relatively cooler air temperatures and wet conditions in June and July. In 2013, the growing season precipitation was slightly below-average, but it was well distributed and above-average in June and July during peak growing season, resulting in excellent crop growth and seed yield. In 2014, the growing season precipitation was near-average.

Table 1. Some characteristics of soil in spring 2012 at initiation of the field experiment at Kelvington, Saskatchewan.

Soil Great Group*	Depth (cm)	Texture	Organic Matter (%)	pH (1:2 Water)	Nitrate-N (kg·ha^{-1})	Extractable P (kg·ha^{-1})	SO_4-S (kg·ha^{-11})	Extractable K (kg·ha^{-1})
Black Chernozem (thin)	0 - 30	Loam	4.0	7.8	12.3	3.4	10.1	773

*Based on Canadian Soil Classification System.

Table 2. Growing season monthly and total precipitation for the four site-years, and average 30-year average precipitation and temperature at Kelvington, Saskatchewan.

		Precipitation in the growing season (mm)*		30-Year average (Melfort Research Farm)	
Month	2012	2013	2014	Precipitation (mm)	Temperature (˚C)
May	72.7	22.7	36	45.6	9.1
June	112.3	96.9	77	65.8	16.9
July	97.8	103.2	78	75.5	18.3
August	68.1	10.6	60	56.8	19.6
Total	350.9	233.4	251	243.7	

*At the nearest Environment Canada Meteorological Station (Melfort Research Farm).

In this study, a randomized complete block design was used to lay out the treatments in four replications. Each plot was 7.5 m long and 1.8 m wide. The 20 treatments were: 1) Control (no fertilizer/amendment) 0 kg N ha^{-1} + 0 kg P ha^{-1}; 2) N (34-0-0) only 100 kg N ha^{-1}; 3) P (0-45-0) only at 20 kg P ha^{-1}; 4) N (34-0-0) + P (0-45-0) 100 kg N ha^{-1} + 20 kg P ha^{-1}; 5) *Penicillium bilaiae* at 60 mg·kg^{-1} of seed + 100 kg N ha^{-1}; 6) Rock Phosphate Granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}; 7) Rock Phosphate Granular (BC Mines) at 20 kg P ha^{-1} + *Penicillium bilaiae* + 100 kg N ha^{-1}; 8) Rock Phosphate Fine (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}; 9) Rock Phosphate Fine (BC Mines) at 20 kg P ha^{-1} + *Penicillium bilaiae* + 100 kg N ha^{-1}; 10) Wood ash (Fly Ash) at 2 Mg·ha^{-1}; 11) Wood ash (Fly Ash) at 2 Mg·ha^{-1} + 100 kg N ha^{-1}; 12) Wood ash (Fly Ash) at 2 Mg·ha^{-1} + 100 kg N ha^{-1} + 20 kg P ha^{-1}; 13) Alfalfa Pellets at 3.5 Mg·ha^{-1}; 14) Compost at 8 Mg·ha^{-1}; 15) Thin Stillage at 20,000 L·ha^{-1}; 16) Distiller grain dry wheat at 2 Mg·ha^{-1}; 17) MykePro; 18) MykePro + 100 kg N ha^{-1}; 19) Bone meal ash at 154 kg·ha^{-1}; and 20) Bone meal ash at 154 kg·ha^{-1} + 100 kg N ha^{-1}.

On average, rock phosphate (Black Diamond Resources or High Bix Manufacturing, Westbank, British Columbia, Canada) contained 7.4% total P; wood ash (Cliff Ronden Company, Edmonton, Alberta, Canada)—0.51% total P, 4.5% total K and 1.3% total S; alfalfa pellets (Western Alfalfa Milling Company Ltd., Norquay, Saskatchewan, Canada)—2.9% total N, 0.2% total P, 2.5% total K and 0.2% total S; compost (called Moo Poo-Spectrum Brands IP Inc., Brantford, Ontario, Canada)—1.3% total N, 0.64% total P, 1.3% total K and 0.3% total S; thin stillage (bioproduct of ethanol—Ethanol, Poundmaker, Lanigan, Saskatchewan, Canada)—0.5% total N, 0.11% total P, 0.16% total K and 0.05% total S; distiller grain dry of wheat (bioproduct of ethanol—Ethanol, Poundmaker, Lanigan, Saskatchewan, Canada)—5.6% total N, 0.77% total P, 1.13% total K and 0.7% total S; and bone meal ash (manufactured by P-Grow, sent by Johnson's Soil Ecosystems, United Kingdom—www.jseco.co.uk)—13.1% total P. *Penicillium bilaiae* inoculant JumpStart® (Novozymes BioAg Inc., Saskatoon, Saskatchewan, Canada) was applied to the seed at a rate of 60 mg·kg^{-1} and MYKE® PRO (Premier Tech Biotechnologies, Rivere-du-Loup, Quebec, Canada) mycorrhizal inoculant was applied with the seed, at seeding, at a rate of 10 kg·ha^{-1}. The two last products do not contain any P, but are expected to increase the release of P from soil and/or rock phosphate fertilizer. The estimated amounts of N, P, K and S applied annually in different treatments are presented in **Table 3**.

In the spring of 2012, 2013 and 2014, triple superphosphate (0-45-0) and rock phosphate fertilizers were sidebanded at seeding, while all other amendments were broadcast on soil surface before seeding. Also, all plots received blanket application (surface broadcast) of K_2SO_4, to supply 50 kg K and 20 kg S ha^{-1}, before seeding. All plots were tilled to incorporate the surface-broadcast blanket K_2SO_4 fertilizer and amendments into the soil just prior to seeding. Plots were seeded to barley with a double-disc press drill with 17.8 cm row spacing.

In each plot, the data were recorded on seed and straw yield, concentration and uptake of total P and total N in seed and straw every year. Seed yield was determined by harvesting 1.25 m wide and 7.0 m long strips with a plot combine and straw yield was calculated from hand harvested samples collected from two 1 m long rows in each plot at maturity. The oven dry (60˚C) samples were analyzed for total N and total P in seed and straw. Total

Table 3. Estimated amounts of N, P, K and S applied annually in different treatments in a field experiment on a P-deficient soil at Kelvington, Saskatchewan.

Treatment		Amounts of nutrients applied annually (kg N, P, K or S ha^{-1})			
No	Amendments	N	P	K	S
1	Control (no amendment)	0	0	50	20
2	N only—100 kg N ha^{-1} (using 34-0-0)	100	0	50	20
3	P only—20 kg P ha^{-1} (using 0-45-0)	0	20	50	20
4	N + P—100 kg N ha^{-1} + 20 kg P ha^{-1}	100	20	50	20
5	*Penicillium bilaiae* + 100 kg N ha^{-1}	100	0	50	20
6	Rock P granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}	100	20	50	20
7	Rock P granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1} + *Penicillium bilaiae*	100	20	50	20
8	Rock P finely-ground (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}	100	20	50	20
9	Rock P finely-ground (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1} + *Penicillium bilaiae*	100	20	50	20
10	Wood ash at 2 Mg·ha^{-1}	0	10	140	46
11	Wood ash at 2 Mg·ha^{-1} + 100 kg N ha^{-1}	100	10	140	46
12	Wood ash at 2 Mg·ha^{-1} + 100 kg N ha^{-1} + 20 kg P ha^{-1}	100	30	140	46
13	Alfalfa pellets at 3.5 Mg·ha^{-1}	102	7	138	53
14	Compost at 8 Mg·ha^{-1}	104	51	154	44
15	Thin stillage at 20,000 L·ha^{-1}	100	22	82	30
16	Distiller grain (wheat)—dry at 2 Mg·ha^{-1}	112	15	83	34
17	MykePro	0	0	50	20
18	MykePro + 100 kg N ha^{-1}	0	0	50	20
19	Bone meal at 154 kg·ha^{-1}	0	20	50	20
20	Bone meal at 154 kg·ha^{-1} + 100 kg N ha^{-1}	100	20	50	20

P in seed and straw samples was measured by using ICP-OES method of Huang and Schulte [18]. Total N in seed and straw samples was determined by sample digestion and detection of N by thermal conductivity using a CNS combustion analyzer [19]. The amounts of total P uptake in kg P ha^{-1} or total N uptake in kg N ha^{-1} were calculated by multiplying the concentrations of total P or total N with yields of seed or straw.

The data were subjected to analysis of variance (ANOVA) using GLM procedure [20]. For each ANOVA, standard error of the mean (SEM) and significance are reported. Least significant difference ($LSD_{0.05}$) was used to determine significant differences between treatment means.

3. Results

3.1. Yield

Compared to unfertilized control, N only treatment did not significantly increase seed yield of barley in any of the three years of the study, suggesting that the test soil was extremely deficient in available P (**Table 4**). Application of P alone significantly increased seed yield in two years (2012 and 2013), but best yield values (in all three years) were obtained when both N and P fertilizers were applied together. Rock phosphate (both granular and finely-ground) and/or *Penicillium bilaiae* did not produce seed yield benefit in any year, even when applied along with N fertilizer, indicating the inability of these treatments to supply adequate, if any, amounts of available P for optimum seed yield. Wood ash fine alone significantly increased seed yield only in 2013, but with the addition of N fertilizer increased seed yield significantly in all three years of the study, however, highest seed yield was obtained when wood ash fine was applied with N + P fertilizers. This suggests that wood ash alone did not provide sufficient amount of available P for optimum crop growth and seed yield. Seed yield of barley increased slightly (not significant in 2012) with alfalfa pellets, moderately (not significant in 2014) with compost, and considerably with DDG-wheat, with highest seed yield obtained from the application of thin stillage, which in some cases (2012 and 2014) resulted in higher barley seed yield than that obtained from the N + P fertilizer combination. There was no seed yield benefit from MykePro alone or bone meal ash alone applications in any year. Application of MykePro or bone meal ash treatments, in combination with N fertilizer, slightly increased

Table 4. Seed yield of barley with various amendments applied annually in 2012, 2013 and 2014 in a field experiment on a P-deficient soil at Kelvington, Saskatchewan.

Treatment		Seed yield (kg·ha^{-1})		
No	Amendments	2012	2013	2014
1	Control (no amendment)	1825	4602	2580
2	N only—100 kg N ha^{-1} (using 34-0-0)	1766	4831	2552
3	P only—20 kg P ha^{-1} (using 0-45-0)	2217	6034	3019
4	N + P—100 kg N ha^{-1} + 20 kg P ha^{-1}	2748	7436	4923
5	*Penicillium bilaiae* + 100 kg N ha^{-1}	1768	4862	2583
6	Rock P granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}	1597	4644	2475
7	Rock P granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1} + *Penicillium bilaiae*	1646	4849	2623
8	Rock P finely-ground (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}	1705	4732	2600
9	Rock P finely-ground (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1} + *Penicillium bilaiae*	1636	4866	2552
10	Wood ash at 2 Mg·ha^{-1}	2025	5403	3038
11	Wood ash at 2 Mg·ha^{-1} + 100 kg N ha^{-1}	2378	5734	3600
12	Wood ash at 2 Mg·ha^{-1} + 100 kg N ha^{-1} + 20 kg P ha^{-1}	2990	7191	4782
13	Alfalfa pellets at 3.5 Mg·ha^{-1}	2066	5494	3614
14	Compost at 8 Mg·ha^{-1}	2392	6178	3032
15	Thin stillage at 20,000 L·ha^{-1}	3133	7380	5010
16	Distiller grain (wheat)—dry at 2 Mg·ha^{-1}	2883	7273	5197
17	MykePro	1410	4300	2511
18	MykePro + 100 kg N ha^{-1}	1941	4991	2517
19	Bone meal	1868	5091	2672
20	Bone meal + 100 kg N ha^{-1}	2170	5631	3569
	$LSD_{0.05}$	297	691	543
	SEM	104.9***	244.1***	191.7***

***Significant at P < 0.001.

seed yield in all three years (only significant for bone meal), suggesting lack of available P for optimum seed yield.

The response trends of straw yield (which was measured only in 2012) to organic and inorganic amendments were similar to seed yield, with only a few minor exceptions related to magnitude of response (**Table 5**). For example, wood ash when applied in a combination with N + P produced greater straw yield than thin stillage, but it did not translate into seed yield to the same extent as thin stillage.

3.2. Total N and Total P Uptake

Total N and P uptake in seed + straw were determined only in 2012. Compared to unfertilized control, N only treatment resulted in some increase in total N uptake in seed + straw, but greatest significant values of total N uptake in seed + straw were obtained when both N and P fertilizers were applied together (**Table 5**). There was no consistent beneficial effect of rock phosphate and/or *Penicillium bilaiae* on total N uptake in seed + straw, even when applied along with N fertilizer. Compared to unfertilized control, wood ash fine alone did not affect total N uptake in seed + straw, but significant increases were observed when wood ash fine was applied with N or N + P fertilizers. This suggests that wood ash provided nearly sufficient amount of available P for optimum crop growth, but in most years it did not translate into higher seed yield. Total N uptake in seed + straw of barley did not increase with compost and increased slightly with alfalfa pellets, but considerable increases in total N uptake in seed + straw were observed with DDG-wheat or thin stillage, which were higher than those obtained with the N + P fertilizer combination. There was no increase in total N uptake in seed + straw from MykePro alone or bone meal ash alone applications. However, application of N fertilizer in combination with MykePro or bone meal treatments increased total N uptake in seed + straw significantly, suggesting that these amendments provided available P to the crop in the growing season, for optimum growth and other nutrient uptake, but it did not translate into higher seed yield.

Table 5. Straw yield, P uptake and N uptake of barley with various amendments in 2012 in a field experiment on a P-deficient soil at Kelvington, Saskatchewan.

Treatment		$kg \cdot ha^{-1}$		
No	Amendments	Straw yield	P uptake	N uptake
1	Control (no amendment)	2637	7.6	67.4
2	N only—100 kg N ha^{-1} (using 34-0-0)	2785	6.9	77.2
3	P only—20 kg P ha^{-1} (using 0-45-0)	3076	10.5	65.6
4	N + P—100 kg N ha^{-1} + 20 kg P ha^{-1}	4486	11.1	90.4
5	*Penicillium bilaiae* + 100 kg N ha^{-1}	2908	7.2	77.5
6	Rock P granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}	2718	6.6	73.6
7	Rock P granular (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1} + *Penicillium bilaiae*	2666	6.6	73.0
8	Rock P finely-ground (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1}	2873	7.2	78.5
9	Rock P finely-ground (BC Mines) at 20 kg P ha^{-1} + 100 kg N ha^{-1} + *Penicillium bilaiae*	2759	6.7	71.7
10	Wood ash at 2 $Mg \cdot ha^{-1}$	2843	8.2	68.0
11	Wood ash at 2 $Mg \cdot ha^{-1}$ + 100 kg N ha^{-1}	3838	9.8	93.8
12	Wood ash at 2 $Mg \cdot ha^{-1}$ + 100 kg N ha^{-1} + 20 kg P ha^{-1}	4958	13.5	96.3
13	Alfalfa pellets at 3.5 $Mg \cdot ha^{-1}$	3157	7.9	77.7
14	Compost at 8 $Mg \cdot ha^{-1}$	2950	10.9	64.6
15	Thin stillage at 20,000 $L \cdot ha^{-1}$	4516	13.8	97.1
16	Distiller grain (wheat)—dry at 2 $Mg \cdot ha^{-1}$	4399	12.1	99.7
17	MykePro	1974	5.0	50.4
18	MykePro + 100 kg N ha^{-1}	3149	8.1	84.5
19	Bone meal	2593	7.1	64.6
20	Bone meal + 100 kg N ha^{-1}	3389	8.5	89.3
	$LSD_{0.05}$	550	1.9	14.4
	SEM	194.1^{***}	0.66^{***}	5.10^{***}

***Significant at $P < 0.001$.

Compared to unfertilized control, N only treatment did not cause any increase in total P uptake in seed + straw, but P alone resulted in significant increase of total P uptake , however greatest P uptake was observed when both N and P fertilizers were applied together (**Table 5**). There was no beneficial effect of rock phosphate and/or *Penicillium bilaiae* on total P uptake in seed + straw, even when applied along with N fertilizer. Compared to unfertilized control, wood ash fine alone increased total P uptake in seed + straw only slightly (not significant), with further increase in total P uptake when wood ash was applied along with N fertilizer, and even higher P uptake values were observed when wood ash fine was applied with N + P fertilizers. This suggests that wood ash provided nearly sufficient amount of available P for optimum crop growth, but it did not translate into optimum seed yield. Total P uptake in seed + straw of wheat did not increase with alfalfa pellets, increased significantly with compost, but considerable higher P uptake increases were observed with DDG-wheat and thin stillage, which were even higher than those obtained with the N + P fertilizer combination. There was no increase in total P uptake in seed + straw from MykePro or bone meal ash even when applied in combination with N, suggesting that these amendments did not provide available P for crop uptake.

4. Discussion

Previous research has shown potential benefits of organic and inorganic amendments, and bioinoculants on crop yield and nutrient uptake [21]-[27]. Similarly in our present study, we investigated the effectiveness of many organic and inorganic amendments, and microbial inoculants/products to prevent P deficiency in barley grown on an extremely P-deficient soil in northeast Saskatchewan. In this study, we added K_2SO_4 fertilizer as a blanket application to all plots to supply adequate amounts of S and K to prevent any deficiency of these nutrients in the crop at the experimental site. In this study, we used inorganic amendments and microbial inoculants or products (e.g., rock phosphate, wood ash, bone meal, *Penicillium bilaiae*, MykePro), either alone, or in a combination with N to prevent deficiency of N in soil, so that yield, total N uptake and total P uptake of barley with these inorganic amendments and microbial inoculants or products can be compared with the best yield, total N uptake and total P uptake of barley obtained with the balanced NP treatment. In this study, we also included some organic amendments (e.g., alfalfa pellets, compost, thin stillage and distiller grain dry of wheat [DGD-wheat]), without any combination with N fertilizer, because these products were expected to supply adequate amounts of N to the barley crop for its optimum growth/yield. The results on yield, total N uptake and total P uptake of barley with various organic and inorganic amendments or microbial inoculants/products are discussed in the following paragraphs, and our findings are applicable for preventing P deficiency in crops under both organic and conventional cropping systems.

Earlier research has suggested that the effectiveness of rock phosphate fertilizer in increasing available P in soil and subsequently improving crop yields in P-deficient soils varies with the source of P rock [24], and soil type/pH and climatic conditions [24] [27]. Field research by Bolland and Gilkes [28] has shown slight to no yield response of crop to application of rock phosphate, and this was attributed to little release of available P from the rock P fertilizer. Similarly, in our present study on a P-deficient soil, there was no beneficial effect on seed yield of barley from both granular and finely-ground rock phosphate fertilizers even after 3 consecutive annual applications, while application of triple superphosphate (synthetic P fertilizer) increased seed yield of barley substantially in all 3 years, provided that N and other nutrients were not limiting in the soil. Because of the increase in surface area for faster microbial interactions and chemical changes, finely-ground rock phosphate was expected to produce greater yield and P uptake of barley compared to granular rock phosphate, but this did not occur in our 3-year study on a P-deficient soil. This suggests that rock phosphate fertilizer used in our study did not release available P in soil solution on this P-deficient soil for effective P uptake of high yielding barley crop with high P requirements.

Jeng *et al.* [25] suggested the use of bone meal ash to prevent P deficiency and increase crop yield in P-deficient soils. In our study, there was a significant (but moderate) increase in seed yield of barley from annual applications of bone meal ash, when N was not limiting. But, the increase in seed yield of barley from bone meal ash was much less than similarly applied triple superphosphate in a combination with N fertilizer, suggesting that bone meal ash may not be a good source of readily available P for optimum yield and P uptake on extremely P-deficient soils.

Application of wood ash to annual cereal or legume crops on soils suspected to be deficient in P has been shown to increase seed yield in Alberta (K. S. Gill—unpublished results) and on an organic farm soil in Saskatchewan [29], and this increase in crop yield from wood ash was attributed to increased supply of P in soil from this treatment. Similarly, in our study, there was a significant (but moderate) increase in seed yield of barley from the application of wood ash in all years. But, the seed yield of barley with wood ash was still significantly lower than triple superphosphate, suggesting that the rate of wood ash used in our study did not supply adequate amounts of available P to barley crop for optimum yield on this P-deficient soil.

Previous research studies have suggested the use of *Penicillium bilaiae* inoculation to increase available P in soil and consequently improve crop yield and P uptake [26] [30] [31]. In a field study in western Canada, Gleddies *et al.* [32] showed positive responses of canola to *Penicillium bilaiae* inoculation on soils extremely deficient in P. However, in our study, there was no beneficial effect of *Penicillium bilaiae* inoculation on seed yield of barley and P uptake on an extremely P-deficient soil, as also shown by other studies [29] [33]. In another field study in USA, rock phosphate application did not show any increase in crop yield and P uptake, even when applied in combination with *Penicillium bilaiae*. Similarly in our study, there was no beneficial effect on seed yield of barley from the granular rock phosphate fertilizer when applied in a combination with *Penicillium bilaiae* inoculation.

The use of other microbial inoculants or products (AMF—arbuscular mycorrhizal fungi or VAM—vesicular-arbuscular mycorrhizal) has been shown to increase crop yield by preventing P deficiency in P-deficient soils [23]. However, in our study, there was only slight beneficial effect of MykePro on seed yield of barley, even when other nutrients were not limiting in the soil.

In our study, among the treatments receiving only organic amendments, annual applications of thin stillage gave the highest seed and straw yield, and total P and N uptake of barley, which was closely followed by DGD-wheat. The yield and nutrient uptake obtained with thin stillage and DGD-wheat were similar to the balanced NP treatment. Other recent studies have also reported that thin stillage was consistently very effective in producing high crop yields and nutrient uptake [29] [34]. This suggests a great potential of thin stillage and DGD-wheat in preventing deficiency of P (and also other nutrients) in crops on soils extremely deficient in P under both organic and conventional cropping systems. Annual applications of compost and alfalfa pellets also increased yield, P uptake and N uptake of barley compared to the control, but yield, total P uptake and total N uptake of barley with these organic amendments, especially alfalfa pellets, were much lower than the balanced NP treatment. This suggests that these organic amendments, particularly alfalfa pellets, may not supply adequate amounts of available P for optimum seed yield under extremely P-deficient soil situations.

The results of previous short-term research studies on the feasibility of rock phosphate fertilizers in improving crop yields on P-deficient soils are inconsistent and not very conclusive, suggesting the need of long-term field experiments on the feasibility of this amendment. Wood ash, because of its basic nature, can also be used to ameliorate acidic soils, in addition to supplying available P to crop plants. But wood ash, because of its powder form and large volumes of application, as well as bone meal ash, because of its powder form, may not be convenient to apply in its original form, requiring to be granulated for their use on a commercial scale. In addition, because of the potential residual effects of organic amendments, such as alfalfa pellets, compost manure, thin stillage and distiller grains, on soil fertility and crop productivity, it is important to have long-term information on the economic feasibility of such amendments. Our present field experiment was conducted over three years on one P-deficient soil/site using one source of rock phosphate. Earlier research has shown that the effectiveness of rock phosphate varies with rock phosphate source/type [21] [24]. Therefore, long-term field studies are required to determine the feasibility of rock phosphate and other inorganic amendments, organic amendments, as well as microbial inoculants/biofertilizers/bioinoculants for preventing P deficiencies and sustainable high production of different crops under varied soil types (with different plant available P levels, pH, texture, organic matter, etc.), climatic and crop growing conditions. Further research is also needed to investigate the effects of composting various rock phosphate fertilizers/sources with animal, hog or poultry manure, or using rock phosphate fertilizers alongside animal/hog/poultry and green manure in preventing P deficiencies and increasing crop yields.

5. Conclusion

Thin stillage provided balanced nutrition and produced seed yield and nutrient uptake of barley similar to balanced N + P fertilizer treatment, which was closely followed by DGD-wheat, with moderate benefit from compost and some benefit from alfalfa pellets. In this extremely P-deficient soil, rock phosphate was not found effective in preventing P deficiency in barley, while wood ash fine and bone meal ash provided moderate increase in barley yield, with little yield benefit from JumpStart (*Penicillium bilaiae* inoculant) or MykePro (mycorrhizal inoculant), when other nutrients were not limiting in the soil.

Acknowledgements

The authors thank D. Leach and K. Strukoff for technical help.

References

[1] Zentner, R.P., Basnyat, P., Brandt, S.A., Thomas, A.G., Ulrich, D., Campbell, C.A., Nagy, C.N., Frick, B., Lemke, R., Malhi, S.S. and Fernandez, M.R. (2011) Input Management and Crop Diversity: Effects on Economic Returns and Riskiness of Cropping Systems in the Semiarid Canadian Prairie. *Renewable Agricultural Food Systems*, **26**, 1-16. http://dx.doi.org/10.1017/S1742170510000591

[2] Macey, A. (2006) Certified Organic Production in Canada. Canadian Organic Growers. (Online) http://www.cog.ca

[3] Entz, M.H., Guilford, R. and Gulden, R. (2001) Crop Yield and Soil Nutrient Status on 14 Organic Farms in the Eastern Part of the Northern Great Plains. *Canadian Journal of Plant Science*, **81**, 351-354. http://dx.doi.org/10.4141/P00-089

[4] Jans, D. (2001) Organic Needs Assessment: Results of Workshops and Questionnaires. Saskatchewan Agriculture and Food, Saskatchewan.

[5] Watson, C.A., Atkinson, P., Gosling, P., Jackson, L.R. and Ryans, F.W. (2002) Managing Soil Fertility in Organic Farming Systems. *Soil Use and Management*, **18**, 239-247. http://dx.doi.org/10.1079/SUM2002131

[6] Malhi, S.S., Brandt, S.A., Lemke, R., Moulin, A.P. and Zentner, R.P. (2009) Effects of Input Level and Crop Diversity on Soil Nitrate-N, Extractable P, Aggregation, Organic C and N, and N and P Balance in the Canadian Prairie. *Nutrient Cycling in Agroecosystems*, **84**, 1-22. http://dx.doi.org/10.1007/s10705-008-9220-0

[7] Miller, P.R., Buschena, D.E., Jones, C.A. and Holmes, J.A. (2009) Transition from Intensive Tillage to No-Tillage and Organic Diversified Cropping Systems. *Agronomy Journal*, **100**, 591-599. http://dx.doi.org/10.2134/agronj2007.0190

[8] Hoyt, P.B. and Leitch, R.H. (1983) Effects of Forage Legume Species on Soil Moisture, Nitrogen, and Yield of Succeeding Barley Crops. *Canadian Journal of Soil Science*, **63**, 125-136. http://dx.doi.org/10.4141/cjss83-012

[9] Foster, R.K. (1990) Effect of Tillage Implement and Date of Sweetclover Incorporation on Available Soil N and Succeeding Spring Wheat Yields. *Canadian Journal of Soil Science*, **70**, 269-277.

[10] Townley-Smith, L., Slinkard, A.E., Bailey, L.D., Biederbeck, V.O. and Rice W.A. (1993) Productivity, Water Use and Nitrogen Fixation of Annual Legume Green-Manure Crops in the Dark Brown Soil Zone of Saskatchewan. *Canadian Journal of Plant Science*, **73**, 139-148. http://dx.doi.org/10.4141/cjps93-017

[11] Izaurralde, R.C., Nyborg, M., Solberg, E.D., Janzen, H.H., Arshad, M.A., Malhi, S.S. and Molina-Ayala, M. (1998) Carbon Storage in Eroded Soils after Five Years of Reclamation Techniques. In: Lal, R., Kimble, J.M., Follett, R.F. and Stewart, B.A., Eds., *Soil Processes and the Carbon Cycle*, CRC Press, Boca Raton, 369-385.

[12] Schoenau, J.J. (2000) The Value of Manure. *Proceedings of the Manure Management* 2000 *Conference*, Calgary, 28 June 2000, 2-5.

[13] Araji, A.A., Abdo, Z.O. and Joyce, P. (2001) Efficient Use of Animal Manure on Cropland—Economic Analysis. *Bioresearch Technology*, **79**, 179-191. http://dx.doi.org/10.1016/S0960-8524(01)00042-6

[14] Fleming, R.A. and Long, J.D. (2002) Measuring Cost of Restricting Access to Cropland for Manure Nutrient Management. *Agronomy Journal*, **94**, 57-64. http://dx.doi.org/10.2134/agronj2002.0057

[15] Feinerman, E., Bosch, D.J. and Pease, J.W. (2004) Manure Applications and Nutrient Standards. *American Journal of Agriculture Economics*, **86**, 14-25. http://dx.doi.org/10.1111/j.0092-5853.2004.00559.x

[16] Ribaudo, M., Cattaneo, A. and Agopoff, J. (2004) Cost of Meeting Manure Nutrient Standards in Hog Production: The Roles of EQIP and Fertilizer Offsets. *Review of Agriculture Economics*, **26**, 430-444. http://dx.doi.org/10.1111/j.1467-9353.2004.00192.x

[17] Keplinger, K.O. and Hauck, L.M. (2006) The Economics of Manure Utilization: Model and Application. *Journal of Agricultural Research Economics*, **31**, 414-440.

[18] Huang, C.L. and Schulte, E.E. (1985) Digestion of Plant Tissue for Analysis by ICP-AES. *Communications in Soil Science and Plant Analysis*, **16**, 943-958. http://dx.doi.org/10.1080/00103628509367657

[19] Association of Official Analytical Chemists (1995) Protein (Crude) in Animal Feed. Combustion Method (990.03). Official Methods of Analysis. 16th Edition, AOAC, Washington DC.

[20] SAS Institute Inc. (2004) Online Documentation for SAS, Version 8. http://support.sas.com/documentation/onlinedoc/index.html

[21] Akande, M.O., Adediran, J.A. and Oluwatoyinbo, F.I. (2005) Effects of Rock Phosphate Amended with Poultry Manure on Soil Available P and Yield of Maize and Cowpea. *African Journal of Biotechnology*, **4**, 444-448.

[22] Blackshaw, R.E. (2005) Nitrogen Fertilizer, Manure, and Compost Effects on Weed Growth and Competition with Spring Wheat. *Agronomy Journal*, **97**, 1612-1621. http://dx.doi.org/10.2134/agronj2005.0155

[23] Chalk, P.M., Souze, R.F., Urquiaga, B.J.R. and Boddey, R.M. (2006) The Role of Arbuscular Mychorrhiza in Legume Sybiotic Performance. *Soil Biology and Biochemistry*, **38**, 2944-2951. http://dx.doi.org/10.1016/j.soilbio.2006.05.005

[24] Haque, I., Lupwayi, N.Z. and Ssali, H. (1999) Agronomic Evaluation of Unacidulated and Partially Acidulated Minjingu and Chilembwe Phosphate Rocks for Clover Production in Ethiopia. *European Journal of Agronomy*, **10**, 37-47. http://dx.doi.org/10.1016/S1161-0301(98)00048-3

[25] Jeng, A.S., Haraldsen, T.K., Gronlund, R. and Pedersen, P.A. (2009) Meat and Bone Meal as Nitrogen and Phosphorus Fertilizer to Cereals and Ryegrass. *Nutrient Cycling in Agroecosystems*, **76**, 183-191. http://dx.doi.org/10.1007/s10705-005-5170-y

[26] Kucey, R.M.N. (1987) Increased Phosphorus Uptake by Wheat and Field Beans Inoculated with a Phosphorus-Solubilizing *Penicillium bilaji* Strain and with Vesicular-Arbuscular *Mycorrhizal fungi*. *Applied Environmental Microbiology*, **53**, 2699-2703.

[27] Rick, T.L., Jones, C.A., Engel, R.E. and Miller, P.R. (2011) Green Manure and Phosphate Rock Effects on Phosphorus Availability in a Northern Great Plains Dryland Organic Cropping System. *Organic Agriculture*, **1**, 81-90. http://dx.doi.org/10.1007/s13165-011-0007-2

[28] Bolland, M. and Gilkes, B. (1990) The Poor Performance of Rock Phosphate Fertilizers in Western Australia: Part 1. The Crop and Pasture Responses. *Agricultural Sciences*, **3**, 43-48.

[29] Malhi, S.S. (2012) Relative Effectiveness of Various Amendments in Improving Yield and Nutrient Uptake under Or-

ganic Crop Production. *Open Journal of Soil Science*, **2**, 299-311. http://dx.doi.org/10.4236/ojss.2012.23036

[30] Beckie, H.J., Schlechte, D., Moulin, A.P., Gleddie, S.C. and Pulkinen, D.A. (1998) Response of Alfalfa to Inoculation with *Penicillium bilaii* (Provide). *Canadian Journal of Plant Science*, **78**, 91-102. http://dx.doi.org/10.4141/P97-043

[31] Vessey, J.K. and Heisinger, K.G. (2001) Effect of *Penicillium bilaiae* Inoculation and Phosphorus Fertilisation on Root and Shoot Parameters of Field-Grown Pea. *Canadian Journal of Plant Science*, **81**, 361-366. http://dx.doi.org/10.4141/P00-083

[32] Gleddie, S.C., Schlechte, D. and Turnbull, G. (1993) Effect of Inoculation with *Penicillium bilaii* (Provide®) on Phosphate Uptake and Yield of Canola in Western Canada. *Proceedings of Alberta Soil Science Workshop*, Edmonton, 22-24 February1993, 155-160.

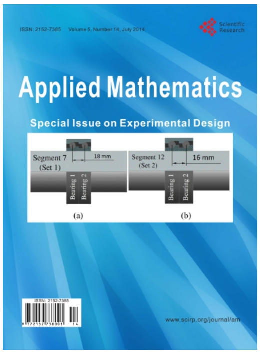
[33] Goos, R.J., Johnson, B.E. and Stack, R.W. (1994) *Penicillium billaie* and Phosphorus Fertilization Effects on the Growth, Development, Yield and Common Root Rot Severity of Spring Wheat. *Fertilizer Research*, **39**, 97-103. http://dx.doi.org/10.1007/BF00750908

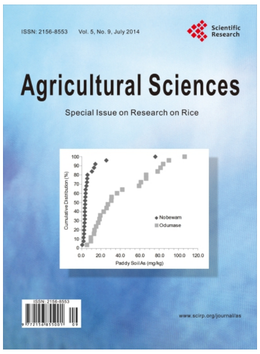
[34] Malhi, S.S., Vera, C.L. and Brandt, S.A. (2013) Relative Effectiveness of Organic and Inorganic Nutrient Sources in Improving Yield, Seed Quality and Nutrient Uptake of Canola. *Agricultural Sciences*, **4**, 1-18. http://dx.doi.org/10.4236/as.2013.412A001

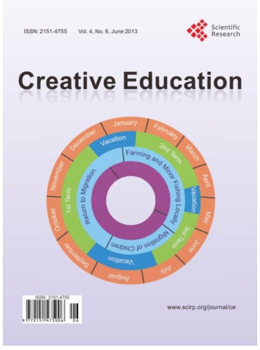

Advances in
Bioscience and Biotechnology

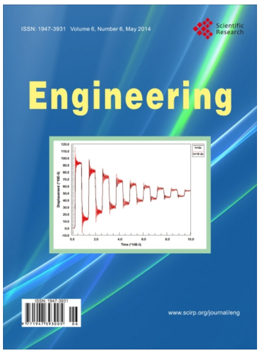

American Journal of
Analytical Chemistry


American Journal of
Plant Sciences
Special Issue on Photosynthesis

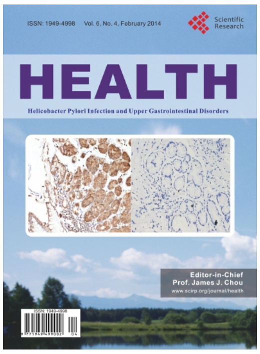

Applied Mathematics
Special Issue on Experimental Design


Agricultural Sciences
Special Issue on Research on Rice


Creative Education

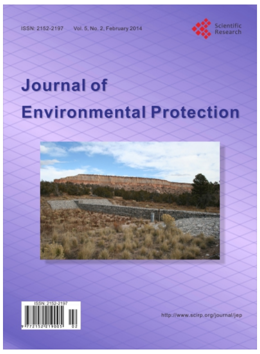

Engineering

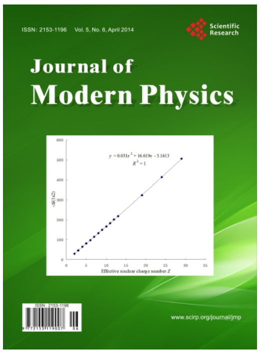

Food and Nutrition Sciences


HEALTH
Helicobacter Pylori Infection and Upper Gastrointestinal Disorders
Editor-in-Chief
Prof. James J. Chou

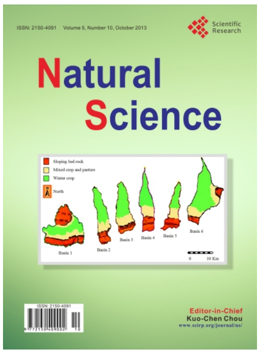

Journal of Computer
and Communications

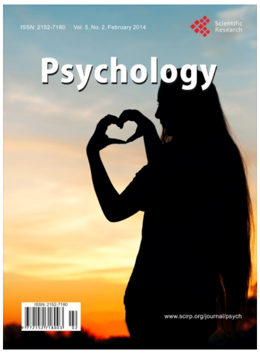

Journal of Cancer Therapy
Special Issue on Bone Tumor Research


Journal of
Environmental Protection


Journal of
Modern Physics


Modern Economy


Natural
Science
Editor-in-Chief
Kuo-Chen Chou


Psychology