Management Strategies and Practices for Preventing Nutrient Deficiencies in Organic Crop Production

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Background

- The interest and demand for organically-grown food and fibre products are increasing in Canada and internationally.
- Maintaining soil fertility, controlling weeds and developing appropriate crop rotations are important issues facing organic agriculture.
- Organic producers in Saskatchewan ranked soil fertility as one of the top three research priorities, and soil P concerned producers the most.
- Crops with taproots can absorb nutrients from deeper depths, and make them available in surface soil after crop residues are returned. This can improve economic productivity.
- Rotations of fibrous and taproot crops in a cropping system can therefore improve the cycling and crop use of nutrients.
- Any nutrient(s) limiting in the soil can cause substantial reductions in crop yield.
- In the Canadian Prairie Provinces, most soils under organically farmed systems are deficient in available N for optimum yield.
- There are many organically farmed soils low in available P, and some soils contain insufficient amounts of S and K for high crop yields.
- However, if soils are deficient in available P, K, S or other essential nutrients, the only alternative is to use external nutrient sources to replenish the deficiencies.
- The N deficiency in soil on organic farms can be corrected by growing N-fixing legume crops in rotations.
- In organic farming, synthetic fertilizers and chemicals cannot be applied to increase crop yields.
- Manure/compost can be used to increase nutrient supplies, but often there is not enough manure to apply on all farm fields, and transporting manure long distances is costly.
- On such soils, rock phosphate fertilizer, elemental S fertilizer, gypsum or wood ash may be used to correct deficiencies of these nutrients.
- The information on the feasibility of these products in preventing nutrient deficiencies under organic farming is lacking under prairie soil-climatic conditions and in other parts of Canada.

Objective

Field experiments are underway to determine the influence of the following management practices and/or amendments on crop yield:

Management Practices

- ✓ Crop diversity/rotation
- ✓ Crop residue
- ✓ Green manure
- ✓ Legumes for seed/forage
- ✓ Cereal-legume intercropping

Amendments

- ✓ *Penicillium bilaiae*
- ✓ Rock phosphate
- ✓ Gypsum
- ✓ Elemental S
- ✓ Compost manure
- ✓ Wood ash
- ✓ Alfalfa pellets
- ✓ Rock P composted in manure

Materials and Methods

Alternative cropping systems experiment

- The on-going field experiment was established in 1995 on a Dark Brown Chernozem (Typic Boroll) loam soil at Scott, Saskatchewan to compare input level and cropping diversity under various alternative cropping systems.
- The 54 treatments were combinations of three **input levels** [organic – **ORG** (no input of fertilizers and other chemicals under conventional tillage), reduced – **RED** (reduced input of fertilizers and other chemicals under no-till) and high – **HIGH** (recommended input of fertilizers and other chemicals under conventional tillage)], three **cropping diversities** (low diversity – **LOW**, diversified annual grains – **DAG** and diversified annual grains and perennial forage crops – **DAP**) and six crop phases including green manure (GM), chem-fallow or tilled-fallow (F).
- Data collection focuses on crop yield, nutrient concentration and uptake, soil quality, economic performance, energy efficiency.

Table 1. Summary of cropping systems.

Crop Diversity	Input Level	Crop Sequence[1]
LOW (low diversity of annual grains)	**High**	F_T-W-W-F_T-C-W
	Reduced	L_{GM}-W-W-F_C-C-W
	Organic	L_{GM}-W-W-L_{GM}-C-W
DAG (diversified annual grains)	**High**	C-R-P-B_M-F_X-W
	Reduced	C-R-P-B_M-F_X-W
	Organic	L_{GM}-W-P-B_M/S_C-S_{CGM}-C
DAP (diversified annual grains and perennial forages)	**High**	C-W-B_F-O/B_R&A-H-H
	Reduced	C-W-B_F-O/B_R&A-H-H
	Organic	C-W-B_F-O/B_R&A-H-H

[1]F_T = tillage fallow, W = wheat, C = canola, L_{GM} = lentil green manure, F_C = chemical fallow, P = field pea, B_M = malt barley, B_F = feed barley, S_C = sweet clover, S_{CGM} = sweet clover green manure, R = fall rye, F_X = flax, O = oats, B_R&A = bromegrass-alfalfa, H = hay.

Materials and Methods

Rock phosphate and other amendments experiments

- A number of field experiments are underway to determine the influence of *Penicillium bilaii* on the release of available P from rock phosphate fertilizer in preventing P deficiency on P-deficient soils, elemental S fertilizers and gypsum in preventing S deficiency on S-deficient soils, and compost manure and wood ash (wood ash is a waste product of forest industry that contains lot of Ca and Mg, about 1% P_2O_5, 5% K_2O, 1% S, and small amounts of other essential nutrients) in preventing deficiencies of N, P, K, S and other nutrients in soils lacking in these nutrients for organic crops.
- Data collection includes yield, produce quality, and nutrient uptake of crops, nutrient accumulation and quality of soil, and greenhouse gas (GHG) emissions.

Summary of Results

Alternative cropping systems

- Crop yields for ORG were 30-40% lower than for the production systems with the HIGH/RED input.
- But, lower input costs plus price premiums normally more than offset lower yield in the ORG system.
- Net energy production was greater for conventional than organic, but energy output to input ratio was greater for the ORG system.
- This indicated favourable economic performance and energy efficiency of organic systems.

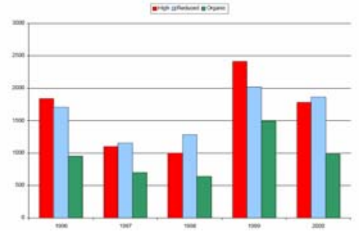

Figure 1. Average annual total production.

Table 2. Effect of crop diversity and input level (average of 5 years from 1996 to 2000) on mean costs and returns for cropping systems – at 3 price premiums received for organically grown grains ($ ha^{-1}).

Input Level	Parameter	Price Premium (%)		
		100	**50**	**0**
High	Gross Return	331	331	331
	Total Cost	205	205	205
	Net Return	125	125	125
Reduced	Gross Return	312	312	312
	Total Cost	200	200	200
	Net Return	112	112	112
Organic	Gross Return	337	276	198
	Total Cost	163	159	154
	Net Return	174	117	44

Table 3. Effect of Input Level on Energy Performance (MJ ha^{-1}) (average of 5 years from 1996 to 2000).

Energy Parameter	Price Premium		
	High	**Reduced**	**Organic**
Gross Energy Output	35071	34135	20186
Total Energy Input	3833	3562	1516
Net Energy Production	30875	30807	18806
Energy Output/Input Ratio	9.2	9.6	13.3

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- Legume crops, green manure and summer fallow helped to replace N in organic systems, suggesting that N deficiency in soil on organic farms can be prevented by using these practices.
- The findings also suggest that application of manure/compost can provide N, P, K, S and other nutrients lacking in the soil.
- In the organic system, the amount of P removed in crop exceeded that of P replaced.
- This resulted in low extractable P in the surface soil and extremely low levels in the subsoil layers, and this can be a major yield limiting factor for high sustainable crop production in the organic systems.
- The soil P results indicate that there may be a little potential for taproot crops to bring P from deeper soil to the surface on soils similar to this site.
- This also suggests that if the whole soil profile is low in available P or other nutrients, it may not be possible to sustain high crop yields under organic farming systems without external nutrient additions.

Table 4. Distribution of extractable P in soil profile in relation to input levels, averaged across three crop diversities and six crop phases, in autumn 2006 at Scott, Saskatchewan.

Input Level	Extractable P (kg ha^{-1}) in soil layers (cm)				
	0-15	**15-30**	**30-60**	**60-90**	**0-90**
ORG	9	7	2	1	19
RED	16	9	3	1	29
HIGH	13	9	2	1	25
$LSD_{0.05}$	3**	ns	ns	ns	6*

*, ** and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

- Amount of nitrate-N in the 0-240 cm soil was usually lower with ORG or RED input than with HIGH input, and nitrate-N in different soil layers suggested some downward movement of nitrate-N in plots receiving HIGH input.
- Nitrate-N was higher in rotations that included GM/F than in rotations with continuous cropping.
- These results suggest that if N fertilizer is applied at high rates and crop frequency is low, there is a potential for accumulation and leaching of nitrate-N in the soil profile, increasing risk of ground water contamination.
- Other earlier research has shown that properly managed organic crop production may considerably reduce potential risk of nitrate leaching in soil because of decreased input of N to the soil-plant system.

Table 5. Distribution of soil nitrate-N in the 0 to 240 cm depth in selected treatments in relation to input level in autumn 2006 at Scott, Saskatchewan.

Input Level	Nitrate-N (kg ha^{-1}) in various soil layers (cm)								
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**120-150**	**150-180**	**210-240**	**0-240**
ORG	10	7	22	34	34	32	28	28	222
RED	18	15	15	22	37	35	33	31	240
HIGH	13	10	17	20	68	70	58	40	356
$LSD_{0.05}$	2***	ns	ns	ns	ns	37•	30•	ns	ns

•,*, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Rock phosphate and other amendments

- In the rock phosphate experiments, there was a significant but small increase in crop yield from granular rock phosphate fertilizer in the year of application on a P-deficient soil.
- The results suggest that it is unlikely that the addition of rock phosphate will produce any economic returns for organic producers in the year of application, but it may provide an economic yield benefit in the long term.
- Application of Penicillium bilaiae alone increased crop yield, but its application in combination with granular rock phosphate did not increase the crop performance over Penicillium bilaiae applied alone on P-deficient soils.
- In our on-going experiments, granular rock phosphate had little benefit in correcting or preventing P deficiency in crops, most likely due to large particle/granule size.
- In future experiments, we are planning to also broadcast and incorporate into the soil a finely-ground rock phosphate fertilizer to increase interaction between P particles and soil microorganisms to increase P release and its availability to crops.

Table 6. Effect of rock P and *P. bilaiae* on seed yield of wheat (average of 6 site-years).

Amendment	Seed yield (kg ha^{-1})		Amendment	Seed yield (kg ha^{-1})	
	O P	**20 kg P ha^{-1}**		**Untreated**	**Treated**
Rock P	883 b	933 a	*P. bilaiae*	872 a	944 b

- In Alberta, the addition of wood ash, without concurrent addition of N, showed increase in seed yield and economic returns of barley and field pea, and an increase in alfalfa forage yield and protein content in Ontario.
- The yield benefit most likely resulted from improvement in the availability of P and/or other nutrients contained in the wood ash.
- In addition to preventing nutrient deficiencies and improving yields of crops grown under organic farming systems, wood ash has other potential benefits, such as reduction in soil acidity (which may last for several years), improvement in soil tilth, increased microbial biomass and reduced weed infestation.
- In Ontario, wood ash improved alfalfa dry matter yield (DMY). In 2006, DMY from 2 cuts was 7.1 Mg ha^{-1} with wood ash and 5.2 Mg ha^{-1} in control treatment. In 2007, DMY was 4.5 Mg ha^{-1} with wood ash and 3.8 Mg ha^{-1} for control.
- Wood ash also increased PC in Cut 1 alfalfa over the control by more than 2.5% in 2006, and by 1.4-1.8% in 2007.
- Manure alone increased PC by only 1.5-1.8% compared to the control in 2006 and 2007. The PC was increased by 2.7-3.5% when wood ash and manure were applied together.
- Soil tests revealed an increase in pH (by 0.5 units). Wood ash also improved available Ca, K, P, Zn, Mn, Cu and B in soil.

Table 7. Seed yield of barley and pea with wood ash and chemical fertilizers blend in 2006 and 2007.

Treatments[z]	Seed yield (kg ha^{-1})			
	2006		**2007**	
	Barley	**Pea[y]**	**Barley**	**Pea[y]**
Control	3753	3977	4838	3983
Fertilizer blend	5849	4923	n.d.	5505
Wood ash	4730	4870	5194	5655
Wood ash + N Fertilizer	6447	5237	n.d.	5627
$LSD_{0.05}$	1017	790		

[z]In 2006, blend of N (180 kg 46-0-0 ha^{-1}) and P (65 kg 11-52-0 ha^{-1}) fertilizers supplied 90 kg N + 34 kg P_2O_5 ha^{-1}; wood ash (3360 kg ha^{-1}) supplied 34 kg P_2O_5 + other nutrients; and wood ash (3360 kg ha^{-1}) + N fertilizer (180 kg 46-0-0 ha^{-1}) supplied 83 kg N + 34 kg P_2O_5 + other nutrients. In 2007, blend of N (59 kg 46-0-0 ha^{-1}) and P (75 kg 11-52-0 ha^{-1}) fertilizers supplied 36 kg N + 39 kg P_2O_5 ha^{-1}; wood ash (4368 kg ha^{-1}) supplied 44 kg P_2O_5 + other nutrients; and wood ash (4368 kg ha^{-1}) + N fertilizer (59 kg 46-0-0 ha^{-1}) supplied 27 kg N + 44 kg P_2O_5 + other nutrients.
[y]There was no N fertilizer applied to pea, but it received granular *Rhizobium* inoculant at a proper rate.

Table 8. Returns above amendment costs for barley and pea with wood ash and chemical fertilizers blend in 2006 and 2007.

Treatments[t]	Returns above costs of amendments ($ ha^{-1})[z]			
	2006		**2007**	
	Barley	**Pea[y]**	**Barley**	**Pea[y]**
Control	379	556	869	876
Fertilizer blend	492	637	n.d.	1144
Wood ash	411	614	865	1157
Wood ash + N Fertilizer	514	642	n.d.	1127

[z]2006 Prices: 46-0-0 = $390 Mg^{-1}; 11-52-0 = $450 Mg^{-1}; Wood ash = 20 Mg^{-1}; Barley = $100.83 Mg^{-1}; Pea = $139.35 Mg^{-1}; Inoculant = $23.17 ha^{-1}. 2007 Prices: 46-0-0 = $605 Mg^{-1}, 11-52 = $578 Mg^{-1}, Ash = $20 Mg^{-1}; Barley = $183.32 Mg^{-1}, Peas = $220.02 Mg^{-1}; Inoculant = $23.17 ha^{-1}.

- The results of our other S experiments suggest that elemental S fertilizer and gypsum may have the potential to correct/prevent S deficiency and improve yields of crops grown on S-deficient soils under organic farming systems.
- Composted livestock manure may offer greater potential in restoring soil P than other strategies, such as granular rock phosphate application.

Conclusions

- Overall, our findings suggest that the sustainability of crop production under organic farming can be increased by improving nutrient use and water use efficiency, most likely through better plant and root growth.
- This will result in higher net economic returns to producers as well as improve soil quality and prevent soil erosion by returning more crop residues to the soil plus minimize environmental damage of nitrate-N (leaching to ground water and nitrous oxide emissions) by leaving less residual nitrate-N in the soil.
- In the short as well as long term, economic outlook for organic systems remains very promising, provided there is a sufficiently large organic price premium, and nutrients and weeds are managed effectively.
- In conclusion, the findings suggest that integrated use of management practices and amendments has the potential to increase sustainability of organic crop production as well as improve soil quality plus minimize environmental damage.