Maximizing N Fertilizer Use Efficiency and Minimizing the Potential for Nitrate-N Accumulation and Leaching in Soil by Balanced Fertilization

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Rationale and Objective

- In the Parkland region and other areas of the Prairie Provinces, most soils are deficient in plant available N, many soils are low in available P, and soils in certain areas contain insufficient amounts of available S or K for optimum crop growth. So, fertilizers are normally applied for high crop yields.
- When a nutrient is lacking in soil, it can reduce utilization of other nutrients, resulting in poor crop yield, and nutrient and water use efficiency.
- This imbalance of nutrients can result in large amounts of residual nitrate-N in soil after harvest, and increase the potential for N loss through denitrification and leaching.
- This poster summarizes the results obtained in field experiments conducted mostly in northeastern Saskatchewan to compare unbalanced versus balanced fertilization for their effects on crop yield, N fertilizer use efficiency (NFUE - kg seed/straw/forage DMY ha^{-1} kg^{-1} of applied N), water use efficiency (WUE), and residual nitrate-N in the soil profile.

Material and Methods

Study 1. N and S Fertilization of Canola (*Brassica napus* L.)

Site 1: Porcupine plain

Fertilizer Treatments: 120 kg N ha^{-1}; 120 kg N ha^{-1} + 15 kg S ha^{-1}

Site 2: Tisdale

Fertilizer Treatments: 120 kg N ha^{-1}; 120 kg N ha^{-1} + 20 kg S ha^{-1}

Site 3: Star City

Fertilizer Treatments: 120 kg N ha^{-1}; 120 kg N ha^{-1} + 30 kg S ha^{-1}

Study 2. N and S Fertilization of Wheat (*Triticum aestivum* L.)

Site 1: Porcupine Plain

Fertilizer Treatments: 120 kg N ha^{-1}; 120 kg N ha^{-1} + 15 kg S ha^{-1}

Site 2: Tisdale

Fertilizer Treatments: 120 kg N ha^{-1}; 120 kg N ha^{-1} + 20 kg S ha^{-1}

Study 3. N and Cu Fertilization of Wheat (*Tritium aestivum* L.)

Site: Porcupine Plain

Fertilizer Treatments: 105 kg N ha^{-1}; 105 kg N ha^{-1} + Variable rates of Cu in 3 experiments

Study 4. N, S and P Fertilization of Timothy (*Phleum partense* L.)

Site: Star City

Fertilizers Treatments: Two Rates of N (0 and 120 kg N ha^{-1}) x Two Rates of S (0 and 15 kg S ha^{-1}) x Two Rates of P (0 and 22 kg P ha^{-1})

Study 5. N, S and K Fertilization of Grass

Site: Canwood

Fertilizer Treatments: 112 kg N ha^{-1}; 112 kg N + 11 kg S ha^{-1}; 112 kg N + 11 kg S + 40 kg K ha^{-1}

Study 6. Organic versus Conventional N and P Fertilization

Site: Scott

Fertilizer Treatments: Organic – No fertilizer input; Conventional – Recommended rates of N and P

Summary of Results

Study 1. N and S Fertilization of Canola (*Brassica napus* L.)

- The N and S imbalance with too much N and too little S in the zero-S treatment on the S-deficient soil produced very low seed yield and NFUE (kg seed ha^{-1} kg^{-1} of applied N) and relatively low oil content of canola seed.

- Compared to N alone, balanced application of N and S resulted in substantial increase in seed yield from 17 to 1378 kg ha^{-1} and NFUE from 0.1 to 7.1 kg seed ha^{-1} kg^{-1} of applied N and oil content from 30.9 to 40.5%.
- At Site 2, the corresponding values were 134 and 765 kg ha^{-1} for seed yield, 1.1 to 6.4 kg seed ha^{-1} kg^{-1} of applied N and 31.0 to 38.2% for oil content.
- The corresponding improvements at Site 3 were 635 to 2422 kg ha^{-1} for seed yield, 5.3 to 20.2 kg seed ha^{-1} kg^{-1} of applied N for NFUE and 33.3 to 37.4% for oil content.
- It should be remembered that protein content generally decreased, because of dilution effect from the substantial increase in seed yield.
- Soil nitrate-N increased from 19 kg N ha^{-1} in NS treatment to 194 kg ha^{-1} in N alone (zero-S) treatment at Site 1 (a substantial increase in soil nitrate-N).
- Corresponding values of nitrate-N in soil for NS versus N alone treatment were 108 and 179 kg N ha^{-1} at Site 2, and 106 and 149 kg N ha^{-1} at Site 3.

Study 2. N and S Fertilization of Wheat (*Triticum aestivum* L.)

- At site 1, compared to N alone, combined application of N and S increased seed yield form 2351 to 2701 kg^{-1}, NFUE for seed from 19.6 to 22,5 kg seed ha^{-1} kg^{-1} of applied N, straw yield from 3810 to 4962 kg ha^{-1}, and NFUE for straw from 31.7 to 41.3 kg straw ha^{-1} kg^{-1} of applied N.
- At Site 2, the corresponding values for N alone versus NS treatment were 1763 and 2061 kg ha^{-1} for seed yield, 14.7 and 17.2 kg seed ha^{-1} kg^{-1} of applied N NFUE for seed, 2475 and 3695 kg ha^{-1} straw and 20.6 and 30.5 kg straw ha^{-1} kg^{-1} of applied N for NFUE for straw.
- Residual soil nitrate-N in soil for NS versus N alone treatments was 78 and 159 kg N ha^{-1} at Site 1, and 112 and 178 kg N ha^{-1} at Site 2.

Study 3. N and Cu Fertilization of Wheat (*Tritium aestivum* L.) - 3 Tests

- Compared to N alone treatments, application of N in combination with Cu increased seed yield from 607 to 2680 or 2850 kg ha^{-1}, NFUE from 5.8 to 25.5 or 27.1 kg seed ha^{-1} kg^{-1} of applied N and Cu uptake 0.9 to 10.7 or 6.4 g Cu ha^{-1} in Experiment 1.
- Corresponding values were 1121 and 1908 kg ha^{-1} for seed yield, 10.7 and 18.2 kg seed ha^{-1} kg^{-1} of applied N for NFUE, and 2.6 and 5.6 g Cu ha^{-1} for Cu uptake in

Experiment 2, and 1367 and 2388 kg ha^{-1} for seed yield, 13.0 and 22.7 kg seed kg^{-1} of applied N for NFUE, and 2.8 and 6.2 g Cu ha^{-1} for Cu uptake in Experiment 3.

- Soil nitrate-N in Experiment 1 decreased substantially with application of N and Cu together in all soil layers compared to N alone. This suggests that nitrate-N accumulation and leaching can be reduced considerably with balanced fertilization.
- Soil nitrate-N in Experiments 2 and 3 also tended to decrease when N and Cu were applied together.

Study 4. N, S and P Fertilization of Timothy (*Phleum partense* L.)

- Combined application of N, S and P together gave the highest forage DMY and NFUE. For example, for N, NP, NS and NPS, respectively, DMYs were 4412, 5524, 7302 and 7998 kg ha^{-1}, and NFUE were 36.8, 46.0, 60.9 and 66.7 kg DMY ha^{-1} kg^{-1} of applied N.
- The corresponding values for soil nitrate-N in the 0-60 cm depth were 16.3, 17.3, 3.2 and 2.6 kg N ha^{-1}.

Study 5. N, S and K Fertilization of Grass

- The DMYs were considerably higher when N and S or N, S and K were applied together compared to N alone (4944 kg ha^{-1} for NS and 5448 kg ha^{-1} for NSK vs 1285 kg ha^{-1} for N).
- NFUE was 11.5 kg DMY ha^{-1} kg^{-1} of applied N with N alone, 44.1 kg DMY ha^{-1} kg^{-1} of applied N with NS, and 48.6 kg DMY ha^{-1} kg^{-1} of applied N with NSK treatment.
- Soil nitrate-N in the 0-60 cm depth decreased from 21.0 kg N ha^{-1} with N alone to 11.3 kg N ha^{-1} with NS, and to 6.9 kg N ha^{-1} with NSK treatment.

Study 6. ORGANIC Input versus HIGH Input N and P Fertilizers

- For 6-year Rotation Cycle 1, WUE increased from 5.5 kg yield mm^{-1} in ORGANIC input (no fertilizer input to a soil low in available P) to 8.5 kg yield mm^{-1} in HIGH input treatment. The WUE values for the 6-year Rotation Cycle 2 were 3.1 and 4.9 kg yield mm^{-1}.
- Crop yields were 1115 kg ha^{-1} for ORGANIC input and 1849 kg ha^{-1} for HIGH input in Rotation Cycle 1, and 673 kg ha^{-1} for ORGANIC input and 976 kg ha^{-1} for HIGH input in Rotation Cycle 2.

Conclusions

- Proper balanced application of N, S, P, or K fertilizers is essential for best crop yields, and highest utilization of nutrients, water and energy, while also reducing accumulation and leaching of nitrate-N in the soil profile. Thus, minimizing the potential for contamination of soil and ground water with nitrate-N.

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Table 1. Seed yield, NFUE, oil content and amount of nitrate-N in the 0-60 cm soil after growing canola without and with applied sulphate-S fertilizers at three sites on S-deficient soils in northeastern Saskatchewan (Study 1 - adapted from Malhi et al. 2005)

Location	Date of initiation & Site	Date of soil sampling	S fertilizer treatment	Seed yield (kg ha^{-1})	NFUE (kg seed ha^{-1} applied N)	Oil content (%)	Nitrate-N in soil (kg N ha^{-1})
Porcupine Plain	1999 – Site 1	Spring 2002	Control	17	0.1	30.9	194**[z]
			Ammonium sulphate	1378	11.5	40.5	19
Tisdale	1999 – Site 2	Autumn 2002	Control	134	1.1	31.0	179•
			Ammonium sulphate	765	6.4	38.2	108
Star City	2004 – Site 3	Spring 2005	Control	635	5.3	33.3	149**
			Ammonium sulphate	2422	20.2	37.4	106

[z]• and ** indicate to treatment effect being significant at $P \leq 0.10$ and $P \leq 0.01$, respectively.

Table 2. Seed yield, NFUE, straw yield and estimated amount of nitrate-N in the 0-60 cm soil after growing wheat without and with applied sulphate-S fertilizers at two sites on S-deficient soils in northeastern Saskatchewan (Study 2 - unpublished)

Location	Date of initiation & Site	Date of soil sampling	S fertilizer treatment	Seed yield (kg ha^{-1})	NFUE (kg seed ha^{-1} applied N)	Straw yield (NFUE[1])	Nitrate-N in soil (kg N ha^{-1})
Porcupine Plain	1999 – Site 1	Spring 2002	Control	2351	19.6	3810 (31.7)	159*
			Ammonium sulphate	2701	22.5	4962 (41.3)	78
Tisdale	1999 – Site 2	Autumn 2002	Control	1763	14.7	2475 (20.6)	178**
			Ammonium sulphate	2061	17.2	3649 (30.5)	112

[z]* and ** indicate to treatment effect being significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Table 3. Amount of nitrate-N in soil, seed yield and NFUE of wheat without and with Cu application in selected treatments in three Cu experiments (Study 3 - unpublished)

Cu application treatment			Nitrate-N (kg N ha^{-1}) in soil depths (cm)				
Formulation	Rate (kg Cu ha^{-1})	Timing	0-15	15-30	30-60	60-90	0-90
Experiment 1							
Control	0	n/a	20.1*[z]	20.1*	18.7*	17.8**	76.6*
Solution (EDTA)	0.50 + 0.50	4-leaf + flag-leaf[y]	6.5	3.2	4.4	5.1	19.2
Solution (EDTA)	4.0	Spring (pre-tillage)[x]	8.2	4.4	5.0	5.5	23.1
			Seed yield (kg ha^{-1})	NFUE (kg seed ha^{-1} applied N)	Uptake of Cu (g Cu ha^{-1})		
Control	0	n/a	607	5.8	0.9		
Solution (EDTA)	0.50 + 0.50	4-leaf + flag-leaf[y]	2680	25.5	10.7		
Solution (EDTA)	4.0	Spring (pre-tillage)[x]	2850	27.1	6.4		
			Nitrate-N (kg N ha^{-1}) in soil depths (cm)				
Experiment 2			0-15	15-30	30-60	60-90	0-90
Control	0	n/a	10.2*	5.2•	5.2*	6.3•	26.9*
Solution (EDTA)	4.0	Spring (pre-tillage)[x]	6.9	3.9	4.5	4.8	20.1
			Seed yield (kg ha^{-1})	NFUE (kg seed ha^{-1} applied N)	Uptake of Cu (g Cu ha^{-1})		
Control	0	n/a	1121	10.7	2.6		
Solution (EDTA)	4.0	Spring (pre-tillage)[x]	1908	18.2	5.6		
			Nitrate-N (kg N ha^{-1}) in soil depths (cm)				
Experiment 3			0-15	15-30	30-60	60-90	0-90
Control	0	n/a	11.4[ns]	7.1[ns]	7.7	7.1•	33.3•
Solution (EDTA)	4.0	Spring (pre-tillage)[x]	10.1	5.1	5.7	6.0	26.9
			Seed yield (kg ha^{-1})	NFUE (kg seed ha^{-1} applied N)	Uptake of Cu (g Cu ha^{-1})		
Control	0	n/a	1367	13.0	2.8		
Solution (EDTA)	4.0	Spring (pre-tillage)	2388	22.7	6.2		

[a]•, *, ** and ns refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$ and $P \leq 0.01$, and not significant, respectively.
[y]Two foliar applications, first at tillering and second at flag-leaf.
[x]Solution Cu-chelate EDTA spray-broadcast on soil surface, followed by incorporation into soil.

Table 4. Forage dry matter yield (DMY), NFUE and residual nitrate-N in soil in autumn 2007 after 3 annual applications of N, P and S fertilizers to timothy in 2005, 2006 and 2007 at Star City in northeastern Saskatchewan (Study 4 - unpublished)

Treatment (kg N, P or S ha^{-1})	Nitrate-N in soil (kg N ha^{-1}) in soil layers (cm)				DMY (kg ha^{-1})	NFUE (kg DMY ha^{-1} applied N)
	0-15 cm	15-30 cm	30-60 cm	0-60 cm		
120N (N)	3.79*[z]	6.39*	6.3*	16.3*	4412	36.8
120N + 22P (NP)	3.9*	7.37*	616*	17.3*	5524	46.0
120N + 15S (NS)	1.34	0.6	1.3	3.23	7302	60.9
120N + 22P + 15S (NPS)	1.0	0.6	1.0	2.57	7998	66.7

[z]* refers to significant treatment effects in ANOVA at $P \leq 0.05$.

Table 5. Forage dry matter yield (DMY), NFUE and residual nitrate-N in soil in autumn 2005 after 26 annual applications of N, S and K fertilizers to grass from 1980 to 2005 at Canwood in northeastern Saskatchewan (Study 5 - unpublished)

Treatment (kg N, S or K ha^{-1})	Nitrate-N in soil (kg N ha^{-1}) in soil layers (cm)				DMY (kg ha^{-1})	NFUE (kg DMY ha^{-1} applied N)
	0-15 cm	15-30 cm	30-60 cm	0-60 cm		
120N (N)	10.3	4.3	4.4	21.0	1285	11.5
120N + 11S (NS)	5.1	2.5	3.7	11.3	4944	44.1
120N + 11S + 40K (NSK)	2.0	1.1	3.8	6.9	5448	48.6

[z]* refers to significant treatment effects in ANOVA at $P \leq 0.05$.

Table 6. Crop yield, water use efficiency (WUE) and residual nitrate-N in 0-90 cm soil in autumn 2006 after 12 years under ORGANIC (no fertilizer input) and HIGH (recommended rates of N and P fertilizers) inputs in DAG crop diversity in two 6-year rotation cycles with various crops from 1995 to 2006 at Scott, Saskatchewan (Study 6 – Malhi et al. 2008 Organic Presentation at SSCA Meeting)

	Rotation Cycle 1		Rotation Cycle 2			
Input level	Yield (kg ha^{-1})	WUE (kg yield ha^{-1} mm^{-1})	Yield (kg ha^{-1})	WUE (kg yield ha^{-1} mm^{-1})	Nitrate-N in soil (kg N ha^{-1}) in selected treatments	
ORGANIC	1115	5.5	673	3.1	123*	94*
HIGH – Conv.	1849	8.5	976	4.9	42	45

[z]* refers to significant treatment effects in ANOVA at $P \leq 0.05$.