Potential of Management Practices and Amendments to Prevent Nutrient Deficiencies under Organic Cropping Systems (June 14, 2013)

S. S. Malhi et al.

Northeast Agricultural Research Foundation, P. O. Box 1240, Melfort, Saskatchewan S0E 1A0; E-mail: ssmalhica@yahoo.ca (Previous Address: Agriculture and Agri-Food Canada, Melfort, Saskatchewan)

Background

The interest and demand for organically-grown food and fiber is increasing. Optimum soil fertility is one of the top three (weeds, nutrients, crop species/rotations) challenges for sustainable organic farming systems. Adequate supply of nutrients from soil is essential for sustainable high yields, produce quality, water, nutrients and energy use efficiency, and soil quality; and to prevent accumulation of nitrate-N in the soil profile (Table 1). In the Prairie Provinces, most soils under organic cropping systems can be deficient in available nitrogen (N), phosphorus (P); and some soils contain insufficient amounts of available sulphur (S) and potassium (K) for optimum crop growth and yield. Returning crop residues alone cannot replenish all the nutrients exported, and in the long run nutrients in soils are depleted, resulting in poor productivity. Therefore, maintaining soil fertility is a key production challenge facing organic farmers.

Most organic producers usually focus on minimizing N deficiency or increasing N availability in soil-crop systems by including legume crops (for grain, forage or green manure - GM) in the rotations. However, if soils are deficient in available P, K, S or other essential nutrients, the only alternative is to use external sources. Manure can provide these nutrients to organic crops, but often there is not enough manure, especially in remote areas where the cost of transporting manure to long distances can be uneconomical. Also most organic producers being grain farmers, they cannot rely on manure to replace nutrients exported. Thus, there is a great challenge to find suitable nutrient sources to replace nutrients harvested and exported from the organic farms. This report summarizes results of management practices and amendments for their potential to prevent nutrient deficiencies in organic crops for sustainable yield of quality produce, while enhancing soil quality/health and minimizing negative environmental impacts (e.g., contamination of ground water with nitrate-N, surface water with labile P and air with greenhouse gas [GHG] emissions).

Summary of Research Findings, Gaps and Future Needs

Deficiencies of N and P are widespread on organic farms, and some soils may also contain insufficient amounts of K, S and some micronutrients for optimum crop growth and sustainable yields. Crop rotations with legumes generally increased yield and protein content. Fertility/quality and productivity of soils could be improved through efficient nutrient cycling by growing deep-rooted legume crops in the rotation. Legumes for green manure could replace summer fallowing, to minimize nutrient inputs, enhance soil quality and increase sustainability of crop production. Because green manure legumes compete with cash crops for space, time, and water, it may not be easy to fit green manure legumes into cropping systems, especially in dry areas. In order to assess the future scope for green manures, there is a need to critically analyse factors that can limit the use of this technology on a commercial scale. Alternatively, intercropping non-legume and legume annual crops or perennial forage grass-legume mixtures may be adopted to improve and sustain crop yields and net returns on organic farms.

On mixed animal and crop farms, application of animal manure/compost and inclusion of perennial forage legumes in the rotation can be a good strategy to prevent multi-nutrient deficiencies in organic crops and improve physical, biological and chemical properties of the soils. However, there is a need of long-term research studies in a wide range of agro-climatic conditions with a view to (i) minimize the impacts of these systems on soil quality, surface water contamination with labile P, groundwater contamination with nitrate-N, and greenhouse gas emissions including N losses, and (ii) sustain a high level of production from such systems.

Agroforestry could be another eco-friendly option on mixed organic farms. Both shade tolerant plants grown under a closed tree canopy and sun loving plants in open areas between trees can be utilized. But the in-depth knowledge on the interactions between crops, trees, livestock and other components appears to be lacking.

Amongst organic amendments/industrial organic products/byproducts, thin stillage was found very effective in improving crop yields. Alfalfa pellets, distiller grain and fish food additives resulted in moderate increase in crop yields. Because of their residual effects on soil fertility and productivity, it may be important to have long-term information on the economic feasibility of such amendments.

If organic farm soils are deficient in P and organic manures are not available, wood ash, an industrial byproduct, is a good source of P, K, S and micronutrients to prevent multiple nutrient deficiencies in organic crops. Wood ash, due to its basic nature, could substitute lime to ameliorate acidic soils. However, because of large volumes of application, it is not always convenient to apply, and therefore it needs to be granulated for its easy use on a commercial scale.

Biofertilizers/microbial inoculants can play an important role in sustaining productivity, but their effectiveness varies with the source, nutrient type and level as well as soil type and climatic conditions. *Rhizobium* inoculation is very effective in increasing BNF and crop yields in most legumes, and the practice is well adopted by the producers. It may be possible to enhance availability of native soil P to crops by the use of some microbial inoculants, such as *Penecillium bilaiae* to increase availability of sparingly soluble soil P. However, the beneficial effects of these microbial inoculants on crop yields have been usually small and inconsistent. Long-term studies are required to assess the visible economic benefits from P solublizing microbial inoculants in soils varying in labile P level, pH and texture under different climatic conditions.

In warm/humid regions, inoculation of *Azospirillum*, *Azotobacter*, blue green algae (BGA) and *Azolla* has been found to increase N supply through BNF in cropping systems. However, high labor requirements, cold climate, short growing season, lack of ability to survive over winter and the need of available P for optimum growth could limit its adoption on a commercial scale in relatively colder countries such as Canada, and further research is needed to determine the feasibility of these products in Canada.

Commercially available mineral amendments can be used to prevent/correct deficiency of a single nutrient. Rock phosphate fertilizer is being promoted as a natural source of P to correct P deficiency. In most field studies, the amount of P that becomes available from rock phosphate in the first crop season is very limited, especially on high pH soils. In only a few cases, however, rock phosphate was found effective to increase herbage/pasture yield on P-deficient soils. In a few other cases, rock phosphate was more effective when it was used in combination with *Penicillium bilaiae*, but the yield increase was usually not economical. The results on the feasibility of rock phosphate in improving crop yields on P-deficient soils are inconsistent and not very conclusive, suggesting the need of long-term studies on the feasibility of these amendments on extremely P-deficient soils under variable agro-climatic conditions.

On organic farms with S-deficient soils, gypsum is an excellent mineral amendment to supply S in readily available form (sulphate). In addition, wood ash can be used to supply S to organic crops on S-deficient soils. A granular rapid release elemental S fertilizer has also shown good potential to prevent S deficiency in organic crops, though information on its use in crops at this stage is too limited to make valid conclusions.

Important strategies to maintain or enhance organic matter in soils include increasing biomass production and return of plant/root residues to soil per unit area by preventing nutrient deficiencies in organic crops and by decreasing loss of soil and organic matter by preventing soil erosion with crop residue cover (Malhi 2012b). However, long-term studies are needed under organic farming systems to investigate the beneficial effects of integrated use of crop management practices, organic manures and amendments on sustainable crop yields, produce quality, net returns, nutrient uptake and use efficiency, nutrient accumulation and distribution in the soil profile or nutrient balances, nitrate leaching and ground water contamination, soil physical, chemical and biological properties, soil organic matter dynamics, and greenhouse gas emissions.

Conclusions

Animal and compost manures are an important souce of plant nutrients, but often there is not enough manure to apply on the entire farm or it may be uneconomical to apply manure in remote areas due to transportation costs. Crop rotations with legumes usually improve grain yields as well as grain protein content. Deep-rooted perennial forages in crop rotations can help to improve soil fertility/quality and productivity through efficient nutrient cycling. Legume green manuring can replace summer fallowing and sustain crop production, mainly by addition of most limiting nutrient N and by increasing the availability of some other nutrients to the succeeding crops. Intercropping of non-legume with legume annual crops and perennial grass-legume mixed stands are effective in maximizing economic yields of grain and forage and protecting soil.

Industrial byproducts/products such as thin stillage showed large beneficial effects in increasing crop yields. Alfalfa pellets, distiller grain and fish food additives resulted in moderate increases in crop yields. *Penicillium bilaiae* and other microbial inoculants (e.g., AMF inoculant) were found effective in solubilizing native soil P and increasing P availability in some cases. But these products are not well adapted by the organic producers due to lack of their noticeable/consistent beneficial impact on crop yield.

Summer fallowing is a relatively widespread practice on organic farms, but the heavy reliance of organic production on tilled summer fallow to control weeds and increase soil fertility can be a serious concern for soil erosion/degradation, loss of organic matter and sustainable organic production in the long run. In addition to increasing crop yields, sustainable crop management practices and the use of amendments return more crop residues to soil, which could enhance soil quality and fertility.

Organic producers should practise integrated use of crop management practices, organic amendments, mineral amendments, industrial byproducts or biofertilizers/microbial inoculants on their farms to improve sustainability of production systems, economic returns, produce quality, nutrient uptake, soil quality and fertility, water and energy use efficiency while minimizing environmental damage.

References

Izaurralde, R.C., M. Nyborg, E.D. Solberg, H.H. Janzen, Arshad, M.A., Malhi, S.S., and Molina-Ayala, M. (1998). Carbon storage in eroded soils after five years of reclamation techniques. *In* Soil Processes and the Carbon Cycle. *(*Lal, R., J.M. Kimble, R.F. Follett and B.A. Stewart (eds.) pp. 369-385. Boca Raton, FL: CRC Press.

Malhi, S.S. (2012a). Relative effectiveness of various amendments in improving yield and nutrient uptake under organic crop production. *Open J. Soil Sci.* In Press.

Malhi, S.S. (2012b). Short-term residual effects of various amendments on organic C and N, and available nutrients in soil under organic crop production. *Agric. Sci*. 3, 1-10.

Malhi, S.S. (2012c). Improving crop yield, N uptake and economic returns by intercropping bayley or canola and pea. *Int. Res. J. Agric. Sci*. In Press.

Malhi, S.S., Heier, K., and Solberg, E. (2000). Effectiveness of elemental S fertilizers on forage grass. *Can. J. Plant Sci.* 80, 105-112.

Malhi, S.S., Schoenau, J.J., and Leach, D. (2010). Maximizing N fertilizer use efficiency and minimizing the potential for nitrate-N accumulation and leaching in soil by balanced fertilization. *Proc. Great Plains Soil Fertility Conference*, 2-3 March, 2010, Denver, CO, U.S.A.

Malhi, S.S., Solberg, E.D., and Nyborg, M. (2005). Influence of formulation of elemental S fertilizer on yield, quality and S uptake of canola seed. *Can. J. Plant Sci*. 85, 793-802.

Malhi, S.S., Zentner, R.P., and Heier, K. (2002). Effectiveness of alfalfa in reducing fertilizer N input for optimum forage yield, protein concentration, returns and energy performance of bromegrass-alfalfa mixtures. *Nutr. Cycl. Agroecosyst*. 62, 219-227.

Schoenau, J. J., Bolton, K., and Panchuk, K. (2000). Managing manure as a fertilizer. *Farm Facts*. *Saskatchewan Agriculture and Food*, ISSN 0840-9447.

Table 1. Effects of balanced fertilization on yield [seed or forage dry matter yield (DMY)], partial factor productivity/N fertilizer use efficiency (PFP/NFUE, kg seed or forage dry matter kg^{-1} of applied nutrient/N), seed quality (oil content, %), water use efficiency (WUE, kg yield kg^{-1} mm^{-1} of water), and soil organic C (Mg C ha^{-1}) and nitrate-N (kg N ha^{-1})[z]

Parameter/study[y]	N alone (unbalanced)	Balanced fertilization
NUE - seed yield/DMY		
Wheat Cu – seed yield (PFP/NFUE)	9.3 to 12.0	19.6 to 20.1 (N + Cu)
Canola S – seed yield (PFP/NFUE)	1.2	10.2 (N + S)
Grass S – DMY (PFP/NFUE)	10.0	42.3 (N + S)
		47.5 (N+ S + K)
Alfalfa P – DMY (5-yr)	2164 (0 P)	6036 (Broadcast-P)
		7192 (Disc-banded P)
Seed quality – canola seed oil content (%)	37.3	41.4 (N + S)
WUE – ACS Scott (1995-2006)		
First 6-yr cycle	5.5 (Organic – no fertilizer)	8.5 (Conventional - N + P)
Second 6-yr cycle	3.1 (Organic – no fertilizer)	4.9 (Conventional - N + P)
Soil quality		
Grass S – TOC (LFOC), 0-10 cm	44.1 (6.71)	51.0 (12.13) (N + S)
		55.7 (14.19) (N+ S + K)
Canola S – TOC (LFOC), 0-15 cm	23.59 (2.758)	25.77 (3.776) (N + S)
Soil nitrate-N – ACS Scott (1995-2006)		
First 6-yr cycle (0-90 cm)	123 (Organic – no fertilizer)	42 (Conventional - N + P)
Second 6-yr cycle (0-90 cm)	94 (Organic – no fertilizer)	45 (Conventional - N + P)
Canola S (0-60 cm)	194	19

[z]Source: Malhi, S.S., Schoenau, J.J., and Leach, D. (2010). Maximizing N fertilizer use efficiency and minimizing the potential for nitrate-N accumulation and leaching in soil by balanced fertilization. Proc. Great Plains Soil Fertility Conference, 2-3 March, 2010, Denver, CO, U.S.A.

[y]ACS = Alternative cropping systems, TOC = Total organic C, LFOC = Light fraction organic C.

Table 2. Seed yield, net returns (NR) and land equivalency ratio (LER) for barley or canola and pea grown as sole crops and in various intercrop combinations at Star City, Saskatchewan (average of 2009 to 2011)[z]

Treatment	Barley-pea			Canola-pea		
	Seed yield (kg ha^{-1})	NR[y] ($ ha^{-1})	LER[x]	Seed yield (kg ha^{-1})	NR[y] ($ ha^{-1})	LER
Barley or Canola, 0 kg N ha^{-1}	2062	309		834	375	
Barley or Canola, 40 kg N ha^{-1}	3065	400		1167	465	
Barley or Canola, 80 kg N ha^{-1} Does not match N rates for inter crops	3975	476		1596	598	
Pea, 0 kg N ha^{-1}	3097	929		2742	823	
Barley or Canola-Pea in Alternate Rows, 0 kg N ha^{-1}	3717	826	1.50	2702	881	1.45
Barley or Canola-Pea in Alternate Rows, 20 kg N ha^{-1} to Barley	3815	752	1.24	3047	971	1.50
Barley or Canola-Pea in Alternate Rows, 40 kg N ha^{-1} to Barley	4067	756	1.15	2965	905	1.31
Barley or Canola-Pea in Same Row, 0 kg N ha^{-1}	3764	824	1.54	2887	953	1.56
Barley or Canola-Pea in Same Row, 20 kg N ha^{-1}	3741	736	1.22	3114	1006	1.51
Barley or Canola-Pea in Same Row, 40 kg N ha^{-1}	3827	682	1.07	3023	962	1.40

[z]Source: Malhi, 2012c.
[y] The cost of N fertilizer was $1500 Mg^{-1}$ of N. The price was $150 Mg^{-1}$ for barley, $450 Mg^{-1}$ for canola and $300 ha^{-1}$ for pea.
[x]LER = (Intercrop1/Sole Crop1) + Intercrop2/Sole Crop2.
[x]***and ns refer to significant treatment effects in ANOVA at $P \leq 0.001$ and not significant, respectively.

Table 3. Dry matter yield (DMY) and net returns above N fertilizer costs (NR) of hay from various bromegrass-alfalfa compositions, treated annually with different rates of N as ammonium nitrate at Lacombe and Eckville in central Alberta, Canada (average of 1993-1995 and two sites)[z]

Composition	N rates (kg N ha^{-1})				
	0	50	100	150	200
	DMY (Mg ha^{-1})				
Pure bromegrass	4.95	7.61	10.41	12.22	14.63
Bromegrass: alfalfa (2:1)	10.98	12.76	13.57	14.24	15.09
Bromegrass: alfalfa (1:1)	11.30	12.84	13.38	14.54	14.81
Bromegrass: alfalfa (1:2)	11.30	13.03	14.15	14.49	15.15
Pure alfalfa	10.47	10.48	10.97	10.44	10.53
	NR ($ ha^{-1}) at N rates (kg N ha^{-1})[y]				
Pure bromegrass	192	261	388	496	615
Bromegrass: alfalfa (2:1)	649	673	672	686	715
Bromegrass: alfalfa (1:1)	714	716	716	741	731
Bromegrass: alfalfa (1:2)	732	788	802	778	798
Pure alfalfa	817	752	755	689	665

[z]Source: Malhi et al., 2002.
[y]The cost of N was $770 Mg^{-1}. The market price of bromegrass was $70 Mg^{-1} for first and $77 Mg^{-1} for second cut. The market price of alfalfa was $90 Mg^{-1} for first and $99 Mg^{-1} for the second cut.

Table 4. Yield of canola, barley and crested wheatgrass from injected liquid swine manure (LSM) and urea in east-central Saskatchewan, Canada[z]

Treatment	Seed yield (Mg ha^{-1})		Hay yield (Mg ha^{-1})
	Canola	Barley	Crested wheatgrass
Control (no fertilizer)	0.56	2.04	1.06
LSM @ 37,059 L ha^{-1} (84 kg N ha^{-1})	1.29	4.03	2.72
LSM @ 74,118 L ha^{-1} (168 kg N ha^{-1})	1.74	4.30	4.99
LSM @ 148,236 L ha^{-1} (336 kg N ha^{-1})	1.62	3.98	4.89
Urea (112 kg N ha^{-1})	1.46	4.09	

[z]Source: Schoenau et al., 2000.

Table 5. Effects of manure (M) and fertilizer (F) on seed yield of wheat (average of 1991 to 1994), and total organic C (TOC), total organic N (TON), light fraction organic C (LFOC) and light fraction organic N (LFON) in soil (0-20 cm) under different levels of simulated erosion (artificial top soil removal) at Cooking Lake, Alberta, Canada[z]

Treatments			Organic C and N in 0-20 cm soil (kg C or N ha^{-1})			
Erosion (cm)	Amendments	Seed yield (Mg ha^{-1})	TOC (Mg C ha^{-1})	TON (Mg N ha^{-1})	LFOC (kg C ha^{-1})	LFON (kg N ha^{-1})
0	Control	2.05	67.72	7.07	2940	150
	Fertilizer	3.32	75.83	7.67	3470	180
	Manure	3.07	76.34	7.97	4620	280
	M + F	3.75	82.92	8.43	5750	360
10	Control	0.81	39.77	4.83	910	40
	Fertilizer	2.66	47.42	5.30	1860	90
	Manure	2.27	55.47	6.12	3000	190
	M + F	3.20	59.11	6.32	4380	270

[z]Source: Izaurralde et al., 1998.

Table 6. Seed yield of barley in 2010 after three annual applications of various amendments (2008 to 2010) in field experiments on certified organic farms at Spalding (Dark Brown Chernozem) and Star City (Gray Luvisol), Saskatchewan, Canada[z]

Treatment	Seed yield (kg ha^{-1})	
Amendments	Experiment 1	Experiment 2
Control (no amendment)	1253	2233
Compost @ 20 Mg ha^{-1}	2576	3570
Wood ash @ 2 Mg ha^{-1}	1779	2705
Alfalfa pellets @ 4 Mg ha^{-1}	2174	3859
Control + Inoculate seed with *Penicillium bilaiae*	1306	2128
Rock phosphate granular @ 20 kg P ha^{-1}	1526	2323
Rock phosphate granular @ 20 kg P ha^{-1} + Inoculate seed with *Penicillium bilaiae*	1534	2227
Rock phosphate finely-ground @ 20 kg P ha^{-1}	1368	2170
Rock phosphate finely-ground @ 20 kg P ha^{-1} + Inoculate seed with *Penicillium bilaiae*	1462	2133
MykePro	1412	2202

[z]Source: Malhi, 2012a.

Table 7. Seed yield of canola in 2011 after three annual applications of various amendments from 2009 to 2011in a field experiment on a Gray Luvisol soil at Star City, Saskatchewan, Canada[z]

Treatment	Seed yield (kg ha^{-1})	
Amendments	2010	2011
Control (no amendment)	463	410
Compost @ 20 Mg ha^{-1}	534	651
Alfalfa pellets @ 2 Mg ha^{-1}	563	628
Distiller grain (wheat) – dry @ 1 Mg ha^{-1}	541	989
Thin stillage @ 20,000 L ha^{-1}	853	1088
Fish food additive @ 1 Mg ha^{-1}	541	832
N only - 80 kg N ha^{-1} (using 34-0-0)	230	247
N + P - 80 kg N ha^{-1} (using 34-0-0) + 20 kg P ha^{-1} (using 0-45-0)	491	854
N + S - 80 kg N ha^{-1} (using 34-0-0) + 20 kg S ha^{-1} (using 0-0-51-17)	680	1083
N + P + S - 80 kg N ha^{-1} + 20 kg P ha^{-1} + 20 kg S ha^{-1}	835	1262
Gypsum @ 20 kg S ha^{-1} + 80 kg N ha^{-1} + 20 kg P ha^{-1}	714	1184
Rapid release elemental S @ 20 kg S ha^{-1} + 80 kg N ha^{-1} + 20 kg P ha^{-1}	615	1187
Glycerol @ 1 Mg ha^{-1}	512	321
Glycerol @ 1 Mg ha^{-1} + 80 kg N ha^{-1}	308	497
Wood ash @ 2 Mg ha^{-1}	453	493
Wood ash @ 2 Mg ha^{-1} + 80 kg N ha^{-1}	834	1250
Penicillium bilaiae + 80 kg N ha^{-1} + 20 kg S ha^{-1}	616	986
Rock phosphate granular (BC Mines) @ 20 kg P ha^{-1} + 80 kg N ha^{-1} + 20 kg S ha^{-1}	638	1010
Rock phosphate granular (BC Mines) @ 20 kg P ha^{-1} + 80 kg N ha^{-1} + 20 kg S ha^{-1} + *Penicillium bilaiae*	568	974
Rock phosphate finely-ground (BC Mines) @ 20 kg P ha^{-1} + 80 kg N ha^{-1} + 20 kg S ha^{-1}	698	1247
Rock phosphate finely-ground (BC Mines) @ 20 kg P ha^{-1} + 80 kg N ha^{-1} + 20 kg S ha^{-1} + *Penicillium bilaiae*	702	1218
Rock phosphate [powder] (BC Mines) @ 20 kg P ha^{-1} + 80 kg N ha^{-1} + 20 kg S ha^{-1}	689	1310

[z]Source: S. S. Malhi – unpublished results.

Table 8. Seed yield of crops in different years and soil properties/nutrients after harvest of 2008 crop with wood ash (ash), and fertilizer nitrogen (N) and phosphorus (P) applications in 2006 and 2007.

Crop/soil property	Check	N + P	Ash	Ash + N
		Seed yield (kg ha^{-1})		
Pea 2006	3977	4923	4870	5237
Barley 2006	3753	5849	4730	6447
Oat 2007	3461	4646	3842	5197
Wheat 2008	1624	1601	1856	1854
Wheat 2010	1796	1890	2107	2056
		Soil properties/nutrients after harvest of 2008 crop		
pH, water	6.20	5.65	6.85	6.70
Phosphorus, ppm	23.5	29.5	35.0	39.0
Potassium, ppm	96.5	93.5	161.5	175.5
Calcium, ppm	1485	1345	1655	1715
Zinc, ppm	3.55	3.50	8.60	9.55
Manganese, ppm	8.0	9.0	10.5	11.0
Copper, ppm	0.55	0.60	0.80	0.75
Sodium, ppm	75	102	118	117

[z]Source: K. S. Gill – unpublished results.

[y]Fertilizer rates were 90 kg N + 34 kg P_2O_5 ha^{-1} in 2006 and 27 kg N + 39 kg P_2O_5 ha^{-1} in 2007.

[x]Application of wood ash (3360 kg ha^{-1} in 2006 and 4368 kg ha^{-1} in 2007) supplied 39 kg P_2O_5 ha^{-1} + other nutrients.

[w]There was no N fertilizer applied to pea, but it received granular *Rhizobium* inoculant at a proper rate.

Table 9. Effects of wood ash (WA) and lime (L) [Experiment 1] or manure (M) [Experiment 2] on total dry matter yield (DMY) (kg ha^{-1}) of alfalfa (2005-2007) and grain yield (kg ha^{-1}) of barley (2008-2010) at Thunder Bay, north-western Ontario, Canada[z]

Treatment	Alfalfa			Barley				Barley		
	2005	2006	2007	2008	2009	2010	Treatment	2008	2009	2010
Control	6561	5177	3852	7991	6515	5369	Control	8270	8061	7446
Wood ash	6606	6550	4578	9447	7367	7178	Wood ash	10179	8680	8603
Lime	6334	6617	4249	7810	7166	6329	Manure	8725	10397	8839
WA + L	6365	4961	4285	8976	7474	6909	WA + M	9751	10516	9665

[z]Source: T. S. Sahota – unpublished results.

Table 10. Effects of elemental S (ES), and gypsum or other sulphate-S fertilizers on yield (kg ha^{-1}) of canola seed or grass forage dry matter yield (DMY)[z]

		Grass DMY increase (kg ha^{-1})		
Experiment/treatment	Year	ES granular	Gypsum	Potassium sulphate
15 kg S ha^{-1})	1	357	1696	2401
	2	195	1256	722
	3	1533	4646	4271

ES formulation	Seed yield increase of canola (kg ha^{-1})			
	Porcupine Plain, Saskatchewan		Canwood, Saskatchewan	Legal, Alberta
Treatment	2000	2001	2001	2000
ES-90 Granular	0	127	1296	299
Biosul-ES90 Granular	143	256	1518	75
Biosul-ES50 Suspension	784	593	1710	637
Sulphate-S	861	581	1788	430

[z]Source: Malhi et al., 2000; Malhi et al., 2005.