Controlled Release of N & P

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Abstract
Controlled and slow-release nitrogen (N) fertilizers have been commonly used in high-value applications such as turf grasses, container-grown nursery stock and vegetable production. Traditional controlled-release products have not been economical for use in production of major grain crops because of high cost and low crop prices. Agrium, a major N manufacturer in North and South America, has developed an economical polymer-coated controlled-release urea fertilizer: ESN, for use in field crops. Release of N from the polymer-coated fertilizer is a diffusion process. Coupling N release with temperature and soil moisture, two of the primary factors in the rate of crop growth and N demand, allows N release to be programmed to closely match crop needs. Research shows that controlled N release improves crop output per unit of applied N, reduces N losses to the environment, and gives a grower greater control over the fate of applied N. Research has also shown greater recovery of applied N, reduced leaching losses, and reduced nitrous oxide emissions with the use of ESN.

Nutrisphere – N (NSN) is a N enhancement product designed to keep N in a plant available form. Specialty Fertilizer Products is the manufacturer of NSN; they indicate increased plant availability being due to reduced volatile loss, and reduced nitrification. This particular technology is theorized to complex multivalent cations in the soil (nickel, in this case) which are intergral to the functioning of the urease enzyme; the urease enzyme can therefore not function in the hydrolysis of urea, and urea N is kept in a stable form. This product represents an emerging N technology within western Canada.

Further, both technologies may be able to convey the same benefit to phosphorous (P) availability. When P is added to the neutral or calcareous soils common to western Canada, fertilizer granules dissolving in the soil water form a phosphate-saturated solution; this solution moves into the soil, dissolving ions like calcium (Ca) and/or magnesium (Mg). Phosphate may then precipitate, forming less soluble forms (Ca and Mg phosphates) of applied fertilizer phosphorous.

A polymer coated P fertilizer (CRP) could limit the contact of applied P with soil through a controlled release action, and an Avail* treated P fertilizer (Malefic Itaconic Copolymer) could reduce potential reaction with soil Ca and/or Mg. It would be expected that by reducing P – soil reactions, that one would be able to increase P plant uptake, and thereby increase crop yield, and improve P use efficiency.

Introduction

Inefficient fertilizer use may contribute to environmental degradation, particularly in intensive agricultural systems where the recovery or use efficiency of nutrients by crops is relatively low. For example, it is estimated that N use efficiency for cereal production worldwide is only 33% (Raun and Johnson, 1999). A portion of the N not used by the crop is presumed to be lost to the environment through denitrification, runoff, volatilization, leaching, and gaseous plant emissions. Such losses raise concerns about surface and groundwater contamination, and greenhouse gas emissions. Additionally, low use efficiency of nutrients applied as fertilizers results in producers receiving lower economic returns from their investment in fertilizer inputs.

It is commonly suggested that the use efficiency of fertilizer P by crops ranges from 10 to 30 percent in the year that it is applied. Remaining P becomes part of the soil P pool which is released to the crop sometime in the future. Increasing the efficiency of fertilizer by improving crop recovery in the year of application could improve crop yields and economic returns.

Phosphate fertilizer material is subject to reactions within soil which can reduce nutrient availability to plants. Reactions with other soil constituents act to make fertilizer P less soluble. Within most soils of western Canada, high soil P is made less soluble by reactions with Ca and Mg, forming less and more slowly soluble forms of P (calcium and magnesium phosphates).

Controlling the release of soil applied P fertilizer, through the use of polymer coatings, may act in reducing the formation of these compounds, thereby having a greater supply of crop P made available. The use of Avail technology may also act to accomplish the same end; the theorized mechanism is different. With Avail, the high charge density of the additive adsorbs or “binds” the soil Ca and Mg, acting to reduce their availability for reaction product formation with applied fertilizer P forms.

Controlled release fertilizers (CRF) are fertilizers designed to slowly release nutrients at a rate that matches the demand of the crop plants. Such products can be used to maximize fertilizer use efficiency and minimize potential losses to the environment. Increased nutrient-use efficiency may also increase yield and quality of crops, thus providing an economic benefit for growers. Controlled or slow release fertilizers can generally be classified into three types: inorganic compounds of low solubility, low solubility organic N-compounds and coated water-soluble fertilizers. The first two categories have limited potential for agricultural use because their rate of nutrient release is difficult to predict and depends upon factors such as soil type, moisture content, microbial activity and history of previous usage. Development of polymer-coated fertilizers looks promising for future widespread use in agriculture since they can be designed to release nutrients in a manner closely matching crop demand. The polymers used are generally very durable and exhibit consistent release rates that are predictable when average temperatures and moisture conditions can be accurately predicted. The rate of nutrient release can be increased or decreased by manipulating properties of the polymer coating.

At present, the use of CRF in agriculture is limited, accounting for less than 1% of worldwide fertilizer consumption. The main reason for this is cost; CRF may range between 3 and 8 times the cost of a corresponding standard fertilizer. Current usage of CRF is limited primarily to nonagricultural markets such as turf grass. The exception to this is Japan, where CRF are widely used on agricultural crops such as rice and vegetables (Shaviv and Mikkelsen, 1993).

There is potential for the increased use of CRF in agriculture in North America if the cost of CRF production can be reduced and advantages such as increased nutrient recovery, improved crop yield and quality, and reduced environmental impacts can be consistently demonstrated. Controlled-release fertilizers will be adopted most rapidly in locations where N losses are potentially large, in crops where in-season N applications are common, in crops where seed-row applied N is desired and in crops with shallow rooting systems.

There have been a limited number of published studies that investigate the value of CRF on large acreage agricultural crops. Those that exist generally indicate there is significant value in using CRF under most conditions. For example, N fertilizer application rates on cotton may be reduced by 40% if controlled-release rather than conventional fertilizers are used (Howard and Oosterhuis, 1997). Trials using polymer-coated urea on winter wheat indicated that there was a 20% yield increase compared to growers' standard practice; research on potatoes, onions and garlic has also shown a general increase in yield and quality when using CRF (Tindall and Detrick, 1999). In western Canada, fall application of polymer-coated urea on barley resulted in decreased nitrate accumulation and fertilizer N loss, while spring application of polymer-coated urea resulted in increased crop N uptake (Nyborg et al., 1993). Other western Canadian work (McKenzie et al., 2007) has shown successful use of CRF in winter wheat production for both seed-placement and side-band applications, and for seed-placement and side-band applications in both spring wheat and canola (Brandt et al., 2004).

Much of the N applied in north American agriculture is applied in advance of crop uptake. The winter and spring weather in this geography is often characterized by precipitation in excess of evapotranspiration, and potential for N loss exists. Use of CRF has the potential to significantly improve N and P use efficiency in these production systems.

Advancements in coating technology have decreased production costs for polymer-coated fertilizers to a level that can be economical for use on commodity grain crops where much of the N fertilizer in North America is used. Agrium (Calgary, Alberta, Canada) has developed an economical, polymer-coated controlled-release urea fertilizer, called ESN , for field crops. Nitrogen release from ESN is by diffusion through the polymer coating, rather than by biological decomposition of the coating. Coupling N release with temperature and soil moisture, primary factors in crop growth and N demand, allows the N supply to be more closely programmed to crop needs. Agrium's work continues in the development of a similar P fertilizer product.

Specialty Fertilizer Products (Belton, Missouri, United States), has developed Nutrisphere – N, an additive for N, and Avail P (an additive for P) products that create a zone or shield around dissolving fertilizer materials (liquid or granular). These products are available for use on all commonly grown agricultural commodity crops.

"Controlled-release" refers to a subset of a larger group of fertilizers being called "enhanced-efficiency" fertilizers. There are many products with different modes of action such as inhibitors and stabilizers: Agrotain (NBPT), N-Serve (nitrapyrin), DCD, Super U, Super N (Agrotain Plus) and Nutrisphere N. There are also uncoated, slowly available compounds such as synthetic organic compounds: urea formaldehyde (UF) & methylene urea (MU), isobutylidene diurea (IBDU). And there are coated water-soluble nitrogen fertilizers, which fall into sulphur (SCU) and polymer coatings. For the SCU's, release is slow but generally uncontrolled; release depends upon destruction of coating, physical breakage, biological oxidation, diffusion, thickness of coating, environmental conditions, etc. By this definition, polymer coatings offer controlled release characteristics. Polymer coatings that are applied to soluble fertilizer (e.g. polyurethanes and polyolefins) release by diffusion through a coating. The release rate is determined by polymer chemistry, thickness, coating process, temperature and moisture; release can be highly controlled and can be designed to match plant uptake.

A listing of these products can be found at: www.fertilizer.org/ifa/news/2005_17.asp

It is beyond the scope of this paper to deal with all of the fertilizers that may be termed "enhanced efficiency", and although the paper was to deal only with controlled release N and P fertilizers, Nutrisphere-N and Avail-P are included in the discussion.

Controlling Nitrogen Fertilizer Release

A large number of field trials were conducted (Agrium internal research program) across western Canada from 1998 to 2000 to determine if ESN could maintain crop yields, and increase grain N and N use efficiency compared to the current practice of pre-plant banding of urea N fertilizer (Haderlein et al., 2001). This early work showed that crop uptake of N from seed-placed ESN was sufficient to provide yields similar to those of pre-plant banded urea N (figure 1).Uncoated urea placed in the seed row significantly reduced plant stand densities as compared to the control at 8 of 11 sites (data not shown); plant stands with seed-placed ESN were not significantly different from side-band applied urea.

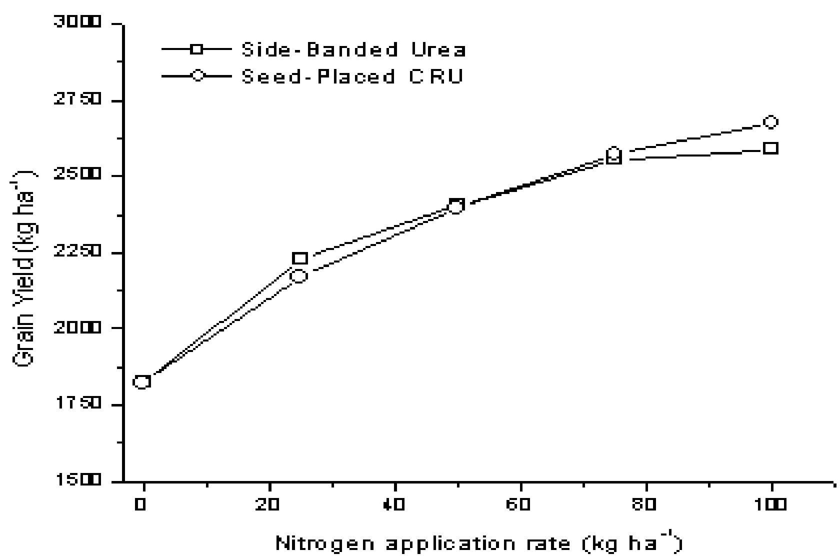

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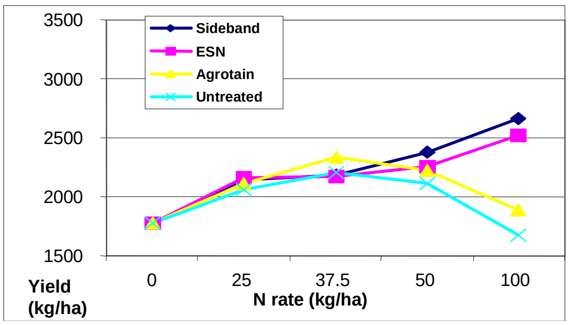
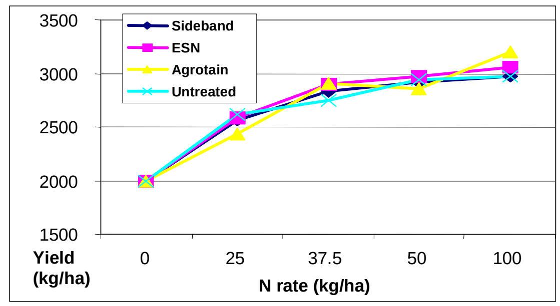
Figure 1. Spring wheat yield as affected by N source and application method (Haderlein et al., 2001).

Brandt et al. (2004) conducted a large number of field trials comparing the use of seed-placed ESN, seed-placed Agrotain treated urea, side-band applied urea and seed-placed uncoated urea, for both spring wheat and canola production (figure 2a – d).



A. Wheat at Scott 2003 and Swift Current 2004



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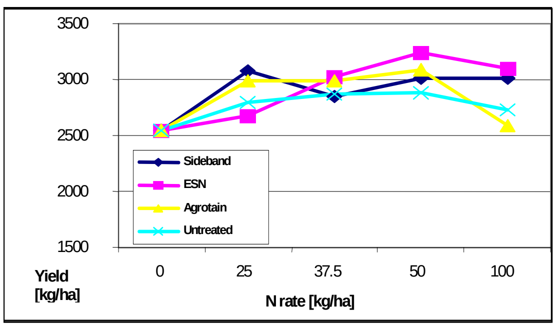
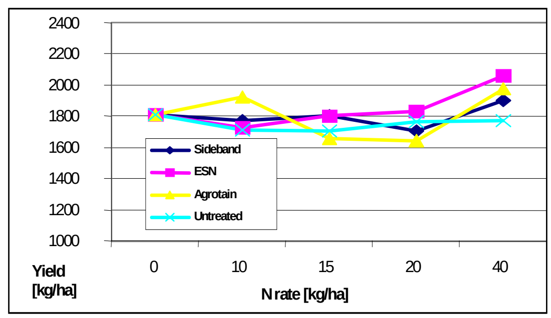


C. Wheat at Scott 2004



D. Canola at Scott 2004

Figure 2. Grain yield as influenced by urea treatment, placement and rate in Saskatchewan (Brandt et al., 2004).

These researchers concluded that ESN "showed a great deal of promise as a means of making seed-placed N safer." ESN provided a margin of safety roughly equivalent to side-band applied urea.

McKenzie et al. (2007) conducted several years' work on the use of ESN as a N management tool for winter wheat production in southern Alberta. Their work suggested that all N requirements may be applied at seeding, precluding the need for spring N top-dressing.

Applied at seeding as a side-band application, urea and ESN performed similarly. Applied in a seed-row application, ESN outperformed urea as N rates increased. Averaged across rates, ESN out-yielded urea when side-band applied by about 1.4 bushels per acre. When seed-placed, ESN out-yielded urea by about 6.4 bushels per acre (figure 3).

Generally, greater yield advantages for ESN over urea occurred at the application rates of 30, 60 and 90 kg/ha N rates for side-band application, and at 60, 90 and 120 kg/ha N application rates for seed-placed application.

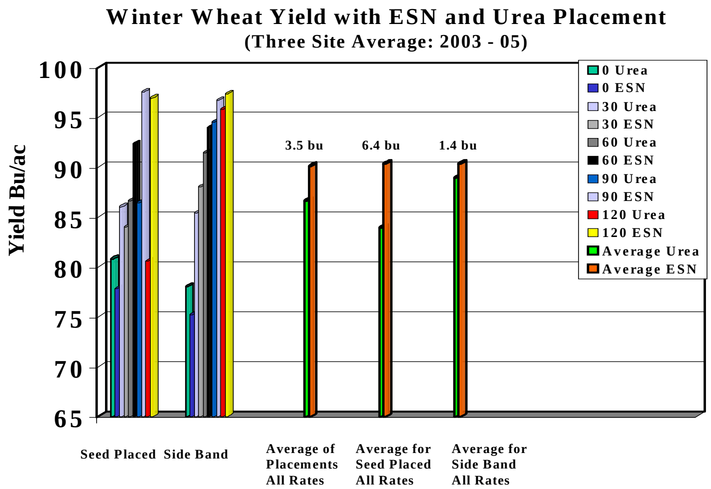


Figure 3. Winter wheat yield as affected by source and placement of N (McKenzie, et al., 2007).

Grant et al. (unpublished) have conducted three years (2004-06; ETAA/GAPS) of ESN research at 9 sites across Canada. This group evaluated the effectiveness of ESN against urea, in improving yield and reducing N loss to the environment.

Tables 1 and 2 would suggest that where N loss potential conditions exist – ESN use can be beneficial. And where N loss conditions do not exist – there is low expectation of beneficial (yield – wise) ESN use. With low soil temperatures and reduced soil moisture, release of N from ESN may be somewhat restricted. This can be overcome by blending ESN with either urea or ammonium sulphate, supplying both early and later season N. As well, use of ESN in a blend will lower overall per acre cost of use.

Table 1. ESN and urea yield comparisons under dry conditions (Grant, 2006; unpublished).

Dry conditions - no yield advantage

		N rate	Yield (t ha^{-1})		
Site	Crop	(kg ha^{-1})	ESN	Urea	Inc.%
		30	3.22	3.24	-0.62
Lacombe	Canola	60	3.22	3.21	0.31
		20	2.42	2.46	-1.63
		40	2.6	2.55	1.96
Swift Current	Wheat	60	2.58	2.62	-1.53
		30	5.64	5.67	-0.53
Lacombe	Barley	60	6.44	6.46	-0.31
		15	2.14	2.32	-7.76
		30	2.31	2.32	-0.43
Swift Current	Wheat	45	2.3	2.36	-2.54

Table 2. ESN and urea yield comparisons under wet conditions (Grant, 2006; unpublished).

Wet conditions – yield advantage

Site	Crop	N rate (kg ha^{-1})	Yield (t ha^{-1}) ESN	Urea	Inc.%
		25	0.67	0.62	8.4
Brandon-ISF	Canola	50	0.70	0.73	-4.6
		25	0.51	0.42	21.3
Brandon-ZTF	Canola	50	0.61	0.50	21.8
		30	1.92	1.67	15.0
Beaverlodge	Canola	60	2.09	1.75	19.4
		25	3.08	2.94	4.8
Brandon-ISF	Wheat	50	3.67	3.59	2.2
		25	2.53	2.50	1.2
Brandon-ZTF	Wheat	50	3.26	3.19	2.2
Harrow	Corn	150	8.54	8.19	5.4

There has been a good deal of work done in the United States on Nutrisphere-N technology; available published work in western Canada is limited (http://www.nutrisphere-n.com/proof.aspx).

Controlling Phosphorus Fertilizer Release

Table 3 shows some early work in western Canada with CRP. Pauly, et al. (2002) showed that coating MAP improved P uptake, fertilizer efficiency and barley dry matter production.

Table 3. Barley dry matter yield, P uptake and net fertilizer P efficiency affected by application of uncoated or coated monoammonium phosphate fertilizers (Pauly, et al., 2002)

Treatment	Dry Matter Yield ------g pot^{-1}------	P Uptake -mg P pot^{-1}-	NFPE --%--
Control	7.76	6.47	NA
Uncoated	18.96	12.39	27.4
Thin-coated	24.41	15.71	42.8
Thick-coated	18.64	13.28	31.5
LSD_{05}	3.37	2.22	

Internal Agrium research on CRP (table 4) indicated the potential for increased response to P when applied as CRP for barley production. This work was re-visited in 2000, with similar results. Based on these initial results, Agrium continued work in the area of CRP fertilizer.

Table 4. Response of barley to added MAP and CRP (Agrium internal research; 1995 & 2000).

Year	Site	Crop	No P control	MAP	CRP	Response over no P control MAP	Response over no P control CRP
			---------- bu/A ----------			%	
1995	Humbolt	Barley	74.1	79.9	85.0	8	15
	Asquith	Barley	84.4	89.8	88.4	6	5
	Neerlandia	Barley	103.9	107.4	112.6	3	8
	Calmar	Barley	70.1	68.9	74.1	-2	6
2000	Bruderheim	Barley	13.6	30.0	39.7	121	192
	Birch Hills	Barley	49.0	52.6	56.4	7	15
	Lamont	Barley	77.1	81.0	74.7	5	-3
	Mean		***67.5***	***72.8***	***75.8***	***8***	***12***

Germination and emergence of seed can be impacted by seed –placed P fertilizer. Work was conducted (Schoenau, et al., 2007) to determine seed placed safety limits for various crops, when using Agrium's experimental controlled release P fertilizer. Table 5 shows seedling emergence rate with regular P fertilizer, and in contrast, table 6 shows the emergence data when using CRP as the seed-placed P source. The controlled release nature of CRP-P acted to reduce seed germination injury.

Table 5. Percentage of seeds planted that emerged over 2 weeks as affected by different rates of conventional MAP fertilizer with or without 20 kg K_2O ha^{-1} potash for wheat, canola, and canary seed. *The 2004 experiment was conducted in the growth chamber and other years were conducted in the laboratory.

Fert. rate	Wheat P only		Wheat With K	Canola P only			Canola With K	Canary P only		Canary With K
kg P_2O_5 ha^{-1}	2004*	2006	2006	2004*	2005	2006	2006	2004*	2006	2006
0	98a	93a	91a	96a	96a	95a	89a	93a	83a	63a
10	96a	95a	91a	96a	98a	98a	86a	83a	79a	61a
20	94a	91a	89ab	88a	90ab	95a	82a	86ab	79a	69a
30	96a	89ab	86ab	94a	83b	91a	80a	82b	73ab	58ab
40	94a	91a	86ab	94a	69c	73b	75a	88ab	68bc	56ab
60		80b	82b		48d	48c	59b		59c	46b
80		64c	68c		48d	43c	45bc		53cd	33c
100		52d	59d			36c	43c		38d	30c

Means in columns followed by a different letter are significantly different at $p < 0.05$.

A study comparing CRP, Avail–P, uncoated P and liquid P was conducted by Agriculture and Agri-Food Canada (unpublished), over two years at one site in Alberta (Lacombe) and two sites in Manitoba (Brandon). Table 7 shows the wheat yield following previous year's crop, for the different P fertilizers used. The yields for the CRP treatment tended to be numerically higher, but over the total study, there were few statistical differences. As well, at the Lacombe site (data not shown), CRP yield for barley was significantly higher than either uncoated P or liquid P treatments.

There is little published information evaluating the performance of CRP under field conditions.

There has been a good deal of US research related to Avail-P (http://www.specialtyfertilizer.com/avail.aspx), but little published work in western Canada (http://specialtyfertilizer.com/PDF/ManitobaCanolaStudy.pdf).

Table 6. Percentage of seeds planted that emerged over 2 weeks as affected by different rates of controlled released phosphorus (CRP) fertilizer with or without 20 kg K_2O ha^{-1} potash for wheat, canola, canary seed, and flax.

Fert. rate	Wheat		Canola			Canary		Flax		
	P only	With K	P only		With K	P only	With K	P only		With K
kg P_2O_5 ha^{-1}	2006	2006	2005	2006	2006	2006	2006	2005	2006	2006
0	93a	91a	90a	95a	89a	81a	63a	60a	67a	65a
10	93a	91a		95a	86a	80a	63a		68a	69a
20	95a	93a	92a	93a	80a	83a	63a	56a	69a	65a
30	93a	91a		86a	82a	78a	61a		72a	64a
40	89a	93a	96a	91a	80a	75a	56a	60a	69a	68a
60	89a	91a	92a	86a	80a	73a	63a	60a	71a	64a
80	91a	91a	94a	91a	80a	75a	58a	59a	65a	63a
100	91a	93a		84a	80a	74a	51a		65a	64a

Means in columns followed by a different letter are significantly different at $p < 0.05$.

Table 7. Influence of preceding crop, tillage system and P treatment on wheat grain yield (t ha^{-1}) at two locations in Manitoba (Grant, 2005; unpublished)

	BRC Site									
	Barley			Canola			Flax			Treat
Treatment	CT	RT	Mean	CT	RT	Mean	CT	RT	Mean	Mean
Control	3.63	2.99	3.31	3.77	3.40	3.59	3.71	3.17	3.44	3.44
APP - Drib-Band	3.61	3.32	3.46	3.70	3.62	3.66	3.81	3.49	3.65	3.59
APP Side-Band	3.67	3.28	3.47	3.99	3.55	3.77	3.28	3.45	3.36	3.54
MAP Side-Band	3.62	2.97	3.30	3.78	3.80	3.79	3.66	3.39	3.53	3.54
Agrium Side-Band	3.66	3.45	3.55	3.75	3.57	3.66	3.77	3.44	3.60	3.61
Avail Side-Band	3.61	3.32	3.47	3.67	3.71	3.69	3.65	3.31	3.48	3.54
Means	3.63	3.22	3.43	3.78	3.61	3.69	3.65	3.37	3.51	3.54

	ZTF Site									
	Barley			Canola			Flax			Treat
Treatment	CT	RT	Mean	CT	RT	Mean	CT	RT	Mean	Mean
Control	2.51	2.35	2.43	3.45	3.16	3.31	3.13	2.10	2.62	2.78
APP - Drib-Band	2.62	2.53	2.57	3.45	2.84	3.14	3.01	2.17	2.59	2.77
APP Side-Band	2.64	2.58	2.61	3.37	2.99	3.18	2.69	2.13	2.41	2.73
MAP Side-Band	2.76	2.64	2.70	3.35	3.13	3.24	3.00	2.03	2.52	2.82
Agrium Side-Band	2.71	2.80	2.76	3.31	3.20	3.25	3.10	1.86	2.48	2.83
Avail Side-Band	2.59	2.64	2.62	3.32	2.94	3.13	3.12	1.89	2.50	2.75
Means	2.64	2.59	2.61	3.37	3.04	3.21	3.01	2.03	2.52	2.78

Table 8 shows the effect of Avail treatment on monoammonium P (MAP), providing a 6 bu/ac corn yield increase.

Table 8. Corn responses in Minnesota to enhanced P availability on high pH soil.

Treatments	Dry weight g/6 plants	P %	P Uptake mgm/6 plants	Grain Yield bu/A
Control, No P	14.5	0.306	44	108
MAP	18.8	0.309	58	116
MAP + Polymer	19.3	0.328	64	122
LSD (0.10)	2.7	0.016	10	5

20 lb P2O5/A banded starter. 0.5% polymer coating. Univ. of Minnesota - Lamberton Soil pH = 7.8. Soil test P = Low (from Sanders and Murphy, 2004)

Table 9 shows the impact of Avail treatment on MAP; benefits appeared to be greater when Avail treated P was band applied, as opposed to broadcast applied.

Table 9. Polymer and P application method effects on Arkansas wheat yields

Treatment	Yield bu/A
Control	46.7
MAP banded	54.7
MAP + polymer, banded	76.9
MAP broadcast	58.2
MAP + polymer, broadcast	65.6
MAP + seed, broadcast	55.1
MAP + polymer + seed, broadcast	68.3
LSD (0.05)	7.5

University of Arkansas

30 lb P_2O_5/A. Soil P test low. Soil pH=7.6 (from Sanders and Murphy, 2004)

Table 10 shows a non-significant wheat response to the Avail treatment.

Table 10. Wheat response to enhanced P availability.

Treatment Applied	Grain Yield bu/A
Control	31.6
MAP	34.2
MAP + Polymer	39.5
LSD (0.10)	7.2

1% polymer Murphy Agro – Kansas State Univ.
20 lb P_2O_5/A banded at planting.

Table 11 shows no statistically significant response to the Avail treatment, but an increase in gross return on potato production.

Table 11. Potato yield and return responses to enhanced P availability.

Treatment lb P2O5/A	Yield Cwt/A	Petiole P %	Gross Return $/A
Control	311 a	0.225 d	1456
60 MAP	330 ab	0.253 cd	1546
60 MAP + polymer	339 ab	0.288 ab	1575
120 MAP	344 bc	0.275 bc	1591
120 MAP + polymer	369 c	0.308 a	1791

Declo sandy loam, pH 7.9; Olsen P 23 ppm Univ. of Idaho
Duncan's multiple range test, 5%. (from Sanders and Murphy, 2004)

Role of Controlled N and P in western Canada

Controlled release N and P fertilizer products hold potential for improving fertilizer use efficiency and reducing environmental impact. The greater the potential risk of "loss" of N and P fertilizer – the greater the role CRF's can play.

Interest and adoption of CRF's is increasing in western Canada. Aside from increased cost of these products, limitations have been related to finding the appropriate fit for use of controlled release N and P products. Research data from use of these products ranges from the highly beneficial, to the statistically "no difference". Like any product, products such as these are to convey a benefit when used in the appropriate circumstance; discerning the potential benefit of use may well be the first step of the learning curve.

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