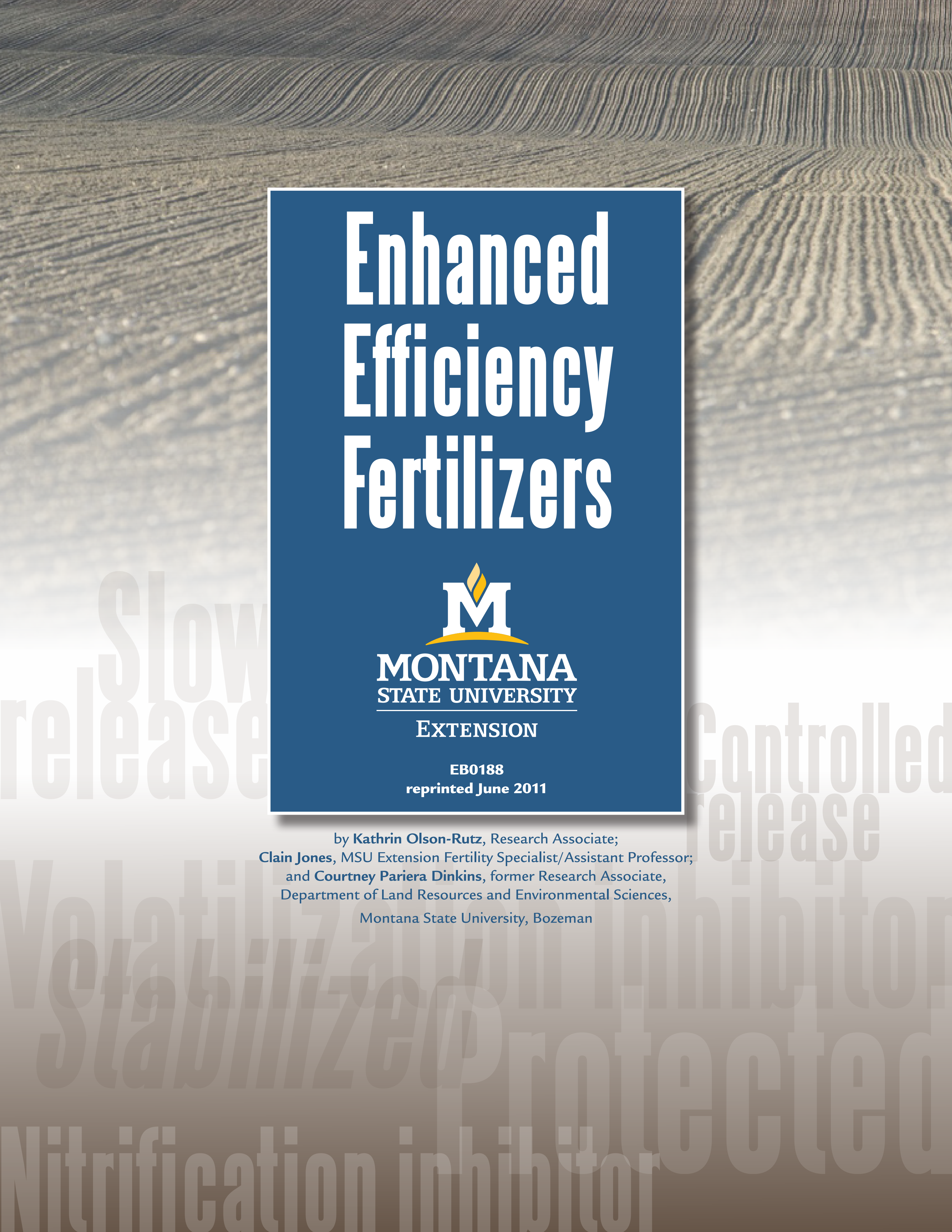

Enhanced Efficiency Fertilizers

MONTANA STATE UNIVERSITY
EXTENSION

EB0188
reprinted June 2011

by **Kathrin Olson-Rutz**, Research Associate;
Clain Jones, MSU Extension Fertility Specialist/Assistant Professor;
and **Courtney Pariera Dinkins**, former Research Associate,
Department of Land Resources and Environmental Sciences,
Montana State University, Bozeman

Enhanced efficiency fertilizers (EEFs) are fertilizers that reduce loss to the environment and/or increase nutrient availability compared to conventional fertilizers. Nitrogen (N), in particular, can be lost to processes such as leaching, ammonia volatilization, runoff, and being tied up by microbes. Until recently, there has been limited interest in using EEFs for agricultural crops in Montana. The potential for substantial N loss in many Montana cropping systems is commonly thought to be relatively low due to our soil characteristics and generally cool, dry environment. Also, EEFs tend to be more expensive than conventional fertilizers. For example, premiums usually range from 10 to 40 percent. Since actual cost increase per ton stays about the same as fertilizer price varies, percent premiums are smaller when fertilizer prices are high and larger when fertilizer prices are low. With recently high fertilizer prices and decreased EEF manufacturing costs, EEFs have become more economical. If EEFs are to be used in agriculture, they must offer the producer sufficient benefit to offset the increased cost.

Purpose of EEFs

EEFs reduce nutrient losses and increase nutrient availability by either slowing release or altering reactions that lead to losses. EEFs can spread out the release of nitrogen (N) over the growing season, ideally matching N supply to plant nutrient demand over time (Figure 1; also see MSU Extension Publication, *Nutrient Uptake Timing by Crops,* EB0191). Adequate and consistent nutrient availability reduces plant stress and may result in better yield *(1)*. Matching N released with N uptake rather than having high levels of N in the soil solution immediately after fertilization can reduce the risk of excessive vegetative growth and lodging in wheat. It also increases the chance that N will be available during grain fill to increase grain protein. Similarly, sustained moderate levels of N can increase yield and quality of warm season crops, such as corn, sugar beet and potato.

EEFs offer the potential to reduce costs associated with split fertilizer applications, by applying the fertilizer only once. They can be applied prior to seeding, thereby allowing greater flexibility to minimize operations being restricted by wet fields, inclement weather or an already full work load. Also, fewer passes on the field limit compaction and can help retain soil moisture.

Some benefits are not always tangible and directly measured by increased profit margin. There may be environmental advantages of using EEFs by reducing ammonia volatilization, groundwater nitrate (NO_3^-) contamination, or nitrous oxide (N_2O, a greenhouse gas) emissions. Whether the goal is to optimize return or benefit the environment, we have provided factors to consider when deciding if you should use EEFs, and some yield differences to help you determine their potential worth.

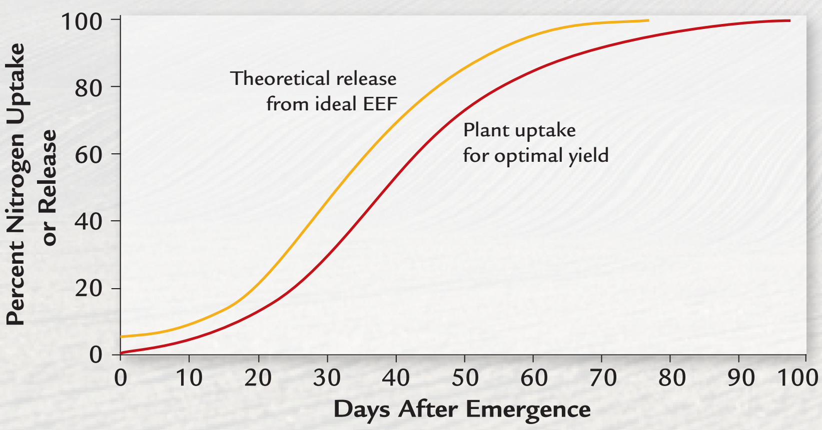

FIGURE 1. Theoretical plant uptake of N during the growing season and matching release of N from an ideal EEF.

Types of EEFs

Enhanced efficiency fertilizer can be divided into two classes, stabilized fertilizers and controlled or slow release products. Stabilized fertilizers have additives that alter or inhibit soil enzymatic and microbial processes. Controlled or slow release fertilizers affect nutrient release. The Association of American Plant Food Control Officials is currently working on specific definitions of these so that it can be determined in a laboratory whether a fertilizer falls into one of these categories or not. The Appendix on page 12 is a partial list of EEFs in our region. Manufacturers' claims have not all been substantiated by independent research. We encourage you to find data from local studies with current products, to help assess your options.

How they function and conditions for effectiveness

NITROGEN EEFS There are a variety of EEFs on the market and they work at different parts of the N-cycle in soils (Figure 2). For more information on plant nutrients and nutrient cycles see the MSU Extension Nutrient Management Modules.

Stabilized N products chemically interrupt N reactions in the soil. These products can be mixed with various sources of N to produce a liquid or granular product, or be added to manure to decrease losses. Urease inhibitors delay the conversion (hydrolysis) of urea to ammonium (NH_4^+), which may rapidly form ammonia gas (NH_3) in the soil. If the ammonia forms near the soil surface, it can be lost to the atmosphere by volatilization, especially under warm, high pH conditions (Figure 3). By slowing the conversion of urea to ammonium, urease inhibitors can also reduce seedling damage from seed-placed N.

The most common urease inhibitor is NBPT. It is effective in soils that have high potential for volatilization (high pH, coarse) and/or not enough moisture to draw the urea away from vulnerable seedlings when seed-placed. Since NBPT degrades in 10 to 14 days *(4)* it can only delay urea hydrolysis for several days to a couple of weeks. However, this often provides time for sufficient rainfall or irrigation (half inch or more) to move the urea into the soil, where it is much less susceptible to volatilization (Figure 3). NBPT-urea appears to be even more effective at reducing volatilization on coarse than fine soils *(3)*.

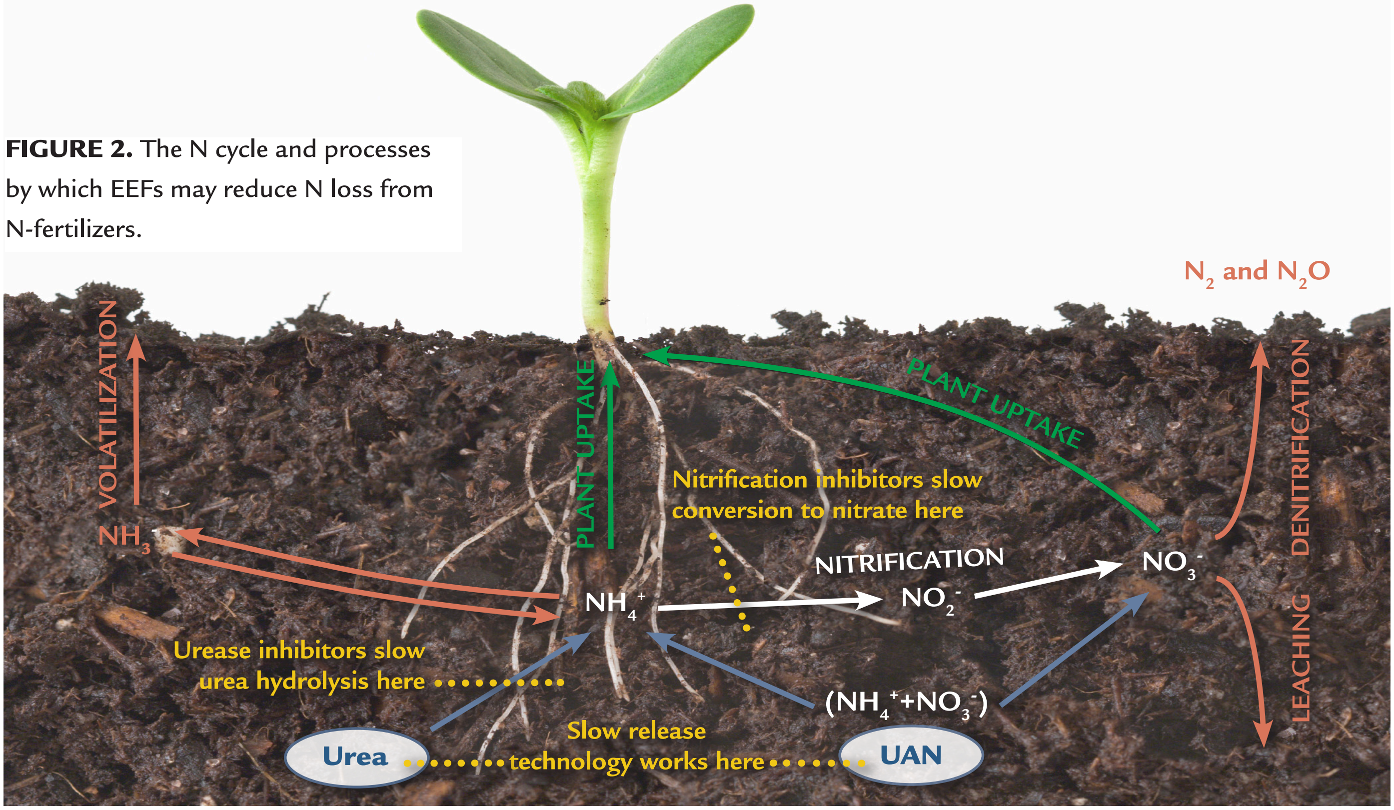
FIGURE 2. The N cycle and processes by which EEFs may reduce N loss from N-fertilizers.

Generally, urea volatilization is low in cool temperatures. However, preliminary data on urea volatilization in Montana suggests that, without sufficient moisture to move the urea into the soil, overwinter urea volatilization can be substantial *(5)*. This may be in part because sunshine can abruptly increase winter soil surface temperatures, especially on dark soil. NBPT may protect against ammonia loss under such conditions.

The effectiveness of NBPT decreases over time and as soil residue, temperature (Figure 4) and moisture content increase *(6)*. Higher concentrations of NBPT are required at higher temperatures and with plant residue *(7)*. The retailer typically takes this into consideration when recommending application rates. NBPT is more effective when used with urea than UAN, because only half of the N in UAN is in the form of urea. When used with UAN the NBPT amended solution should be applied to the field soon after mixing, as NBPT gradually decomposes in the presence of water *(4)*. In a blended fertilizer, NBPT should be applied to the N source before adding to the phosphorus (P) and potassium (K) blend.

Ammonia an inch or two below the soil surface is generally not lost to volatilization, except in sandy soils, but will quickly convert to nitrate through the nitrification process. Nitrate is susceptible to leaching, mainly

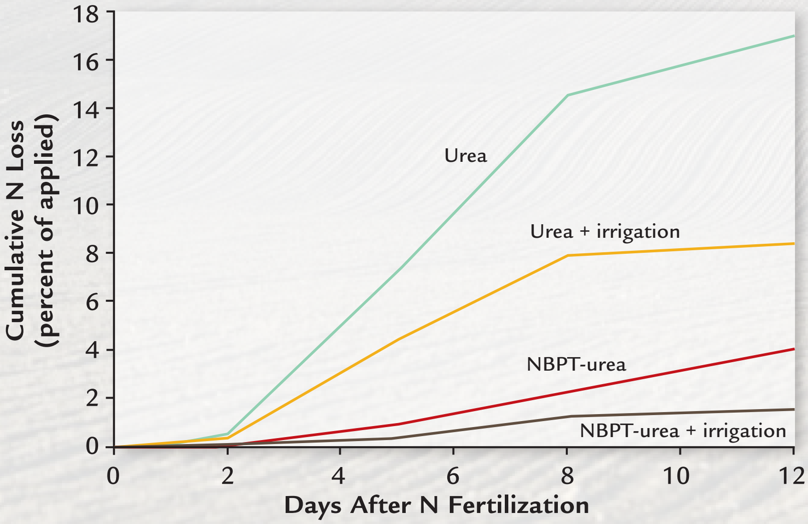

FIGURE 3. Cumulative ammonia loss from 89 lb N/acre urea and NBPT-urea applied in May on a field in Manitoba on clay loam soil with irrigation (0.79 inches on days 2 and 8) and without *(3)*.

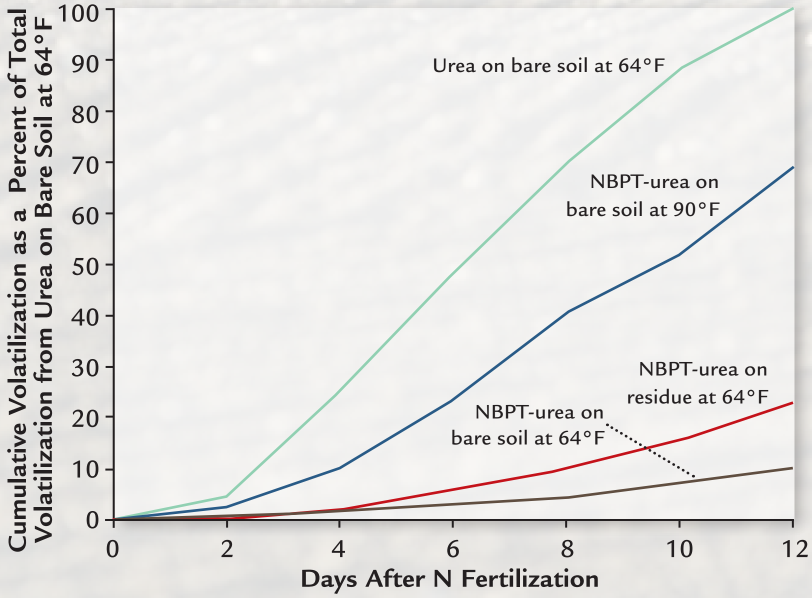

FIGURE 4. Relative cumulative ammonia volatilization from urea and NBPT-urea under lab conditions at different temperatures, on bare soil and on soil with plant residue. Volatilization is expressed as percent of total cumulative loss by urea on bare soil at 64°F *(7)*.

under irrigated or high rainfall conditions and in coarse soils, or can be lost to gaseous N through denitrification (Figure 2). Nitrification inhibitors are generally antibiotics that slow the bacterial conversion of ammonium to nitrate and may be effective at reducing N loss for several weeks depending on conditions. They could hurt other N cycling reactions but they only function in a limited area around the granule. The benefits of nitrification inhibitors are greatest in conditions where leaching and denitrification losses are sufficient to reduce crop yields *(8)*. In Montana, those conditions would be most likely on irrigated fields. The most common nitrification inhibitor available in our region is DCD (Appendix).

Slow- and controlled-release N products release their nutrients at a slower rate than conventional fertilizers. Slow release fertilizers use additives such as urea-aldehyde products that slowly decompose by chemical and/or biological processes in the soil delaying N release. Solubility and N release can be varied by altering the chemical composition of the aldehyde additive *(9).* These products are mixed with liquid or granular fertilizer at the point of manufacture or at the blending plant. At the time of writing, there was little independent research done with these fertilizers to test their effectiveness.

Controlled release fertilizers use coatings which delay or extend the nutrient availability. They are made at the manufacturing plant. Sulfur coatings have been used to delay urea release from individual fertilizer granules at different times to achieve an extended period of N supply. Nitrogen release from sulfur-coated urea (SCU) has been somewhat unpredictable, and use of SCUs has become less common. More recently, semi-permeable polymer coatings have been developed that permit water to move in through the coating and dissolved urea to move out (Figure 5). The release rate can be controlled by the coating process, chemistry and thickness.

There are several products with different polymer coatings. For simplicity we will use PCU to represent all of them. The release of N from PCUs is determined by soil moisture and temperature. Moisture generally does not limit nutrient release in the range of soil moisture adequate for crop growth, but is necessary to allow diffusion of urea from the PCU prill. Moisture limitations on nutrient release rate are most commonly a factor with surface application in areas of sparse rainfall *(10).* In the presence of moisture, temperature is the major controlling mechanism of release rate. In one lab study on a silt loam soil, only 30 percent of N was released

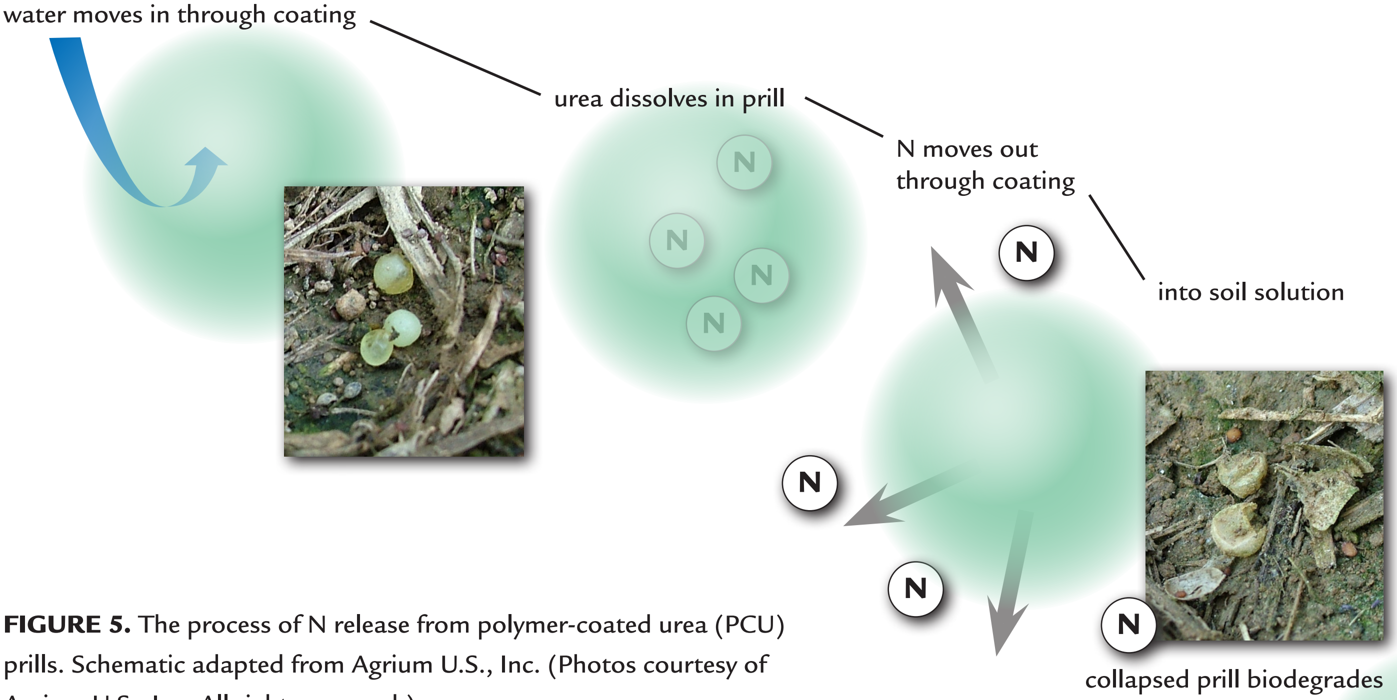

FIGURE 5. The process of N release from polymer-coated urea (PCU) prills. Schematic adapted from Agrium U.S., Inc. (Photos courtesy of Agrium U.S., Inc. All rights reserved.)

from PCU prills buried in soil at 59°F after 40 days, whereas 90 percent was released in the same time at 68°F and above *(11)*. This greatly influences the potential utility of PCUs in the northern Great Plains, especially for small grains which are generally fertilized from mid-fall to mid-spring when temperatures are cool.

Since a 'typical' April soil temperature in central Montana at one inch below the surface is below 50°F *(12),* Montana cropping systems would see limited N release of spring applied PCU until after the end of May (Figure 6). This would likely be too late to supply small grain crops the high amounts of N required to sustain early vegetative growth. For this reason, if PCUs are used in the spring with cool-season crops, it is strongly recommended to blend PCUs with conventional urea especially if soil nitrate-N is low, such as on recrop. Also, to account for the delayed release, optimal timing of PCU application may be 4 to 6 weeks earlier than for conventional urea. Since the rate of N release from PCUs can be controlled by coating thickness, future products may be developed that allow timely release of N for small grain production in our region.

Delayed release should be less of an issue with fall incorporated PCU and on crops such as corn or sugar beet, which have high nutrient demands later, when warm temperatures allow for greater N release. Most N uptake for sugar beet and corn occurs late enough in the season when soil temperatures are high enough for substantial release of N from PCUs (Figure 6). Therefore, PCUs likely have a high chance for being effective with warm season crops.

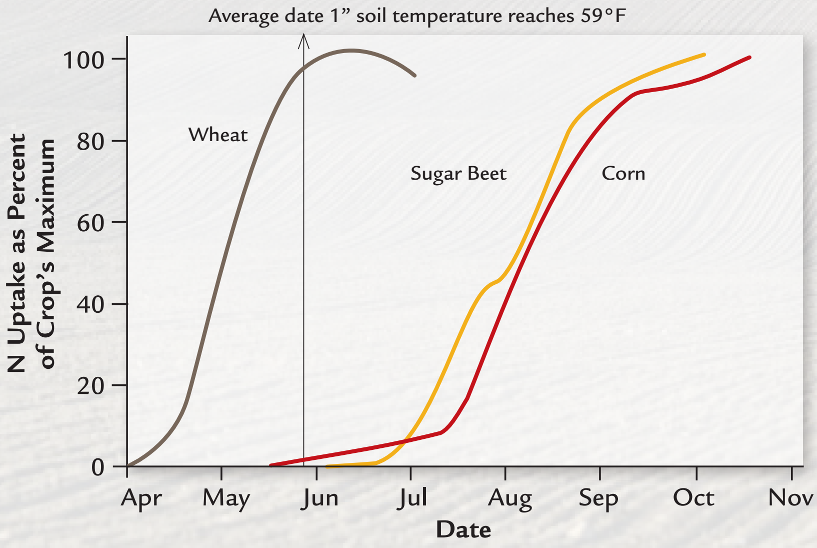

FIGURE 6. Nitrogen uptake by corn *(13)* and wheat shoots *(14),* and sugar beet roots and shoots *(15)*, over time, as a percent of their maximum N uptake. The date when soil temperature at 1-inch depth reached 59°F comes from Moccasin, Montana in 2006 *(12)*. Corresponding air temperatures that year were close to the 1971-2000 average air temperatures (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt5761). In the lab, buried PCUs release 30 percent of N by day 40 at soil temperatures of 59°F *(11)*.

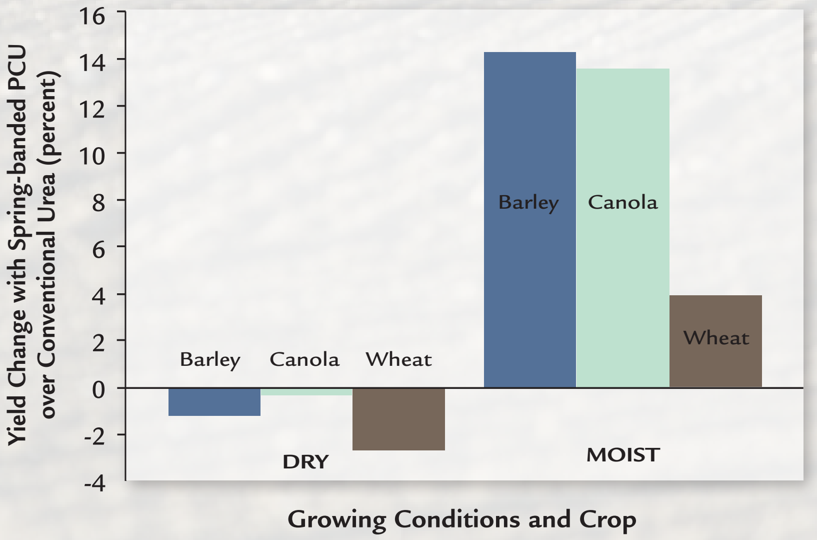

FIGURE 7. Barley, canola and wheat yield as affected by spring-banded applications of PCU compared to conventional urea under relatively dry conditions at Beaverlodge, Lacombe, Melfort, and Swift Current, and relatively moist conditions at Beaverlodge, Brandon, and Swift Current, Canada *(8)*. Moist sites had excess moisture during the fall to spring (October to late June) period that led to the potential for denitrification.

The gradual release of urea from slow and controlled release N fertilizers provides a slow stream, rather than pool of ammonium for plant uptake. Therefore less is potentially lost to leaching, denitrification, and volatilization. The slowed urea release may also moderate the pH increase around the fertilizer prill, which slows the production of ammonia and decreases volatilization loss. One lab study followed ammonia volatilization from PCU and conventional urea on bare soil at 64°F. By the end of 2 weeks, the PCU prills had lost only 10 percent of the total ammonia lost by the conventional urea over the same time *(16)*.

PHOSPHORUS EEFS Phosphorus (P) availability can decrease through crop removal, soil erosion, surface runoff, binding to soil particle surfaces, and formation of minerals. Mineral formation is the major factor contributing to decreased P use efficiency in Montana soils. Specifically, P fertilizer quickly reacts with calcium (Ca^{2+}) and magnesium (Mg^{2+}) to create relatively insoluble phosphates that are minimally available to plants. Cool, dry, alkaline soils, common in Montana, further limit plant available P, and P EEFs are designed to overcome these limitations.

Slow release P. Polymer and other coatings slow the release of P from the fertilizer and are designed to increase P use efficiency. The effectiveness depends on the thickness of the polymer coating and temperature, but will also vary with soil type and moisture. Coated P may extend P availability into the second season after application *(17)*. Because young plants need P for early season growth during a time when P availability is low in Montana soils, the slow release P product available at the time of this writing is not expected to be very beneficial here.

Shielded P. Another technology, used in Avail®, is the addition of high capacity exchange resins or polymers which bind cations from the soil solution and hinder the formation of less soluble phosphates *(17)*. This could help maintain P locally in a plant available form. These polymers are organic structures and as such, their effectiveness is influenced by soil micro-organisms, moisture and temperature. Avail® can be added to a P fertilizer granule or liquid at the manufacturing plant or distribution location. The coating should be applied to the P fertilizer separately from the urea or UAN, as P release rates are slower than those of N from the same resin-coated prills *(18)*.

Potential applications and performance of nitrogen EEFs

The effectiveness of EEFs depends on several environmental and management factors. To determine the potential value of EEFs, the following should be considered.

IRRIGATED VERSUS DRYLAND PRODUCTION Irrigated fields are well suited for PCUs because irrigation, especially flood and furrow irrigation, can lead to substantial leaching and denitrification losses, leading to yield losses. For example, furrow irrigated winter and spring wheat had consistently higher yields with incorporated PCU than conventional urea in Idaho (11 bu/acre difference for winter wheat and 7 bu/acre for spring wheat; *19*). Pre-plant conventional urea at high rates may have reduced wheat yield in this study due to high N available during early vegetative growth and less N available during reproductive growth.

Under moisture conditions that promote significant N losses, spring-banded PCU increased barley, canola and wheat yields in western Canada (Figure 7). The moist sites had excess moisture from October to June, which led to conditions ideal for N denitrification. PCU did not offer an advantage over banded conventional urea under drier conditions that did not promote N losses (Figure 7), and would thus likely have less utility in an average or below average moisture year in Montana.

Corn yields were higher with PCU than conventional urea under relatively high rainfall or irrigated conditions with high potential N loss (Figure 8). Montana's dryland cropping systems generally receive less than the 10 inch break even point during the growing season, suggesting that PCUs may only increase yields on irrigated systems here.

Irrigation gives the producer the capability to soak in urea within a few days of application. Adding NBPT to surface applied urea, followed by at least ½ inch of water within 7 days essentially eliminates volatilization (Figure 3). In dryland production, especially when temperatures are warm, growers should ideally incorporate urea or apply it before a predicted rainstorm. Since this can be impractical, producers may benefit from the addition of NBPT to urea under such conditions.

Nitrification occurs quickly in warm wet conditions, but can also happen during the cool dry season of late fall and winter, with the potential for subsequent leaching on shallow, coarse soils once moisture is received or irrigation is started in the spring. In wet soils, these losses can create an N deficiency. Yield benefits with nitrification inhibitors are inconsistent *(21)* and there is limited information on nitrification inhibitor effects on production in our region. However, nitrification inhibitors are effective at reducing N lost to leaching and denitrification for several weeks and may benefit yield when compared to conventional urea *(22)*, especially in irrigated systems.

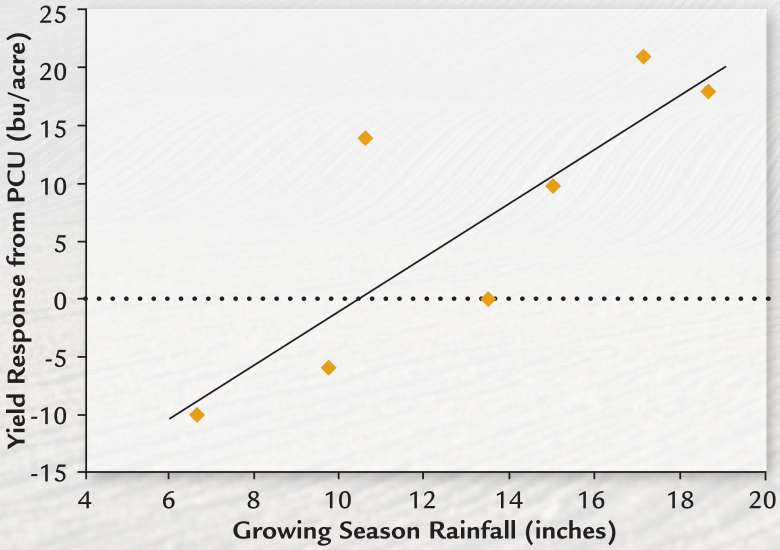

FIGURE 8. Corn yield response to PCU over conventional urea as affected by growing season rainfall in Illinois, 2003-2005. Points above zero denote greater yield with PCU than with conventional N sources. Line shows best fit of the data and illustrates trend *(20)*.

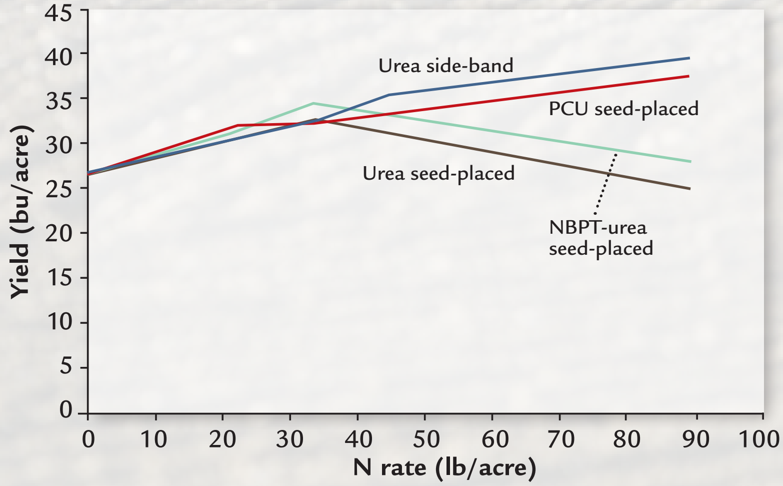

FIGURE 9. Dryland spring wheat yield as affected by seed-placed PCU, NBPT-urea, and conventional urea, and side-banded conventional urea as a control *(24)*.

PLACEMENT The vast majority of N application in Montana and the northern Great Plains is broadcast which can be inefficient under certain conditions. Yield benefits with NBPT-urea can occur when soil and environmental conditions promote extensive volatilization losses, crop yield potential is high, and soil N levels are limiting *(8)*. The use of NBPT in broadcast urea may be particularly beneficial in warm, dry, spring applications *(8)*. However, if there is limited potential N loss then fall broadcast EEFs do not consistently improve yield over conventional urea *(23)*.

Seed-placed N can improve N use efficiency and reduce application costs. However, seedling damage and reduced stand density are common on dry sites when all of a crop's needed N is seed-placed. MSU recommends no more than 10 lb N/acre as urea be seed-placed using conventional seeders (*Fertilizer Guidelines for Montana Crops,* EB0161). If there is at least half an inch of moisture to move conventional urea away from the germinating seed, then seed-placed EEFs may offer no benefit over conventional urea at rates as high as 100 lb N/acre *(24)*. However, under dry conditions, both PCU and NBPT-urea fertilizers are very effective at reducing seedling damage. Research suggests that the safe rate of seed-placed N can be increased up to 50 percent when using NBPT-urea as compared to untreated urea or UAN *(25)* and 2- to 4-fold for PCUs *(24)*. Barley seedlings damaged from high rates of untreated urea appeared to have reduced vigor, decreased ability to compete with weeds and volunteer wheat, and delayed maturity. These all contributed to lower yields at high rates of seed-placed urea without NBPT *(26)*.

PCU can be better at reducing seedling damage than NBPT-urea, especially as N rate increases. The actual safe rate will vary. Under dry conditions, spring wheat plant density decreased with NBPT-urea at 22 lb N/acre, whereas PCU did not decrease plant density until rates above 45 lb N/acre. The reduced stand density with NBPT- and conventional seed-placed urea resulted in reduced yields, whereas yields increased with high levels of seed-placed PCU and side-banded conventional urea (Figure 9). Others reported up to 100 lb N/acre could be safely seed-placed using PCU on dryland winter wheat, versus only 27 lb N/acre of conventional urea, with grain yield and protein content the same between PCU and side-banded conventional urea *(27)*.

Side-banding overcomes the rate restriction, allows more N to be placed without damaging seedlings, and usually provides good yield responses. In general, yield of dryland winter wheat is similar between fall seed-placed PCU, side-banded PCU, and side-banded conventional urea, at rates up to 100 lb N/acre, all of which outperformed seed-placed conventional urea *(28)*. Similarly, in 11 field trials with dryland spring wheat and barley, yields from seed-placed PCU were similar to side-banded conventional urea *(29)*. There is generally no yield gain by seed-placed PCU over side-band urea because moisture is the limiting factor to production and N loss in a cool semi-arid climate is relatively low. However seed-placement decreases equipment and operating costs and causes less soil disturbance.

High maximum safe rates assume the PCU prills are intact. Commercial seeding equipment may damage 30 to 40 percent of the prills, making them effectively an uncoated urea granule *(30)*. Similarly, if granules absorb water, then freeze and crack, their release rate may be affected *(31)*. These concerns may be addressed by improved fertilizer manufacturing technology.

High rates of seed-placed EEF can provide N later in the growing season to boost protein, but results are inconsistent. Some researchers found protein content increased by 1.5 percent protein but only at high rates of seed-placed EEF *(25)*, while others found protein to be 0.4 to 0.9 percent protein higher with seed-placed PCU than side-banded urea at rates of 22 to 90 lb N/acre *(29)*.

TIMING Potential yield benefits from the use of EEFs increase with the length of time the fertilizer is in, or on the soil before crop uptake. Many producers prefer fall N application, to take advantage of seasonal N pricing and accessibility to fields, and to balance spring workloads. In contrast, split applications of conventional fertilizer allow the producer to adjust N to the current growing season. However, the success is very dependent on the ability of the producer to synchronize the application with a precipitation or irrigation event.

Also, split applications and top-dressing require a second pass, may be delayed due to field conditions, should be incorporated or irrigated, and have a risk of volatilization loss or being tied up by microbes in warmer temperatures.

Fall incorporated pre-plant or seed-placed PCU may eliminate the need for split applications and can produce yields and protein content equal to late winter top-dressing with untreated urea. Conversely, applying PCUs in the late winter/early spring is not as effective for yield as top-dressing with untreated urea. The PCU prill may not release sufficient N in time for the plants' high nutrient demand (Figure 6) leading to nutrient deficiency and compromised yield *(28)*. Even with furrow irrigation, winter wheat top-dressed with PCU late in the winter had lower yields (145 bu/acre) than when top-dressed with conventional urea (157 bu/acre; *19*). Top-dressing may allow the PCU prills to dry out and restrict urea release. Yet, sprinkler irrigated winter wheat had higher yields with late-winter top-dressed PCU (145 bu/acre) than both top-dressed conventional urea (132 bu/acre) and split applied conventional urea (138 bu/acre; *19*). Sprinkler irrigation may help incorporate the prills. Incorporation appears important, since even in flood irrigated fields, unincorporated PCU prills tended to float away, and release insufficient N *(11)*.

Wheat protein content may get a boost by the addition of NBPT to spring surface applications of N in warm, dry weather *(6)*. However, top-dressed PCU has not been found to increase winter or spring wheat protein content compared to conventional urea, especially under dryland systems *(28, 32)*. Formulating the PCU with a thinner coating to release at least 80 percent of the fertilizer by heading time would improve its effectiveness *(33)*. Until more specialized PCUs are available, blending PCU with an immediately available N source is an option for spring applications. The blend is adjusted for time of application, growing conditions and production goals. The later the application, the less PCU a grower should use; the greater the N-loss potential, the more PCU; and the greater the protein impact desired, the more PCU if seed-placed. The producer should consult the manufacturer for specific recommendations.

WARM SEASON CROPS Crops such as corn and sugar beet have high nutrient demands during the summer (Figure 6). Fertilizers applied at this time have higher potential for loss than when applied during cooler periods; therefore using stabilized or slow release N sources may be very beneficial. In addition, N release from PCU more closely matches nutrient demands of these crops than those of cool season crops. Specifically, PCU has been found to slowly release N throughout the entire 126 day growing period of corn *(33)*. Based on over 200 comparisons, PCU increased average corn yields over conventional fertilizer, yet the results were not consistent (Figure 10). Differences in effectiveness of PCU in these studies were mainly due to differences in precipitation and N-loss potential.

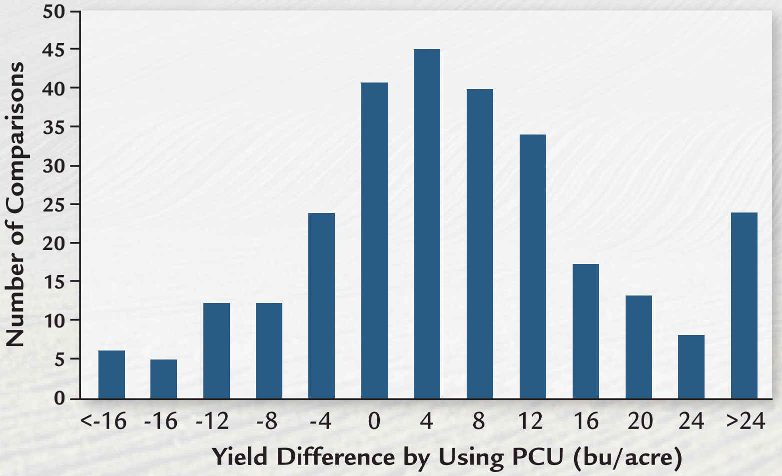

FIGURE 10. Frequency distribution of corn-yield response for pre-plant PCU compared with pre-plant conventional N fertilizer at equal N rates (U.S. corn-belt, 2000-2004). Positive numbers denote greater yield with PCU than with conventional N sources *(9)*.

Sugar beet production may benefit from EEFs. Their seedlings are very sensitive to fertilizer damage, yet there is a critical amount of N needed from the day of germination to optimize yields. Also, the plant's peak N demands are in mid-summer, months after seeding (Figure 6), yet the plant must experience N deficiency in late summer to accumulate quality sugar *(34)*. This uptake pattern lends itself to a blended application of immediately available N combined with a long term slow- or controlled-release N source. In addition, with high applications of fertilizer and frequent irrigation, there is potential for high N losses. Nitrate-N concentrations in groundwater under flood irrigated sugar beet can exceed the EPA limit of 10 ppm in some years *(35)*. Although limited research with EEFs in sugar beet production has shown that injection of N does more to increase yield than use of EEFs *(36)*, EEFs may reduce the negative environmental impacts of N leaching losses. Insufficient studies have been conducted at this time to optimize rate, timing, and placement of EEFs in sugar beet production.

Potatoes require steady, but not excessive, N supply for maximum tuber yield and quality *(37)*. They too are heavily irrigated with high potential for N leaching. PCU effectively increased potato yield and quality when compared to conventional urea applied all at once or split as 3 in-season applications. The optimum fertilization appeared to be a single application of PCU at 67 percent of growers' standard practice applied at emergence. The optimal time of application may vary with potato variety. Also, post harvest soil analyses showed that nitrate levels in and below the rooting zone were reduced with PCU *(37)*.

A liquid fertilizer containing a methylene urea and triazone blend with urea offers a potato fertilization option that can be more readily adjusted to the current growing season than a pre-plant fertilizer. This product was applied with UAN at potato tuberization, in conjunction with conventional urea at emergence, at a total N rate 66 percent of the standard rate. This was compared to conventional urea at emergence combined with 4 split applications of urea at a total 240 lb N/ac (full standard rate) and 160 lb N/ac (66 percent standard rate). Preliminary results indicate both total potato and U.S. No. 1 yields increased with the product blend at the reduced N rate compared to the conventional urea at both the reduced and full N rates. At the time of this writing, work is ongoing to determine the best management practice *(38)*.

FORAGES In pasture and forage production systems, potential volatilization is high due to surface application, limited or no cultivation or incorporation, and high urease activity due to plant residue *(6)*. The plant residue also supports many soil microbes which can use and tie-up the fertilizer N. Broadcast NBPT-urea increased dry matter yield and N uptake of ryegrass/white clover pasture when compared to conventional urea *(39)*. The 17 percent yield increase was delayed and came from the 2nd and 3rd cuttings. In contrast, fall and spring broadcast PCU on irrigated timothy hay, consistently yielded lower than conventional urea and ammonium nitrate treatments *(27)*. However, protein content was consistently higher with PCU in the second cutting. In a 2-year study on meadow brome-grass, conventional urea and UAN provided higher yield than several stabilized and slow-release N sources applied in early June. In the second year, when fertilizers were applied in mid-April, yields were higher with EEFs than with urea, but were still no better than with UAN. However, the slow-release fertilizer's gradual release of N maintained more uniform growth over the season *(40)*.

Production goal and timing should be considered when evaluating the efficacy of EEFs and potential blends with immediately available N sources for forage crops. Release from PCUs can be delayed due to cool temperatures, lack of moisture, or because prills can get intercepted by a thatch layer. Coated urea granules have been found in the thatch layer of timothy weeks and even months after broadcast application *(27)*. Delayed release of a large proportion of the fertilizer N applied may be desirable for season-long grazing. In contrast, if the goal is a large first cutting off non-irrigated hay fields, then straight PCU may not be a good fit.

ENVIRONMENTAL BENEFITS Even when yields are not significantly improved, nitrogen EEFs can benefit the environment, either directly by reducing greenhouse gas emissions and water contamination or indirectly by reducing the number of passes on a field. Nitrification inhibitors should provide benefits in areas where denitrification or leaching losses are high, such as under wet soil conditions, or where an excess of N is applied *(8)*. However, not all products are equally effective *(33)*. Adding the nitrification inhibitor DCD to NBPT-urea decreased nitrous oxide flux for over 35 days as compared to NBPT-urea only. However, this dual nitrification and urease inhibited urea increased ammonia volatilization and can either increase or decrease nitrate leached from soils, when compared to NBPT-urea *(39)*.

PCU can help limit negative effects of nitrate leaching and nitrous oxide (a greenhouse gas) emission. Apparent N recovery was 6.5 to 14.9 percent higher for pre-plant PCU than dry urea in irrigated spring wheat *(41)*, therefore less was lost to the environment. In a furrow irrigated barley study, PCU reduced nitrous oxide emissions by 35 percent, in contrast to conventional urea. Total N fertilizer losses averaged 10 and 1.9 percent for conventional urea and PCU respectively *(33)*.

Even in dryland cropping systems, average N recovery over 11 field trials was 4.2 percent higher for spring seed placed PCU than side-banded conventional urea. One site had recovery increases as high as 35 percent. A 4.2 percent improvement in N use efficiency across a large region would translate into a substantial reduction in N loss from systems using N fertilizer *(29)*. For discussion on management of N fertilizer to minimize losses, see MSU Extension publications, *Management of Urea Fertilizer to Minimize Volatilization* (EB0173), and *Crop and Fertilizer Management Practices to Minimize Nitrate Leaching* (MT201103AG).

Potential applications and performance of phosphorus EEFs

Currently there is limited research in our region on the effectiveness of adding Avail® (Appendix) to enhance the efficiency of P-fertilizer. Avail® can increase corn and soybean yields in the Midwest *(42)*, where binding of P to the soil particle surface, rather than mineral formation causes much of the P limitation. The shielding benefit did appear to last through one growing season and perhaps slightly beyond. Yield benefits in corn were equal between fall and spring applied MAP treated with Avail® *(42)*. In contrast, in Alberta, where soil and climate are more similar to Montana's, dryland spring wheat yields did not increase with the addition of Avail® *(43)*. An Idaho study on irrigated spring malt barley found a small but non-significant trend toward higher grain yield with Avail® (3 to 9 bu/acre; *44*). However, the trial was somewhat compromised by a large amount of lodging and a soil that was only moderately deficient in P.

The benefits of enhanced efficiency P fertilizers are especially attractive to canola producers since P fertilizer is a major input cost for canola production, an adequate supply of P is needed in the first two to six weeks of growth to optimize canola yield, and canola seedlings are very sensitive to seed-placed fertilizer (http://www.canola-council.org/canola_growers_manual.aspx). Limited preliminary results of trials in western Manitoba indicated enhanced efficiency P fertilizers could help reduce canola seedling damage, but yields were more dependent on favorable growing conditions than the use of enhanced efficiency P *(45)*. In three years of studies in North Dakota, canola yields changed by -30 to 150 lb/ac with the addition of Avail® to the P fertilizer. There was a trend, although not statistically significant, towards minimal increased yields with Avail®, but overall the results are still inconclusive *(46)*.

There has only been limited testing of Avail® in Montana and results were varied. This is possibly because Olsen P values were above critical levels *(47, 48)*. Also, because of our calcareous soils, adding enough Avail® to have a significant effect may not be cost effective.

Potatoes, however, clearly benefitted from a 1 percent Avail® coating in one study on calcareous loam to sandy-loam soils (1.3 to 10 percent calcium carbonate). The U.S. No. 1 potato yields were 0.6 to 1.5 tons/acre higher and total yields were 1.5 to 2.1 tons/acre higher with the Avail® than with untreated MAP *(49)*. Limited reports on sugar beet are less conclusive. Adding 1.5 percent Avail® increased yields by 2.4 tons/acre in one study *(50)*. Although percent sugar decreased from 17.9 to 17.6 percent, the higher yield provided a positive return on the investment.

Conclusions

Using EEFs will not increase crop yields and nutrient recovery under all circumstances. The greatest benefits will be expected where nutrient losses and/or limited nutrient availability limit crop yield or where seedling damage from applied fertilizer is sufficient to reduce crop yield. NBPT protects urea for a limited time from volatilization so it can be incorporated or moved into the soil with adequate moisture. In dry and warm seeding conditions PCU and NBPT-urea can limit fertilizer damage to seedlings for a short time, until sufficient moisture disperses the urea. PCUs are not recommended as the sole fertilizer in unincorporated broadcast applications on small grains, as their N release may be too slow in our cool, dry climate, to produce an economic yield advantage over conventional fertilizers.

EEFs generally delay the release of nutrients, therefore the timing of their application is important. They must be applied sufficiently before peak crop demand. Blended formulations and improved technology should enable a closer match between fertilizer availability and crop uptake, to increase yield and protein benefits. The goal of the producer is to apply the right nutrient source at the right rate, time and place for their specific crop needs and production goals. It should be recognized that changing the nutrient source to an EEF may also necessitate a change in the rate, timing and placement for optimum response to the EEF. Producers should consult the product supplier for specific recommendations.

APPENDIX. A partial list of EEFs in our region that are known to and/or claimed to increase nutrient availability, their common names and the affected process. Portions of this table are adapted from other sources *(2)*.

Type and Chemical	Common name(s)	Affected Process
Stabilizers and Inhibitors		
2-chloro-6 (trichloromethyl) pyridine (Nitrapyrin)	N-Source®, N-Serve®, Instinct®	Nitrification
Dicyandiamide (DCD)		Nitrification
Ammonioum thiosulfate		Nitrification, Volatization
N-butyl-thiophosphoric triamide (NBPT)	Agrotain®	Volatilization
NBPT + DCD	Agrotain®Plus, SuperU®	Nitrification, Volatilization
Controlled- and Slow- Release		
Polymer-coated (PCU)	ESN®, Polyon®, Duration®	Release
Sulfur-coated	SCU	Release
Polymer + sulfur-coated	Tricote, Poly-S®	Release
Urea formaldehyde	Nitroform®	Release
Methylene urea	Nutralene®	Release
Methylene urea + triazone	Nitamin®, Nitamin Nfusion®	Release
Triazone	N-Sure®	Release
Other		
Malic+ itaconic acid co-polymer with MAP	Avail®	Decreases P mineral precipitation
Humic/fulvic acid with P	Carbond®P	Decreases P mineral precipitation
P blend with S	MicroEssentials 10, 15, SZ™	Decreases P mineral precipitation, slows S release

Manufacturers' claims have not all been substantiated by independent research. Mention or omission of a commercial company or trade name does not imply endorsement or censure by the authors or Montana State University.

References

1. Hall, W. 2005. *Benefits of enhanced-efficiency fertilizers for the environment*. In: IFA International Workshop on Enhanced-Efficiency Fertilizers. June 28-30. Frankfurt, Germany. 10 pp. http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Conference-proceedings/Agriculture-Conferences/2005-IFA-Agriculture-Workshop
2. Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson. 2005. *Soil Fertility and Fertilizers: An Introduction to Nutrient Management*. 7th ed. Prentice Hall, Inc., New Jersey, USA. 515 pp.
3. Rawluk, C.D.L. 2000. *Effect of soil texture, temperature and irrigation on the performance of urea fertilizers amended with the urease inhibitor N-(N-butyl) thiophosphoric triamide*. Thesis. University of Manitoba, Canada.
4. Watson, C. 2005. *Urease Inhibitors*. In: IFA International Workshop on Enhanced-Efficiency Fertilizers. June 28-30. Frankfurt, Germany. 8 pp. http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Conference-proceedings/Agriculture-Conferences/2005-IFA-Agriculture-Workshop
5. Engel, R. Associate Professor. Dept. Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana.
6. Grant, C.A. 2004. *Potential uses for Agrotain and polymer coated products*. In: Proceedings, Direct Seeding: The Key to Sustainable Management. Annual Meeting, Saskatchewan Soil Conservation Association. February 11-12. Regina, Saskatchewan. p. 76-86.
7. Carmona, G., C.B. Christianson and B.H. Byrnes. 1990. *Temperature and low concentration effects of the urease inhibitor N-(n-butyl) thiophosphoric triamide (nBTPT) on ammonia volatilization from urea*. Soil Biology and Biochemistry. 22:933-937.
8. Grant, C.A. and R. Dowbenko. 2008. *Enhanced Efficiency Fertilizers*. Reduced Tillage Linkages. http://www.reducedtillage.ca/docs/Enhanced_Efficency_Fertilizers.pdf. 22 pp.
9. Blaylock, A.D. and T.A.Tindall. 2006. *Advances in slow-release nitrogen fertilizers*. In: Proceedings, Great Plains Soil Fertility Conference. March 7-8. Denver, Colorado. p. 37-43.
10. Blaylock, A. Senior Agronomist. Agrium U.S., Inc. Denver, Colorado.
11. Golden, B. Senior Graduate Assistant. Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas.
12. Chen, C. Scientist. Associate Professor. Central Agricultural Research Center, Moccasin, Montana.
13. Heard, J. 2004. *Nutrient accumulation and partitioning by grain corn in Manitoba*. http://www.umanitoba.ca/afs/agronomists_conf/proceedings/2004/heard_nutrient_uptake_corn.pdf
14. Malhi, S.S., A.M. Johnston, J.J. Schoenau, Z.H. Wang and C.L. Vera. 2006. *Seasonal biomass accumulation and nutrient uptake of wheat, barley and oat on a Black Chernozem Soil in Saskatchewan*. Canadian Journal of Plant Science. 86:1005-1014.
15. Carter, J.N. and D.J. Traveller. 1981. *Effect of time and amount of nitrogen uptake on sugarbeet growth and yield.* Agronomy Journal. 73:665-671.
16. Koenig, R. Associate Professor. Dept. Crop and Soil Sciences, Washington State University, Pullman, Washington.
17. Tindall, T.A. and A. Blaylock. 2006. *Recent advances in P fertilizer technologies – polymer coatings*. In: Proceedings, Great Plains Soil Fertility Conference. March 7-8. Denver, Colorado. p. 31-36.
18. Broschat, T.K. and K.K. Moore. 2007. *Release rates of ammonium-nitrogen, nitrate-nitrogen, phosphorus, potassium, magnesium, iron and manganese from seven controlled-release fertilizers*. Communications in Soil Science and Plant Analysis. 38:843-850.
19. Brown, B. 2009. *Slow-release nitrogen in Pacific Northwest wheat production systems*. Crops and Soils. 42:27-28.
20. Ebelhar, S.A., C.D. Hart and J.D. Hernandez. 2005. *Nitrogen source and rate effects on corn in southern Illinois*. http://www.cropsci.illinois.edu/research/rdc/dixonsprings/pdfs/ESN%20Effects%20on%20Corn%20in%20Illinois%2005.pdf
21. Frye, W. 2005. *Nitrification inhibition for nitrogen efficiency and environment protection*. In: IFA International Workshop on Enhanced-Efficiency Fertilizers. June 28-30. Frankfurt, Germany. 8 pp. http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Conference-proceedings/Agriculture-Conferences/2005-IFA-Agriculture-Workshop
22. Tiessen, K.H.D., D.N. Flaten, C.A. Grant, R.E. Karamanos and M.H. Entz. 2005. *Efficiency of fall-banded urea for spring wheat production in Manitoba: Influence of application date, landscape position and fertilizer additives*. Canadian Journal of Soil Science. 85:649-666.
23. Brown, B. 2008. *Improved topdressed N?* The Cereal Sentinel. 49:10-12. www.ag.uidaho.edu/SWIdaho/Newsletters/Sentinel49.pdf
24. Brandt, S., D. Steinley, B. Nybo, K. Stonehouse and S. Chalmers. 2005. *Urea treatment affects safe rates of seed placed N*. In: Proceedings, Annual Meeting, Saskatchewan Soil Conservation Association. February 15-16. Saskatoon, Saskatchewan p. 134-143.

25. Malhi, S.S., E. Oliver, G. Mayerle, G. Kruger and K.S. Gill. 2003. *Improving effectiveness of seedrow-placed urea with urease inhibitor and polymer coating for durum wheat and canola*. Communications in Soil Science and Plant Analysis 34:1709-1727.

26. Grant, C.A. and L.D. Bailey. 1999. *Effect of seed-placed urea fertilizer and N-(n-butyl) thiophosphoric triamide (NBPT) on emergence and grain yield of barley*. Canadian Journal of Plant Science. 79:491-496.

27. McKenzie, R.H. and S. Brandt. 2006. *Environmentally smart nitrogen and the direct seeding advantage*. Reduced Tillage Linkages – Direct Seeding Advantage Conference. Nisku, Alberta, Canada.

28. Middleton, A.B., E. Bremer and R.H. McKenzie. 2004. *Winter wheat response to nitrogen fertilizer form and placement in southern Alberta*. Canadian Journal of Soil Science. 84:125-131.

29. Haderlein, L., T.L. Jensen, R.E. Dowbenko and A.D. Blaylock. 2001. *Controlled release urea as a nitrogen source for spring wheat in western Canada: yield, grain N content and N use efficiency.* In: Proceedings, Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection. 2nd International Nitrogen Conference on Science and Policy; The scientific World 1. October 14-18. Washington, D.C. p. 114-121.

30. Barker, B. 2008. *ESN fertilizer fits winter wheat in the fall.* Top Crop Manager. April-West edition. Vol. 34, No. 12, p. 82.

31. Killorn, R and J. Moore. 2006. *Comparison of ESN and urea as sources of fall- and spring-applied N fertilizer for corn production*. Iowa State University, Northern Research and Demonstration Farm. ISRF06-22. 2 pp.

32. Brown, B. 2008. *Slow release N for winter wheat*. The Cereal Sentinel. 49:8-10. www.ag.uidaho.edu/SWIdaho/Newsletters/Sentinel49.pdf

33. Shoji, S., J. Delgado, A. Mosier and Y. Miura. 2001. *Use of controlled release fertilizers and nitrification inhibitors to increase nitrogen use efficiency and to conserve air and water quality*. Communications in Soil Science and Plant Analysis. 32:1051-1070.

34. Cattanach, A., W.C. Dahnke and C. Fanning. 1992. *Fertilizing Sugarbeet*. North Dakota State University. SF-714. http://www.ag.ndsu.edu/pubs/plantsci/soilfert/sf714.pdf

35. Eckhoff J. and C. Flynn. 2007. *Fine-tuning applied nitrogen rates for sprinkler and flood irrigated sugar beet production*. Fertilizer Fact #43. Montana State University Extension, Bozeman, Montana. http://landresources.montana.edu/fertilizerfacts/pdf/FF43LGppQse_p`ccr.pdf

36. Norton, J. Assistant Professor. Department of Renewable Resources, University of Wyoming, Laramie, Wyoming.

37. LeMonte, J.L., T.W. Taysom, B.G. Hopkins, V.D. Jolley and B.L. Webb. 2009. *Residual soil nitrate and potato yield with polymer coated urea*. In: Proceedings, Western Nutrient Management Conference. Vol 8. March 4-5. Salt Lake City, Utah. p. 77-78.

38. Hopkins, B.G. Professor. Dept. Plant and Wildlife Sciences, Brigham Young University, Provo, Utah.

39. Zaman, M., M.L. Nguyen, J.D. Blennerhassett and B.F. Quinn. 2008. *Reducing NH_3, N_2O and NO_3-N losses from a pasture soil with urease or nitrification inhibitors and elemental S-amended nitrogenous fertilizers*. Biology and Fertility of Soils. 44:693-705.

40. Malhi, S.S., K. Heier, M. Zhang and M. Nyborg. 1998. *Meadow bromegrass response to coated and conventional urea fertilizers*. Canadian Journal of Plant Science. 78:589-595.

41. Brown, B. 2008. *Preplant slow release N for furrow irrigated hard spring wheat*. American Society of Agronomy - Crop Science Society of America - Soil Science Society of America. Poster No. 602-3. October 5-9. Houston, Texas.

42. Gordon, W.B. 2007. *Management of Enhanced Efficiency Fertilizers*. In: Proceedings, North Central Extension-Industry Soil Fertility Conference, Vol. 37. November 14-15. Des Moines, Iowa. p. 19-23.

43. Karamanos, R. Agronomy Manager. Viterra Inc. Calgary, Alberta, Canada.

44. Stark, J. Professor. Idaho Falls Research and Education Center, University of Idaho, Idaho Falls, Idaho.

45. Grant, C. and J. Relf-Eckstein. Brandon Research Centre, Agriculture and Agri-Food, Brandon, Manitoba, Canada.

46. Lukach, J. Superintendent. Langdon Research Extension Center, North Dakota State University, Langdon, North Dakota.

47. Jackson, G. and J. Miller. Professor and Research Associate. Western Triangle Agricultural Research Center, Conrad, Montana.

48. Carlson, G. and P. Lamb. Agronomist and Research Associate. Northern Agricultural Research Center, Havre, Montana.

49. Hopkins, B.G., C.J. Rosen, A.K. Shiffler and T.W. Taysom. 2008. *Enhanced efficiency fertilizers for improved nutrient management: potato (Solanum tuberosum)*. Crop Management. http://www.plantmanagementnetwork.org/pub/cm/symposium/enhanced/potato/

50. Tindall, T.A. 2007. *Recent advances in P fertilizer technologies – polymer coatings and Avail® technology.* In: Proceedings, Western Nutrient Management Conference. Vol 7. March 8-9. Salt Lake City, Utah. p. 106-110.

Acknowledgements

We would like to extend our utmost appreciation to the following volunteer reviewers of this document:

- Tom Allen, Liberty County Extension Agent, Chester, Montana
- Dr. Alan Blaylock, Senior Agronomist, Agrium U.S. Inc., Denver, Colorado
- Dr. Rick Engel, Associate Professor, Dept. Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana
- Dr. Cynthia Grant, Research Scientist, Agriculture and Agri-Food Canada, Brandon, Manitoba, Canada
- Dr. Grant Jackson, retired Professor of Agronomy, CPSS, CPAg, Montana State University Western Triangle Agricultural Research Center, Conrad, Montana
- Mike Lang, CCA, Northern Ag Service, Inc., Malta, Montana

Extension Materials

Crop and Fertilizer Management Practices to Minimize Nitrate Leaching (MT201103AG). Free.

Fertilizer Guidelines for Montana Crops (EB0161). Free.

Management of Urea Fertilizer to Minimize Volatilization (EB0173). Free.

Nutrient Uptake Timing by Crops: to assist with fertilizing decisions (EB0191). Free.

Nutrient Management Modules (#4449-1 to 4449-15). Free. http://landresources.montana.edu/nm

The publications listed above are available at http://landresources.montana.edu/soilfertility/publications.html and clicking on the title. Printed copies may be ordered through MSU Extension Publications at the following address. A shipping and handling fee will be charged for hard copies.

MSU Extension Publications
P.O. Box 172040
Bozeman, MT 59717-2040
(406) 994-3273
email: orderpubs@montana.edu
website: www.msuextension.org/store