California Regional Water Quality Control Board
Central Coast Region

895 Aerovista Place, Suite 101, San Luis Obispo, California 93401-7906
(805) 549-3147 • Fax (805) 543-0397
http://www.waterboards.ca.gov/centralcoast

Linda S. Adams.
Secretary for Environmental Protection

Arnold Schwarzenegger
Governor

Agricultural Order Renewal
Public Comments and Alternatives to
02/01/2010 Preliminary Draft Staff Recommendations

Group 10: Comment Letters

Comment ID	Individual Submitting	Affiliation	Date Received
T1	Tim Hartz	UC Davis Department of Environmental Toxicology	4/1/2010
T2	Keith M Backman	Dellavalle Laboratory, Inc.	4/1/2010
T3	Mary Bianchi	UC Cooperative Extension (Summary Comments)	4/1/2010
T4	Mary Bianchi	UC Cooperative Extension, San Luis Obispo County	4/1/2010
T5	Eric Ellison, Kerry Nichols	SGS Fertilizer Services	4/1/2010

To: Michael Thomas, Assistant Executive Officer
Central Coast Regional Water Quality Control Board

From: Tim Hartz, Department of Plant Sciences, University of California - Davis
Michael Cahn and Richard Smith, University of California Cooperative Extension, Monterey, Santa Cruz and San Benito Counties

Subject: Preliminary draft Agricultural Order

Thank you for the opportunity to meet with you and other members of the Regional Board staff in Salinas to discuss the technical aspects of the Draft Agricultural Order. To follow up on that discussion, the following points summarize our concerns regarding provisions in the draft order. We have limited our comments to those provisions dealing with our areas of experience, irrigation and nutrient management.

Overall evaluation:

We understand that serious water quality problems exist along the Central Coast, and that the Board has a statutory obligation to protect water quality. In fulfilling that obligation it is inevitable that some elements of the proposed waiver will impose burdens on irrigated agriculture. However, the complexity of the draft order as written would result in growers spending substantial time and money in activities that may not materially affect water quality. We believe that a significant streamlining of requirements is possible without weakening water quality protection.

Specific comments:

Page 23, section 114:

The requirements listed to qualify for 'low risk' status essentially excludes vegetable and strawberry growers; particularly problematic are the 1,000 foot setback from an impaired waterbody, and the prohibition of the use of some pesticides that are currently crucial for successful production. If those requirements were strategically modified so that progressive growers could qualify for at least a 'lower risk' status it would provide an incentive to adopt improved practices. For example, growers who demonstratively practice IPM, and who eliminate or contain runoff, could be candidates for some lower risk status, regardless of their proximity to an impaired waterbody, or their periodic use of pesticides listed in Attachment A.

Additionally, the requirement to have a Certified Crop Advisor or equivalent sign off on Nutrient Management Plans presents a problem in the short term because there are currently insufficient numbers of qualified people to perform this function for the large number of Farm Plans covered by these regulations. A phase-in period for this requirement would be needed.

Page 52, section 6:

The wording of this section seems to require that all discharges to groundwater meet all water quality standards. In the context of NO_3-N the implication is that the 10 PPM standard would apply to each and every discharge event (each irrigation or rainfall that resulted in leaching beyond the root zone, regardless of the volume leached). This is

not only an impossible standard to consistently meet in a row crop context, it also ignores the distinction between nitrate concentration and nitrate load. More efficient irrigation may increase nitrate concentration in leachate, but reduce the environmental nitrate load. Throughout the draft the emphasis on nitrate concentration, without reference to load, is problematic.

Pages 53-54, description of monitoring requirements:

As written it is unclear what individual growers will be required to do, and what monitoring can be done by the CMP or other groups. Individual discharge characterization monitoring and individual discharge monitoring appear particularly troublesome. Regarding surface water, we understand that these requirements only apply to operators with tailwater discharges. Since growers will be required to eliminate tailwater discharges within 2 years of the adoption of the order, there appears to be little value in spending time and money characterizing the water quality of such discharges.

Regarding discharges to groundwater, characterization monitoring for individual growers would be a complicated undertaking, and one in which the value of the data would be suspect. Some degree of discharge (leaching) is likely to take place in each field, with each irrigation. Beyond the technical issues involved in collecting a representative sample of the discharge and estimating the discharge volume, the fact that each discharge event represents a unique set of circumstances (soil nitrate concentration, irrigation volume and uniformity, soil conditions, plant rooting depth, etc.) means that leachate nitrate concentration will vary widely event to event.

Lastly, the requirement that all monitoring be done using EPA methods, and by parties who have filed a QAPP, effectively mandates that all monitoring be done by professionals. We suspect that the sheer volume of work required to conduct this monitoring on hundreds (perhaps thousands) of farm parcels would overwhelm the available technical service providers.

Pages 55, sections 26:

As previously stated, it will be impossible for vegetable and strawberry growers, even organic growers, to consistently meet the 10 PPM NO_3-N standard in leachate. Some leaching is inevitable; depending on the quality of the irrigation water, some leaching may be needed to manage salts, and even the most efficient irrigation system creates some percolation. The most that growers could accomplish would be to reduce the loading of nitrate to ground water by managing fertilizer and irrigation as efficiently as possible. Again, the key is load, not concentration.

Page 56, section 27:

The definition of 'excessive' fertilizer application is nebulous. There are no clear standards established for what would constitute excessive fertilization. Although we have collected data on nutrient uptake of some of the major vegetable crops, we have not done this for all important regional crops, including strawberries. Furthermore, given the dynamic nature of the crop rotations practiced, the differences in seasonality (spring vs.

summer crops), and the wide range of nitrate concentrations in irrigation water, crop nutrient requirements will vary substantially among fields and circumstances.

Page 57, section 32e:

To reiterate our concern, the current requirements essentially exclude all conventional vegetable and strawberry growers from obtaining 'low risk' status. Outlining an achievable path to that status would provide an incentive for improvement.

Pages 61-68, Part E:

The list of issues that a grower has to address in the Farm Plan is extensive with regard to irrigation and nutrient management. It is unclear what level of detail is expected, and whether the Farm Plan is intended primarily for planning or reporting purposes. As written it could be interpreted to require that irrigation and fertilization in each field be monitored, evaluated and recorded. Such detail would overwhelm farm management.

The issue of tile drain discharge (page 63, section 51) is particularly problematic. Tile drain discharge is essential to the productivity of the land drained; it is unavoidable that drain discharges will be high in salinity, and often in nitrate as well; such discharges will perpetually exceed water quality standards at the field or farm edge, and pollutant concentration (but not load) may actually increase as irrigation efficiency is improved. A regional approach to the remediation of tile drain discharges will be needed, and extensive monitoring of discharge from individual fields or farms may be of marginal value.

Page 69, section 76:

This section seems at cross purposes with the drive to eliminate tailwater discharge. Completely eliminating field runoff is impractical in many field situations. Sprinklers are the only suitable method to establish crops from seed in some soil types, and for some crops (baby greens, for example) drip irrigation is simply not a realistic option. Therefore, the use of on-farm tailwater containment ponds is likely to be an integral part of a grower's plan to eliminate tailwater discharge from the farm. However, by mandating that pond water consistently meet water quality standards (for nitrate, in particular), this section would seem to require such ponds to be lined to prohibit percolation of the contained water. Water quality monitoring has shown that surface tailwater nitrate concentration tends to be close to the nitrate concentration of the well water used for irrigation. Therefore, tailwater originating from well water currently above the nitrate standard would run afoul of this section, even though it represents the current quality of the underlying groundwater.

Comments regarding the Preliminary Draft of the Ag Order: Attachment 3

Page 12 Item 57
Correction: The drinking standard is 10 mg/L nitrate-N (or 45 mg/L nitrate).
A high percentage of the drinking and ag water wells in the State are greater than 1 mg/L of nitrate. Thus fresh water from most wells cannot ever be added to streams?

Also regarding Item 57
When the Water Board staff picked 1 mg/L, is it nitrate or nitrate-N? (Also stated on page43)
Plus **Page 41** of this document lists the surface water objective as 10 mg/L NO3-N Muni or >30mg/L NO3-N Agriculture.
[is greater than the appropriate symbol here or is something mismarked?]

My research of the CCAMP web site found their reference material to indicate "their action level" as 10 mg/L of nitrate.
Their data was found on the following web site:
http://montereybay.noaa.gov/monitoringnetwork/pdf/ss2000.pdf
The document on page 7 stipulates that at that time it was :
Clip:
The CCAMP "action levels" are intended to identify water quality conditions that warrant consideration of corrective measures, but do not necessarily imply violations of water quality regulations.

To examine the effect on trout I found the following web site:
https://www.was.org/WASMeetings/Meetings/ShowAbstract.aspx?Id=19866

A clip from this article:

The Conservation Funds Freshwater Institute
1098 Turner Road
Shepherdstown, WV 25443
j.davidson@freshwaterinstitute.org
Very little research has been conducted regarding the toxicity of nitrate-nitrogen to salmonids. The most relevant paper, Westin (1974), determined that the 96-hr and 7-day LC50s for rainbow trout fingerlings were 1,360 and 1,060 mg/L nitrate-nitrogen. These levels are relatively high and are typically not reached in

most aquaculture systems; therefore, aquaculturists generally ignore nitrate-nitrogen as a potentially toxic parameter. Despite the relatively high LC50 concentrations, Westin concluded that nitrate-nitrogen should be kept at 1/10th of the lethal concentration to avoid chronic toxicity and ensure an optimal culture environment. Thus, the maximum recommended concentration is actually much lower, i.e. approximately 100 mg/L.

Therefore, I assume the BIOSTIMULATION regulatory numbers are derived from data regarding research of plants within the aquatic system in an effort to impede plant growth in the habitats?
(Since on a normal basis plants consume CO2 & release O2, which could be valuable in the absence of river cascades, so a controlled amount of plant growth is beneficial. I did not find any plant scientist in the CCAMP that developed such Biostimulation research documentation). I would like to see more information to determine if this is a guess or science.

Page 25 Item 57

100 mg/L nitrate is just over 2 times the drinking water standard, not 10 times.

Page 34 Item 26

I followed the references to see if the Nitrate Hazard Index would be a valuable tool for the monitoring of crops and groundwater. It seemed very subjective with no particular techniques for field specialists to train to use. I was disappointed with their closing comment that I will clip and paste in the attached link:
http://www.lib.berkeley.edu/WRCA/WRC/pdfs/HINumberInterp.pdf
Clip:
The main message is that the hazard index number per se is of little value unless it is less than 20, which is an indicator that no special management is necessary. If the number is greater than 20, comparing a number of 40 to 60 is not useful. Identifying the factors that lead to the number is important because they identify the management factors, for that specific field, that would reduce the potential for N leaching. Management guidelines for specific hazard factors are presented in other parts of this report.

I am not sure it is a measurable science to be used for regulation.

Tables 1A & 1B
This is the table for **Surface Water Quality Objectives**.
Many of the numeric symbols are preceded by the ">" symbol. Using ammonia on page 40 as the example, is the intent to create surface water with levels greater than [">"] 30 mg/L? Should the author have used less than "<", or do I not understand these objectives as maximum contaminant levels? This situation arises many times in this chart, primarily in nutrients and salts. [I think the data may have been copied from a chart that

established maximums.]

Also in this table some categories have huge numerical ranges for their objective. For example Boron on page 49. Mean values of 0.1 to 2.8 Boron. In our lab we issue cautionary warnings when levels are high. The 0.1 is barely detectable and the 2.8 is high enough to be toxic to most plants. We should have numbers that mean something that can be used as monitoring evaluation points. This situation exists on many items on pages 47-49.

Page 53 Item 14

More description needed. Discharge Characterization Monitoring. As stated in the documents this also applies to normal irritations that could potentially make it to ground water. This could mean recording the amount of each irrigation in acre inches, fertilizer included, & source water or laboratory testing each irrigation for the same.

Page 57 Item F7

Will setback guidelines for groundwater wells be added? (as is done by RWQCB in the San Joaquin valley).

Page62 Item 47
Comment: DUs are very difficult to do on a furrow system. In fact it is still subject to arguments by researchers.

Page 62 Item
Will the Board specify how the farmer is to establish duration and frequency? (for example: third party monitoring, test book values, Evapotranspiration values from the radio, etc., etc. Most farmers will argue that their own duration and frequency is just perfect!)

Page 65 Item 60-g
Growers in the San Joaquin valley have argued in wording like this that the calculations from best guesses regarding leaching are OK, instead of actual testing to determine carryover N. The wording should include the requirement for soil test to x feet if that is the intention of the Board.

Keith M. Backman, CCA, CPH
Sr Consultant/ Consultant Manager
Dellavalle Laboratory, Inc.
Hanford, CA

Cell 559 647-5330

Summary of Comments from University of California Cooperative Extension Advisors and Specialists - Preliminary Draft Report Staff Recommendations for Agricultural Order February 1, 2010

Comments Received from
Dr. Jay Gan, Water Quality Specialist and Professor of Environmental Chemistry UC Riverside
Mary Bianchi, Horticulture Advisor San Luis Obispo County
Dr. Lisa Thompson, Specialist in Anadromous and Inland Fish, UC Davis
Dr. Royce Larsen, Area Natural Resource Watershed Advisor, San Luis Obispo County
Dr. Rob Atwill, Specialist Veterinary Medical Extension, UC Davis
Dr. Tim Hartz, Vegetable Crops Specialist, UC Davis
Michael Cahn, Irrigation and Water Resources Advisor, Monterey County
Richard Smith, Vegetable and Weed Science Advisor, Monterey County

Comments listed by Section, page number, item number and source
Submitted April 1, 2010

V. IMPACTS TO WATER QUALITY FROM AGRICULTURAL DISCHARGES

Page: 13

64 From Jay Gan UC Riverside
Need to be more specific; what species?

64 From Jay Gan
"Lethal" probably is not a good term to use.

64 From Jay Gan
The second half of the sentence is out of place and could be misleading. The high application rates are mainly due to the use of fumigants that are really not water quality risk pesticides. The use of Pyrethroids and OPs would be much lower.

65 from Mary Bianchi UC Cooperative Extension
Please provide citations, which will help readers identify location of work and authors.

#67 From Jay Gan
What species?

#67 from Mary Bianchi
Please provide citations, which will help readers identify location of work and authors.

Page: 14 and 15

#68 -From Jay Gan
“toxic” is too vague of a term; what does it really mean? I assume that there were mortality tests, if so, what species? What are the mortality ranges?

69 from Mary Bianchi
Please provide citations, which will help readers identify location of work and authors.

Page: 15

#77 from Mary Bianchi
Please provide citations, which will help readers identify location of work and authors.

Page: 16

#79 from Mary Bianchi
This paragraph starts with an important issue and ends with statements that indicate the authors do not have sufficient information to verify their conclusions. In these cases it is usually best to fall back on "If you can prove it you can say it".

80 from Mary Bianchi
Are these public supply wells or shallow domestic wells? What is the source of the information?

#81 from Mary Bianchi
Please provide citations, which will help readers identify location of work and authors.

Page: 17

83 from Mary Bianchi
Please provide citations, which will help readers identify location of work and authors.

84 from Mary Bianchi
Please provide citation.

84 from Mary Bianchi
Relationships between drinking water and diet are discussed in the literature. A more comprehensive understanding of the combined impacts could help to prioritize water quality activity within the region.

#85 from Mary Bianchi
Please provide citation. Please define "many". DPH surveys indicate 9% of public supply wells in survey concluding 2000 exceeded drinking water standard (see #78)..

85 from Mary Bianchi
Please identify the probability associated with "likely". Please advise as to those nitrate issues, for example Los Osos, where nitrate contamination of ground water are not associated with agricultural use.

87 from Mary Bianchi
Please provide citations, which will help readers identify location of work and authors.

#88 from Mary Bianchi

Perhaps this statement would be improved with a more exact reference to the number of systems affected.

Page: 18

89 from Mary Bianchi

Please define excessive

89 from Mary Bianchi

Please indicate how agricultural reuse of municipal waste water might be influenced by this order.

90 from Mary Bianchi

Please indicate the allocation of groundwater overdraft to agriculture versus municipal use.

#91 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

#92 from Mary Bianchi

Perhaps it would be valuable to discuss the point at which fertilizer applications transition to an accepted production practice to waste. No intention to be obnoxious -I think this would be a good discussion!

Page: 19

93 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

93 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

#96 from Lisa Thompson UC Davis

Definitions of warm/cold habitat. How and where were different streams designated as WARM or COLD? Attachment 3 references the Basin Plan, and I was able to find the definitions of habitat criteria for WARM and COLD habitat in Chapter 2 (Present and Potential Beneficial Uses)and Chapter 3 (Water Quality Objectives) and Table 3-5. However, I was unable to find a table or list of which streams or parts of streams have been designated as COLD or WARM, and whether a stream's designation changes seasonally.

Page: 21

#105 from Royce Larsen and Rob Atwill UC Cooperative Extension and UC Davis

The write up about the riparian areas functions and values in attachment 3 seem to be good. However, there are misinterpretations about wildlife and pathogens and whether riparian and wetland vegetation is a risk for food safety as found in paragraph 105, on page 21 of attachment 3.

First, we are unaware of scientifically peer-reviewed data indicating that the major sources of *E. coli* O157:H7 for the geographical region of concern are from domestic pigs and cattle, and not wildlife? Existing data sources we have disagree with this statement.

What is considered a domestic pig? The wild pig, which is a European wild boar / domestic feral pig hybrid, is designated as a game animal and is regulated under the Fish and Game Code which means wild feral pigs are wildlife.

There are minimal commercial pig operations upstream from irrigated agricultural fields. The 2008 Monterey County Crop report shows 1300 head of hogs in Monterey County. So if the domestic pig operations discussed in paragraph 105, are wild feral pigs then that is wildlife issue, not a commercial pig operation issue. Scientifically peer-reviewed data show that *E. coli* O157:H7 capable of causing human illness have been present in the feces of wild feral pigs, then that is a wildlife source. So the question of what data says they are not needs to be clarified.

The 2006 outbreak investigation focused on wild pigs (which are wildlife), cattle, and flowing water from the stream. The official 2007 CALFERT report found that the wild pigs, cattle and water from the stream all carried a strain of *E. coli* O157:H7 strain that matched the outbreak strain. In addition, wild pig tracks were found in the field. Wildlife (i.e. wild pigs) are not under the care of ranchers or farmers, and they cannot determine where these animals do, or do not go.

In paragraph 105, the statement that the 2006 report of the spinach outbreak "the bacteria was not determined to be from wildlife" is misleading. The report stated that no definitive determination could be made regarding how the spinach was contaminated and that included the wildlife (wild pigs), cattle and water from the nearby stream. The wild pigs, cattle and water all showed a similar strain of *E. coli* O157:H7 as the outbreak strain, so they could all have been the source, they just could not make the direct link of which caused the contamination.

Also, there are more pathogens than *E. coli* O157:H7 that are shed by domestic and wild animals that can contaminate leafy greens, including *Salmonella*, *Campylobacter*, and other Shiga toxin-producing *E. coli* such as *E. coli* O111 or *E. coli* O26. Studies do show that wildlife, including wild pigs, coyotes, deer mice, skunks, deer, elk, raccoons, rodents, birds, etc. along with domestic livestock, can carry one or more of these pathogens. There is incomplete data to show what risks these wildlife species may, or may not, have to food safety. More research is needed to determine what the risks are from wildlife, but wildlife

does have the potential to contaminate leafy greens given their proven access to produce fields via behaviors such as perching and foraging. Therefore, to say that the removal of riparian vegetation, buffers, etc. is unwarranted should not be made.

The paper by Lowell et. al. 2010. Safe and Sustainable: Co-Managing for Food Safety and the Ecological Health in California's Central Coast Region, has a good review about wildlife and pathogens. Also, there are new data from the Central Coast showing that wildlife is a potential threat to food safety. This concept of riparian and wetland vegetation needs a lot more discussion and research before concluding any results.

#105 from Lisa Thompson

What literature references were used to develop this section? The text states that certain management practices are "not supported by the literature", but no references are given.

Page: 22

#107 from Mary Bianchi

This is a simplistic discussion of the relationship between riparian vegetation and pest management. While research has shown that proximity to diverse flowering plant species has increased generalist predator numbers in vineyards, for instance, the effects are limited by the extent to which these insects will move into the cropped areas (Nicholls et al 2001). Additionally, economically significant diseases (e.g. Pierce's disease of grapes, almond leaf scorch transmitted by sharpshooters, squash mosaic virus transmitted by beetles, tobacco ringspot transmitted by nematodes, squash leaf curl transmitted by whiteflies, spotted wilt of tomatoes trans-mitted by thrips, and aster yellows of carrots transmitted by leafhoppers) may be vectored from riparian vegetation to crops by insects that harbor on riparian vegetation (Brown et al. 2002; Zhang et al 2007) Conservation biological control is an evolving science with much we still need to understand.

VI. AGRICULTURAL REGULATORY PROGRAM

#112 from Mary Bianchi

The Farm Plan in whatever format may best be used for planning and education purposes. A management practice checklist that provides specific management practice information might be more effective in evaluating compliance.

Page: 23

#114 from Tim Hartz, Michael Cahn and Richard Smith UC Davis and Cooperative Extension

The requirements listed to qualify for 'low risk' status essentially excludes vegetable and strawberry growers; particularly problematic are the 1,000 foot setback from an impaired waterbody, and the prohibition of the use of some pesticides that are currently crucial for successful production. If those requirements were strategically modified so that progressive growers could qualify for at least a 'lower risk' status it would provide an incentive to adopt improved practices. For example, growers who demonstratively

practice IPM, and who eliminate or contain runoff, could be candidates for some lower risk status, regardless of their proximity to an impaired waterbody, or their periodic use of pesticides listed in Attachment A. Additionally, the requirement to have a Certified Crop Advisor or equivalent sign off on Nutrient Management Plans presents a problem in the short term because there are currently insufficient numbers of qualified people to perform this function for the large number of Farm Plans covered by these regulations. A phase-in period for this requirement would be needed.

#114c from Mary Bianchi

Publication 8161 (cited in Attachment A as the resource for pesticides included in the table in #34 of Attachment A) indicates that several of the cited pesticides do not have a high potential to degrade or pollute surface water. Additional information is is available from ANR Publication 8403.

Page: 24

#117 from Mary Bianchi

The Farm Plan may best be used for planning and education purposes. A management practice checklist that provides specific management practice information might be more effective in evaluating compliance.

#120 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

Page: 25

#121 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

122 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

123 from Mary Bianchi

Please provide citations, which will help readers identify location of work and authors.

ATTACHMENT A. APPLICABLE WATER QUALITY CONTROL PLANS AND DEFINITIONS

Page: 31

#4 from Lisa Thompson

Definitions of warm/cold habitat. How and where were different streams designated as WARM or COLD? Attachment 3 references the Basin Plan, and I was able to find the definitions of habitat criteria for WARM and COLD habitat in Chapter 2 (Present and Potential Beneficial Uses)and Chapter 3 (Water Quality Objectives) and Table 3-5. However, I was unable to find a table or list of which streams or parts of streams have

been designated as COLD or WARM, and whether a stream's designation changes seasonally.

Page: 35

#34 From Jay Gan

This list is too comprehensive to be useful; Should check to see if most of these are even used in this region. I would suggest listing just those with acute toxicities.

#34 From Mary Bianchi

A review of publication 8161 would indicate that a table following the format of tables 6, 7, 8 from Publication 8161 provide more information. Publication 8403 would provide additional information.

Page: 37

#35 From Jay Gan

add leaching to

Page: 46

Temperature (BPGO, III-4) In Table from Lisa Thompson

How does the Ag order account for shifts in distribution of resident rainbow trout/juvenile steelhead in dry versus wet years, and between seasons in a given year? In the attached pdf file (Thompson Salinas trout distribution 31March2010 unpublished data) we show the changes in distribution of trout in the upper Salinas River basin between 2004 (a dry year), and 2005 and 2006 (wetter years). Trout were observed further downstream in the tributaries in the wetter years. However, even within 2005 trout distribution began to recede upstream by August as the summer season progressed. Obviously there is a need for mainstem baseflows and appropriate water temperatures for migration to and from the ocean, whereas at other times of year steelhead would not be using the mainstem for migration. There is also a need for clear passage for fish along the mainstem (during migration periods) and within the tributaries year-round. Fish may need to move upstream within the tributaries to seek colder water in mid-summer, but their movement may be blocked by poorly designed culverts or Arizona crossings. It is not clear what water temperatures would have existed in the lower reaches of the tributaries prior to the development of the past 100+ years; trout may have historically sought cooler, higher elevation habitat as refugia during hot weather and droughts

ATTACHMENT B TERMS AND CONDITIONS

Page: 52

#6 from Tim Hartz, Michael Cahn and Richard Smith

The wording of this section seems to require that all discharges to groundwater meet all water quality standards. In the context of NO3-N the implication is that the 10 PPM standard would apply to each and every discharge event (each irrigation or rainfall that

resulted in leaching beyond the root zone, regardless of the volume leached). This is not only an impossible standard to consistently meet in a row crop context, it also ignores the distinction between nitrate concentration and nitrate load. More efficient irrigation may increase nitrate concentration in leachate, but reduce the environmental nitrate load. Throughout the draft the emphasis on nitrate concentration, without reference to load, is problematic.

Page: 53

#14 from from Tim Hartz, Michael Cahn and Richard Smith

Pages 53-54, description of monitoring requirements:

As written it is unclear what individual growers will be required to do, and what monitoring can be done by the CMP or other groups. Individual discharge characterization monitoring and individual discharge monitoring appear particularly troublesome. Regarding surface water, we understand that these requirements only apply to operators with tailwater discharges. Since growers will be required to eliminate tailwater discharges within 2 years of the adoption of the order, there appears to be little value in spending time and money characterizing the water quality of such discharges. Regarding discharges to groundwater, characterization monitoring for individual growers would be a complicated undertaking, and one in which the value of the data would be suspect. Some degree of discharge (leaching) is likely to take place in each field, with each irrigation. Beyond the technical issues involved in collecting a representative sample of the discharge and estimating the discharge volume, the fact that each discharge event represents a unique set of circumstances (soil nitrate concentration, irrigation volume and uniformity, soil conditions, plant rooting depth, etc.) means that leachate nitrate concentration will vary widely event to event.

Lastly, the requirement that all monitoring be done using EPA methods, and by parties who have filed a QAPP, effectively mandates that all monitoring be done by professionals. We suspect that the sheer volume of work required to conduct this monitoring on hundreds (perhaps thousands) of farm parcels would overwhelm the available technical service providers.

Page: 55

#26 from from Tim Hartz, Michael Cahn and Richard Smith

As previously stated, it will be impossible for vegetable and strawberry growers, even organic growers, to consistently meet the 10 PPM NO3-N standard in leachate. Some leaching is inevitable; depending on the quality of the irrigation water, some leaching may be needed to manage salts, and even the most efficient irrigation system creates some percolation. The most that growers could accomplish would be to reduce the loading of nitrate to ground water by managing fertilizer and irrigation as efficiently as possible. Again, the key is load, not concentration.

Page: 56

#27 from from Tim Hartz, Michael Cahn and Richard Smith

The definition of 'excessive' fertilizer application is nebulous. There are no clear standards established for what would constitute excessive fertilization. Although we have collected data on nutrient uptake of some of the major vegetable crops, we have not done this for all important regional crops, including strawberries. Furthermore, given the dynamic nature of the crop rotations practiced, the differences in seasonality (spring vs. summer crops), and the wide range of nitrate concentrations in irrigation water, crop nutrient requirements will vary substantially among fields and circumstances.

Page: 59

#32e from from Tim Hartz, Michael Cahn and Richard Smith

To reiterate our concern, the current requirements essentially exclude all conventional vegetable and strawberry growers from obtaining 'low risk' status. Outlining an achievable path to that status would provide an incentive for improvement.

#32e from Mary Bianchi

Publication 8161 (cited in Attachment A as the resource for pesticides included in the table in #34 of Attachment A) indicates that several of the cited pesticides do not have a high potential to degrade or pollute surface water. Additional information is is available from ANR Publication 8403.

Page: 69

#35 from Lisa Thompson

How is control of water temperature to be addressed in Farm Water Quality Management Plans? It is not clear whether this would fall under Irrigation management, or perhaps Aquatic Habitat Protection. If a landowner with riparian property has no tailwater discharge entering the stream, and substantial overhead (tree) cover for shade, but water temperatures still exceed the limits defined on page 46-47, is he/she liable? The water entering the landowner's property from upstream may already be near the temperature limits. How will the heating of stream water as it flows downstream from property to property be addressed?

Page: 61

Part E. from Tim Hartz, Michael Cahn and Richard Smith

The list of issues that a grower has to address in the Farm Plan is extensive with regard to irrigation and nutrient management. It is unclear what level of detail is expected, and whether the Farm Plan is intended primarily for planning or reporting purposes. As written it could be interpreted to require that irrigation and fertilization in each field be monitored, evaluated and recorded. Such detail would overwhelm farm management. The issue of tile drain discharge (page 63, section 51) is particularly problematic. Tile drain discharge is essential to the productivity of the land drained; it is unavoidable that drain discharges will be high in salinity, and often in nitrate as well; such discharges will

perpetually exceed water quality standards at the field or farm edge, and pollutant concentration (but not load) may actually increase as irrigation efficiency is improved. A regional approach to the remediation of tile drain discharges will be needed, and extensive monitoring of discharge from individual fields or farms may be of marginal value.

Page: 63

#53 from Jay Gan –

Are there concentration-based standards for the different pesticides? If the standards are based on toxicity, what species? I doubt if there are limits for most pyrethroids, not to mention other pesticides. Also, toxicity to water column or benthic organisms? What organisms?

Page: 68

#70 from Jay Gan

I am not clear about what this means. This seems to be difficult to achieve technically.

Page: 69

#76 from from Tim Hartz, Michael Cahn and Richard Smith

This section seems at cross purposes with the drive to eliminate tailwater discharge. Completely eliminating field runoff is impractical in many field situations. Sprinklers are the only suitable method to establish crops from seed in some soil types, and for some crops (baby greens, for example) drip irrigation is simply not a realistic option. Therefore, the use of on-farm tailwater containment ponds is likely to be an integral part of a grower's plan to eliminate tailwater discharge from the farm. However, by mandating that pond water consistently meet water quality standards (for nitrate, in particular), this section would seem to require such ponds to be lined to prohibit percolation of the contained water. Water quality monitoring has shown that surface tailwater nitrate concentration tends to be close to the nitrate concentration of the well water used for irrigation. Therefore, tailwater originating from well water currently above the nitrate standard would run afoul of this section, even though it represents the current quality of the underlying groundwater.

UNIVERSITY *of* CALIFORNIA
Agriculture & Natural Resources

COOPERATIVE EXTENSION • SAN LUIS OBISPO COUNTY
2156 Sierra Way, Suite C • San Luis Obispo, CA 93401-4556
Telephone (805) 781-5940 Fax (805) 781-4316

April 1, 2010

To: Roger Briggs, Executive Officer Central Coast Regional Water Quality Control Board
Michael Thomas, Assistant Executive Officer

From: Mary Bianchi, Horticulture Advisor UC Cooperative Extension San Luis Obispo County

Re: Preliminary Draft Agricultural Order

The Preliminary Draft Report Staff Recommendations for Agricultural Order page 24 #117 proposes that "*The development and implementation of Farm Plans was a requirement of the 2004 Order. This Order extends and builds upon that requirement by requiring the submittal of the Farm Plan, upon notice by the Executive Officer, to verify the implementation of management practices focused on priority water quality issues, . .* ". This letter seeks to provide information regarding potential unintended consequences of this condition.

The University of California Farm Water Quality Planning Program was developed at the request of the agriculture industry, and pre-dated the 2004 Agricultural Order. It is based on the premise that education and information are crucial to changing attitudes and actions related to water quality. The UC Agriculture and Natural Resources Publication 8332 Farm Water Quality Plan (Farm Plan) was developed with co-authors from the USDA Natural Resources Conservation Service and the Central Coast Regional Water Quality Control Board. It is recognized as containing all required components of a water quality management plan, and is intended to support producer's collaborative work with Cooperative Extension, NRCS and other technical service providers in addressing on-farm water quality management.

The Farm Plan is a self-assessment tool, best delivered during Farm Water Quality Short Course programs. Cooperative Extension was the spokesperson for water quality planning collaboration throughout the 62 Short Courses held on the Central Coast from 2001 through 2007. In each of these courses, we introduced the Farm Plan to agriculture producers as a publication designed to guide them through development of a living water quality management plan for their operation. In more than 25 of these short courses I personally characterized the Farm Plan as a document that would support their efforts while remaining on their operation as part of their business plan. Farm Plans were further characterized as a useful tool to guide on-farm discussions with Regional Board staff should questions arise regarding water quality planning.

UC Cooperative Extension is dedicated to the creation, development and application of knowledge in agricultural, natural and human resources, including irrigation methods that use less water, practices to protect watersheds from pollutants from agriculture, and partnering with agricultural, environmental and government groups to address water issues. The content of our publications, including the Farm Plan, is educational and based on peer review of best available science rather than regulatory compliance. As lead author of the Farm Plan I have serious concerns about the repurposing of this publication from education to compliance and the potential unintended consequence of damage to the long history of trust developed between Cooperative Extension and irrigated agriculture producers. Requiring the submittal of Farm Plans is inconsistent with our characterization of the Farm Plan during the Short Course programs, has the potential to affect our ability to work with producers most in need of technical support for management practice implementation, and may give the impression that Cooperative Extension is acting as an agent of the Regional Board.

University research and education into new and more efficient methods and practices are only as effective as producers willingness to adopt them. Although the University of California is under no obligation to continue distribution of the Farm Plan, we feel that access to templates that are technically sound and science based and support financial success and environmental stewardship serves the best interests of agricultural producers and the public. We will continue to provide this free publication to producers and support their ongoing efforts to protect and improve water quality.

cc. Central Coast Regional Water Quality Control Board
Jeffrey Young, Chair
Russell Jeffries, Vice Chair
John Hayashi, Member
David Hodgin, Member
Monica Hunter, Member
Tom O'Malley, Member
Gary Shallcross, Member

Angela Schroeter
Howard Kolb

University of California
Jake McGuire, Controller & Business Services Director
Catherine Montano, Coordinator, Administrative Policies and Business Contracts
Robert Sams, Director, Communication Services and Information Technology
Brian Oatman, Environmental Health &Safety Manager
Anthony Garvin, Office of General Counsel

Daniel Mountjoy, Assistant State Conservationist for Field Operations, USDA - Natural Resources Conservation Service
Lisa Lurie, Agriculture Water Quality Coordinator, Monterey Bay National Marine Sanctuary
Johnny Gonzales, State Water Resources Control Board

Fertilizer Efficiency Technologies for Sustainable Agricultural Production: A Description of Products Offered by Simplot Grower Solutions in the Santa Maria Valley

Eric H. Ellison, Agronomy Manager, Simplot Grower Solutions, California
Submitted April 1, 2010

Growers of the Central Coast of California are facing a new Conditional Agricultural Waiver proposed by CCRWQCB that imposes new environmental regulations on agricultural waste water. This new Ag waiver is abrupt in defining limits on discharges and does not consider the progress made by growers over the past five years to improve water quality in response to the 2004 conditional Ag waiver. Part of this progress includes the adoption of fertilizer efficiency technologies that allow for reduced fertilizer inputs without a loss in productivity.

The J.R. Simplot Company or "Simplot" offers as part of their retail agribusiness or "Simplot Grower Solutions" product portfolio a variety of product technologies that are aimed at increasing fertilizer efficiency. Such technologies are important to the challenge of improving the quality of agricultural waste water because they offer potential for reducing fertilizer inputs without a loss in productivity. Efficiency technologies are also important to the future of Simplot agribusiness. As a leading fertilizer manufacturer, Simplot is challenged by energy costs and a limited supply of mineral reserves. Simplot has responded to this challenge by converting to industrial processes that are more energy efficient and by promoting efficiency technologies that allow for reduced fertilizer inputs by growers. The latter improves the sustainability of Simplot agribusiness by extending their supply of mineral resources used to make fertilizer.

Two nutrients at the focal point of issues concerning agricultural waste water quality are nitrogen and phosphorus. Of importance in this regard are efficiency technologies available for each of these nutrient fertilizers. The following describes several fertilizer efficiency technologies that are offered by Simplot Grower Solutions in California and provides examples of how they are utilized by growers in the Santa Maria Valley.

Efficiency technology overview

1) Phosphorus efficiency technologies
   a) Organic acid materials
2) Nitrogen efficiency technologies
   a) Controlled release nitrogen
   b) Nitrogen stabilizers
3) Other efficiency technologies
   a) Humic acids
   b) Micronutrient coatings for granular fertilizers
   c) Soil erosion polymers
4) Summary of technologies

1. Phosphorus efficiency technologies

Agricultural soils that are above environmental thresholds for soil test phosphorus pose a threat to surface water quality when they are transported to lakes or streams as suspended sediment in agricultural waste water or storm water runoff. There are two approaches to managing this problem. One approach is to lower the level of soil test phosphorus in affected soils by reducing or nulling the amount of fertilizer phosphorus applied. Through this approach, phosphorus removed in the harvested portion of the crop will eventually lower the amount of phosphorus in the soil to levels below environmental thresholds as long as the amount removed is greater than the amount of fertilizer phosphorus applied. Another management approach is to reduce the transport of affected soils as suspended sediment either by collecting waste water in sedimentation ponds or riparian zones, or by controlling soil erosion and tailwater runoff in grower fields. The following describes chemical technologies offered by Simplot that are aimed at increasing the efficiency of phosphate fertilizers applied to agricultural soils.

1a. Organic acid materials. Commercially available organic acid materials that are utilized as fertilizer additives have been documented to increase the efficiency of phosphate fertilizers. These materials include 1) solutions of humic acids derived from Leonardite, which is a naturally-occurring product found in coal deposits; and 2) solutions of organic acid polymers of synthetic origin. Organic acid materials increase phosphate fertilizer efficiency by coating the surface of phosphate minerals and subsequently inhibiting phosphate "tie-up" or the formation of insoluble phosphate precipitates. In soil types that are conducive to the formation of these precipitates, organic acid materials added directly to the fertilizer can prevent tie-up and keep fertilizer phosphate in a form more available to the crop over the growing season. These materials are particularly effective in alkaline, calcareous soils that are conducive to the formation of highly insoluble calcium phosphate minerals such as hydroxyapatite. The appended document entitled "Phosphorus Dynamics in Organic Matter-Amended Soils" provides a good review of the chemistry of phosphorus – organic matter interactions that affect phosphorus availability in soils. It provides the necessary background for understanding the efficacy of commercially available phosphate efficiency products that are based on organic acids.

The objective in applying organic acid-based materials with phosphate fertilizers is to apply a smaller amount of fertilizer while achieving similar or enhanced productivity. In essence these materials are used to prevent phosphate tie up and maintain a higher concentration of dissolved or plant-available phosphorus in the soil relative to that obtained by applying fertilizer alone. This is accomplished by applying the fertilizer and organic acid material together in a small volume of soil. Such is the case for banded applications of fertilizer. Use of these materials is cost prohibitive for treating large volumes of soil.

One approach that Simplot is using to reduce the amount fertilizer phosphorus applied to crops in the Santa Maria Valley is to treat all granular phosphate fertilizer materials with a relatively new efficiency product called Avail. Avail is a low molecular weight, highly water soluble copolymer of maleic acid and itaconic acid both of which are dicarboxylic acids. As formulated, a highly concentrated aqueous solution of Avail is spray-coated onto the surface of

granular fertilizer materials such as monoammonium phosphate (MAP or 11-52-0). In Santa Maria, Avail-treated MAP is typically added to fertilizer blends and applied pre-plant to vegatable crops or strawberries by listing the fertilizer blends into beds. By using Avail, growers can reduce the amount of fertilizer phosphate they apply without a tradeoff in yield. For example, before Avail emerged as an efficiency product, growers who applied N-P-K blends such 15-15-15 or 17-17-17 at 400-500 lb/ac are now applying similar amounts of 15-12-15 or 17-13-17 without any tradeoff in yield. Growers have also observed increases in crop quality due to Avail. The use of Avail has resulted in a 20-25 percent reduction in the amount of phosphate fertilizer applied.

By coating granular fertilizers with Avail, the Avail polymer is placed directly with the fertilizer. Since phosphorus and the polymer are both essentially immobile in soils, the polymer works in a small volume or in the vicinity of the fertilizer granule as needed to be effective. The advantage of Avail over other organic acid materials such as humic acid is that it can be spray-coated onto granular fertilizers in high enough concentrations to be effective and without changing the physical properties of the granule. No other phosphate efficiency product offers such flexibility to treat granular fertilizer. Avail has also been formulated for liquid fertilizers typically utilized in starter applications.

Avail works as a crystallization inhibitor, similar to the mode of action of humic substances which inhibit the formation of insoluble phosphate precipitates. However, Avail is more specific in its mode of action. Humic substances carry excess "baggage" or molecular moieties that do not contribute in any way to their mode of action. The Avail polymer contains only carboxylic acids which function specifically to sequester metal cations, such as calcium, and as contact points for specific adsorption to crystal faces.

Avail efficacy and performance have been demonstrated in hundreds of field trials carried out across the United States and globally. These studies are ongoing. Earlier studies on Avail are summarized in the appended article entitled "Improving N and P Use Efficiency With Polymer Technology" which includes a description of field trial results on wheat, corn, grasses, potatoes, and soybeans. Of more regional interest, a field trial conducted in 2009 on bell peppers in the Oxnard area showed increased fertilizer efficiency due to Avail usage with liquid ammonium polyphosphate (APP or 10-34-0). The results of this trial are shown in the table at left and demonstrate two common observations in using Avail. The first is that lowering the amount of phosphorus applied by twenty percent relative to the grower standard practice (compare treatments 3 and 1), resulted

Bell Pepper Replicated Trial Location: Oxnard, CA Conducted by Dave Holden Consulting Soil Test P (Olsen) = 102 ppm	
Treatment	**Yield (tons/ac)**
1. 10-34-0, 25 gal/ac = GSP	20.6
2. Avail SD + GSP **(+$23.25/ac)**	22.3
3. Avail SD + 10-34-0, 20 gal/ac **(+$6.1/ac)**	20.4
LSD (0.10) = 1.7 tons/ac; CV=5.9% Δ(2 - 1) = 1.7 tons/ac Benefit : Cost = 19:1 Treatment 2 gained $419.00/ac with peppers @ $260/ton	

in no tradeoff in yield. The second observation is that inclusion of Avail in the grower standard practice increased yield and produced a significant return on investment (compare treatments 2 and 1). As more information becomes available about how to use Avail, fertilizer inputs can hopefully be decreased by more than 20-25 percent, thus contributing even further to a decline in soil test phosphorus in problem fields.

2. Nitrogen efficiency technologies

Nitrate nitrogen is a threat to both surface and ground water quality, causing concerns about human health and the vitality of aquatic life and ecosystems. While there is ample evidence that nitrate in agricultural waste water originates at least in part from the use of nitrogen fertilizers, there is much less evidence that nitrogen fertilizers are a significant source of nitrate contamination in groundwater. The dynamics of nitrate movement in groundwater is not well understood. The nitrate anion (NO_3^-) is very stable in water and can be laterally transported long distances as a solute in groundwater. More studies are needed to properly identify the sources of nitrate contamination in groundwater below grower fields, and whether it orginates from, for example, dairy manure that was applied 50 years ago and 5 miles away, or from present-day agricultural operations. Present-day growers cannot, ad hoc, be held responsible for nitrate levels in groundwater under the land they are farming without further and more detailed studies on the potential sources of nitrate contamination.

Growers have responded to increased global demands for food by planting cultivars having higher yield potentials. In response to the higher nutrient demands of these new cultivars, there has been a natural increase in the amount of fertilizer nutrients applied. In turn, this has led to increased losses of fertilizer nitrogen and other nutrients to the environment. While growers strive for efficiency in using nitrogen fertilizers, there are many unknowns about the amount and type of fertilizer to apply, and when and where to apply the fertilizer. Resolution of these unknowns as well as practical and economically viable solutions to the problem of nitrogen fertilizer efficiency are needed and must be arrived at scientifically through the development and testing of new technologies and practices. The ultimate goal is to match the amount of fertilizer applied exactly with the demands of the crop. While this goal is impossible to achieve in practice, a variety of technologies and approaches are being developed and explored to address the problem of nitrogen fertilizer efficiency. The burden of this problem cannot be saddled on growers alone and will require more time and a more concerted effort to overcome.

The objective in using nitrogen fertilizer efficiency technologies is to prevent fertilizer nitrogen in the form of urea or ammonium ion (NH_4^+) from quickly converting to nitrate via enzymatic or microbial processes. There are two basic approaches used to achieving this objective. One approach involves the use of chemical processing to produce new materials referred to as controlled release nitrogen (CRN). A second approach involves adding a material to conventional nitrogen fertilizers that works to keep nitrogen in urea or ammoniacal form. These materials are referred to as nitrogen stabilizers. An excellent description of CRN and nitrogen stabilizers is provided in the attached document entitled “Enhanced Efficiency Fertilizers.”

2a. Controlled release nitrogen. For strawberry production in the Santa Maria Valley, Simplot uses a CRN product referred to as Polyon which is a polymer-coated urea-based fertilizer. The polymer coating provides a diffusive barrier to the release of urea-nitrogen to the soil. Polyon is typically applied pre-plant in strawberry beds in the Fall and is used as a tool to keep urea in the rootzone through the Winter or rainy seasons until Spring. As soil temperatures rise and plant growth is stimulated in the Spring, fertilizer nitrogen is released to the plant. The higher the temperature, the higher the rate of diffusion through the polymer coating and the more nitrogen is released per unit time. The use of Polyon has resulted in marked improvements in nitrogen use efficiency and crop production over conventional fertilizers and other CRN such as sulfur coated urea. High value crops such as strawberries can support the cost of the Polyon technology.

Other CRN products offered by Simplot that may be cost-effective for row and vegetable crops include N Sure and Greenfeed. Both products are concentrated nitrogen solutions. N Sure is a mixture of urea triazone, urea, and water. Greenfeed is a mixture of methylene urea, urea and water. Free urea is included in both products to provide a more immediate source of nitrogen to growing crops and comprises 25 percent of the total nitrogen of each product. In the soil, both urea triazone and methylene urea break down slowly by hydrolysis to release urea. As the temperature increases, the rate of hydrolysis also increases and more nitrogen becomes available to the crop. Both materials can also be applied foliarly. For foliar applications, a larger amount of nitrogen can be safely applied relative to free urea because of the slow-release nature of the reacted components. Unfortunately, there are few studies documenting the performance of these materials on vegetable and row crops. More work is needed to evaluate their cost-to-benefit ratio relative to conventional nitrogen fertilizers, as well as any differences between urea triazone and methylene urea as sources of CRN.

2b. Nitrogen stabilizers. Nitrogen stabilizers can be conveniently added to conventional fertilizers such as UAN 32 and urea. Products of synthetic origin that are offered by Simplot include Agrotain, Agrotain Plus, and Nutrisphere N which is registered in all states except California. The attached document entitled “Nitrogen Management of No-till Corn and Grain Sorghum Production” compares the yield performance of Nutrisphere N against other nitrogen stabilizers and demonstrates very positive results. Another attached report entitled “2009 Greenhouse Gas Emissions With Different N Sources” demonstrates efficacy of Nutrisphere N in lowering N_2O emissions similar to other nitrogen efficiency materials including Super U and ESN. Hopefully, Nutrisphere N will clear California registration hurdles soon so that it can be tested and understood without the restriction of a crop destruct order.

Nitrogen stabilizers are presently used only sparingly but offer potential for reducing in-season nitrogen applications. More studies are needed to evaluate their effectiveness for reducing nitrogen fertilizer applications on vegetable crops.

3. Other efficiency technologies

3a. Humic acids. Humic acids derived from Leonardite are utilized on many crops including strawberries and vegetables. A variety of humic acid-based products are available that vary in the geographical source of the Leonardite used and how the Leonardite is processed to produce a finished product. Depending on how they are processed, products can differ in the amount of humic acid, fulvic acid, and humin they contain, but there is no clear understanding of how these differences affect performance. As fertilizer efficiency materials, humic acids are applied either as liquid suspensions in drip, preplant, or sidedress fertilizer applications, or as granular solids in granular fertilizer applications. An excellent description of humic acid materials is given in the attached document entitled "Humic Acid Materials for Agriculture."

One common application of humic acid suspensions is in drip irrigation. When combined with liquid ammonium polyphosphate (10-34-0), humic acids provide a means to apply 10-34-0 through drip lines by inhibiting precipitation reactions of orthophosphate with calcium or magnesium. The success of this application in inhibiting precipitation reactions over applications of 10-34-0 alone implies that humic acids offer potential to prevent precipitation reactions or phosphate tie-up in soils. Humic acids are commonly advertised as phosphate efficiency materials and are routinely utilized to reduce the amount of fertilizer phosphate applied to crops.

The efficacy of humic acids as a nitrogen stabilizer is not well understood. Some have suggested that nitrate ion is selectively held by humic acids, presumably by positively charged sites that are not typically found in high concentration on soil colloids or soil organic matter. Such an association could prevent nitrate leaching. However, selectivity of humic acids for nitrate ion over other anions in the soil has not been conclusively demonstrated and based on chemical principles is not expected. Other suggested modes of action include inhibition of the urease enzyme wherein the conversion of urea to ammonium ion is inhibitied, and inhibition of nitrification wherein the bacterial conversion of ammonium to nitrate is inhibited. None of these modes of action have been clearly demonstrated for humic acids despite their use as nitrogen fertilizer additives. More studies are needed to resolve whether humic acids offer any benefits as nitrogen stabilizers.

There is much controversy and misunderstanding about the efficacy and mode of action of humic acids as fertilizer efficiency materials. While these products may increase yield in certain applications, the cause of the yield increase may not be clear. For example, humic acid products have been demonstrated to increase soil biological activity, buffer the effects of rootzone salinity, improve rootzone soil structure, and improve the availability of micronutrients. All of these factors can contribute to an increase in yield, but may not directly affect fertilizer efficiency.

Although the complex chemistry of humic acid materials makes their mode of action difficult to ascertain, these materials cannot be dismissed as fertilizer additives or as fertilizer efficiency materials. Conversely, humic acid materials do not offer value in all applications. Their efficacy must be confirmed for all applications and soil types.

3b. Micronutrient coatings for granular fertilizer. Granular fertilizer blends applied to soils sometimes include micronutrients in the form of zinc, iron, copper, or manganese sulfate. As

the amount of micronutrients applied is typically low, there is always concern about the degree of dispersion of the applied micronutrient granules in the rootzone. As a possible solution to this problem, Simplot has adopted a new technology for coating granular N-P-K fertilizers with micronutrients in oxide and sulfate form. These materials are formulated as dry, dispersible powders that include special materials to aide in the attachment of the powder to granular N-P-K fertilizers. By attaching the micronutrient powder to N-P-K granules, dispersion of the micronutrient in the soil is increased which helps to make the fertilizer more available to plant roots. By using this approach, the amount of material needed to raise the level of micronutrients in plant tissue is much lower compared to granular sulfates. The primary advantage of the coating technology is more efficient use of applied micronutrients and potential for lower levels of micronutrients in runoff.

3b. Soil erosion polymers. Simplot offers advanced formulations of polyacrylamide-acrylate copolymers for soil erosion control. These materials are utilized to increase flocculation of suspended sediment in agricultural waste water and to improve surface soil structure. When used correctly, these materials can increase the rate of infiltration of irrigation and rain water, reduce tailwater runoff, and significantly reduce suspended sediment in tailwater runoff. All of these factors contribute to reducing the negative environmental impacts of agriculture.

4. Summary of efficiency technologies

The tables below summarize the fertilizer efficiencies discussed above. While technologies such as Polyon are well established, others are only beginning to be understood, tested, and utilized. As newer technologies and practices become established, growers will have more tools available to them to maintain production and at the same time meet standards for agricultural waste water discharge. More research and testing is needed to further evaluate the viability of fertilizer efficiency technologies for improving water quality.

Summary of fertilizer efficiency technologies utilized by Simplot Grower Solutions in California. Table 1. Efficiency Fertilizers. Table 2. Fertilizer Additives.

Table 1. Efficiency Fertilizers

Product	**Supplier**	**Formulation**
Polyon	J.R. Simplot	Polymer-coated urea
Greenfeed	Caltech	Concentrated solution of urea and methylene urea, 27% N
N sure	Tessenderlo Kerley	Concentrated solution of urea and urea triazone, 28% N
DDP Micronutrients	Wolftrax	Finely-divided powders for coating granular solids

Table 2. Fertilizer Additives

Product	Supplier	Formulation	Fertilizers Treated	Application
Avail, Avail SD	Specialty Fertilizer Products	Concentrated maleic acid – itaconic acid co-polymer solution	Liquid or solid (granular) phosphate	Spray coating on granular fertilizers; Additive to liquid fertilizers
Golden Bio	Plant Health Technologies	Concentrated fulvic acid solution derived from Leonardite	Liquids	Additive to liquid fertilizers
BA Humus	Plant Health Technologies	Concentrated humic acid solution derived from Leonardite	Liquids	Additive to liquid fertilizers
BA Humus DC	Plant Health Technologies	Granular humic acid derived from Leonardite	Solids (granular)	Additive to granular fertilizers
Nutrisphere N (not registered in California)	Specialty Fertilizer Products	Concentrated maleic acid – itaconic acid co-polymer solution	Liquid or solid (granular) urea or ammoniacal	Spray coating on granular fertilizers; Additive to liquid fertilizers
Agrotain	Agrotain Int'l	Concentrated solution of NBPT	Liquid or solid (granular) urea	Spray coating on granular urea; Additive to liquid fertilizers
Agrotain Plus	Agrotain Int'l	Powdered mixture of NBPT and DCD	Liquid urea or ammoniacal fertilizer	Additive to liquid fertilizers

PHOSPHORUS DYNAMICS IN ORGANIC MATTER-AMENDED SOILS

Paul Grossl[1], Steven Trolove[2], Rich Koenig[3], and Clain Jones[4]
[1]Associate Professor of Biogeochemistry, Dept. of Plants, Soils, and Climate,
Utah State University, Logan, UT;
[2]Research Scientist, New Zealand Institute of Plant & Food Research,
Havelock North, NZ;
[3]Chair and Extension Soil Specialist, Dept. of Crop and Soil Sciences,
Washington State University, Pullman, WA;
[4]Soil Fertility Specialist, Dept. of Land Resources and Environmental Sciences,
Montana State University, Bozeman, MT

ABSTRACT

Generally, phosphorus (P) is considered immobile in calcareous soils. Yet, numerous studies have found that the addition of organic wastes (e.g. manures) can enhance P mobility in these soils. We believe that the soluble organic matter present in these wastes increases P solubility by inhibiting the sorption of inorganic P on soil colloidal surfaces and subsequently preventing the formation of insoluble calcium phosphates. This results in increased P bioavailability. Likewise, tests used to assess phosphorus (P) status in manure amended calcareous soils may inaccurately estimate the amount of potentially mobile P due to the influence of soluble organic matter. This can lead to incorrect applications of manure – possibly an increase in mobile P – which potentially threatens the quality of receiving waters. We examined P dynamics in calcareous systems in order to understand and determine which test most accurately predicts the fate of P in these environments. This study included batch and kinetic experiments using mineral phases found in calcareous soils such as calcite, brushite, and the iron oxide ferrihydrite. Humic acid obtained from the International Humic Substances Society was used as an analogue for manure. Our hypothesis was that the soluble organic matter from the manure inhibits the sorption of P and possibly affects the extractability of P by commonly used soil tests such as the Olsen bicarbonate extract or a calcium chloride extract. Sorption kinetics may be responsible for differences observed between the extractants (water, $CaCl_2$, and $NaHCO_3$) and solid phases responsible for regulating soluble P levels in soils. By fully understanding P dynamics in organic matter-amended soils the proper tests can be chosen that accurately assess P status and ultimately lead to sustainable waste management.

INTRODUCTION

Agricultural runoff has been implicated in accelerated eutrophication of surface waters in developed farmland areas (Sharpley and Menzel, 1987). This is particularly the case where P has accumulated in surface soils due to high inputs of fertilizer, municipal biosolids, or manure and is compounded by situations facilitating erosion, whereby bioavailable P enters a surface water body. Ultimately, phosphate sorption/desorption on soil surfaces is the factor controlling soluble phosphate levels in natural waters. Sorption reactions include precipitation of metal phosphates and adsorption-desorption processes occurring at aqueous/solid interfaces. Mineralization of organic P forms also provides a source of P; however, phosphate bioavailability is still controlled

by sorption/desorption processes on soil surfaces. In calcareous systems, with pH values ranging from near neutral and above, dicalcium phosphate dihydrate (DCPD), octacalcium phosphate (OCP), and hydroxyapatite (HAP) are major P solid phases (Lindsay, 1979). DCPD and OCP are important reaction products of P fertilizers in soil and are precursors to the formation of thermodynamically more stable HAP (Lindsay, 1979; Stumm and Morgan, 1981; Fixen et al., 1983; O'Connor et al., 1986; Amacher et al., 1995).

The presence of soluble organic matter is ubiquitous in natural systems. It is widely documented that soluble organic constituents enhance phosphate solubility and mobility (Traina et al., 1986; Inskeep and Silvertooth, 1988; Grossl and Inskeep, 1991, 1992). Recent studies indicate that organic matter, associated with animal waste applications, enhances the solubility of phosphate in soils (O'Connor et al., 1986; Harris et al., 1994; James et al., 1996; Erich et al., 2002; Maughn, 2002; Siddique and Robinson, 2003). Common organic acids have been shown to inhibit the precipitation of calcium phosphate minerals (Inskeep and Silvertooth, 1988, Grossl and Inskeep, 1991, 1992). The proposed mechanism of inhibition is the adsorption of organic acids onto crystal surfaces, which block sites acting as nuclei for new crystal growth. Others report that organic ligands compete with phosphate for sorption sites on oxide and clay surfaces (Nagarajah et al., 1970; Lopez- Hernandez et al., 1986; Violante et al., 1991; Violante and Gianfreda, 1993). Commercial humic acid products are currently available and marketed to increase available soil P. Yet, Jones et al. (2007) report that the recommended rates of application of these humic acid products may be too low to enhance spring wheat growth or available P levels.

We surmise that when manure is applied to calcareous soils, soluble organic matter prevents precipitation of insoluble Ca phosphates, and phosphate activity in these soils is controlled by rapid adsorption/desorption on colloid surfaces and formation of more soluble Ca phosphates, metastable to HAP. This results in enhanced phosphate bioavailability. Calcium phosphate precipitation can be conceptually explained using principles of chemical kinetics and reaction pathways (Grossl and Inskeep, 1992). Starting with a solution supersaturated with respect to DCPD, OCP, and HAP, precipitation can proceed either through a parallel or series reaction pathway. In either case, DCPD would precipitate first and since the formation of OCP and HAP are inhibited to a greater extent by DOC, present at levels realistic for many soil environments, DCPD would remain as a metastable solid phase controlling the activity of phosphate in soil solutions and prolonging the bioavailability and mobility of P in pastures.

Tests used to assess phosphorus (P) status in manure-amended calcareous soils are often inaccurate and underestimate the amount of potentially mobile P. This could lead to over applications of manure and an increase in mobile P which potentially threatens the quality of receiving waters. The "*Change-Point*" determined with a 0.01M $CaCl_2$ extract could be a useful indicator of the soil Olsen P-test concentration where P becomes mobile – this occurs at an Olsen P test value of approximately 60 ppm (Hesketh and Brookes, 2000). This *change point* was also observed for a calcareous Millville silt loam fertilized with increasing rates of inorganic P, however, not when this soil was fertilized with poultry manure.

The **objective** of this study was to measure the sorption behavior of P on different soil constituents with and without exposure to soluble organic matter. We hypothesize that soluble organic matter from manure inhibits the sorption of P and consequently influences soil test P levels.

MATERIAL AND METHODS

Supersaturated solutions of phosphate and Ca^{2+} were equilibrated with the soil solid combinations listed in Table 1. Soil solids included the iron oxide ferrihydrite (F); $CaCO_3$ or calcite (C), and dicalcium phosphate dihydrate (DCPD, also coded as P in Table 1) known as brushite. Combinations of these were added to a quartzite sand base resulting in 9 g total of solid material. The ferrihydrite was prepared as described by Amacher (2001), and reagent grade $CaCO_3$ and brushite were used. Experiments were conducted by adding 290 mL of 10.3mM $CaCl_2$ solution (pH 7.5) into containers to which no humic acid would be added, and 270 mL of 11.1mM $CaCl_2$ solution was added to containers to which 20 mL of 75mM C humic acid solution (pH 7.5) was added. This gave a final humic acid (Leonardite, Humic Acid Society Standard) concentration of 5mM C. To each container, 10 mL of 3,000 µg P mL^{-1} (as Na-phosphate) solution was added, followed immediately by the pre-weighed solid materials for that treatment and the time recorded. This process was repeated for each container. The pH was adjusted to pH 7.5 if necessary with 0.5M NaOH or HCl, and then each container was sampled at 5 minutes after the addition of solids. The pH was again adjusted after 5 minutes, 2.5 hours, 6 hours and then daily thereafter. Containers were sampled at 5, 20 and 60 minutes, and 0.5, 1, 3, 7, 14, 21 and 28 d after P and solid addition.

Table 1. Weight (grams) of the soil constituents in each treatment.

Trt. name	Sand	Ferrihydrite	$CaCO_3$	DCPD	Humic acid
F	8.1	0.9	–	–	–
F+C	6.3	0.9	1.8	–	–
F+C+P	5.4	0.9	1.8	0.9	–
F+P	7.2	0.9	–	0.9	–
C	7.2	–	1.8	–	–
C+P	6.3	–	1.8	0.9	–
P	8.1	–	–	0.9	–
Sand	9	–	–	–	–
F	8.1	0.9	–	–	5mM C
F+C	6.3	0.9	1.8	–	5mM C
F+C+P	5.4	0.9	1.8	0.9	5mM C
F+P	7.2	0.9	–	0.9	5mM C
C	7.2	–	1.8	–	5mM C
C+P	6.3	–	1.8	0.9	5mM C
P	8.1	–	–	0.9	5mM C
Sand	9	–	–	–	5mM C

At sampling, 15 mL of solution was removed from each container and filtered through a 45µm nitrocellulose filter. Solutions were stored in a refrigerator before being colormetrically analyzed for P (Murphy and Riley, 1962). At the end of the experiment, treatment samples were centrifuged at 3,500 rpm for 10 min then filtered through a 45µm nylon membrane. The filtrate was analyzed for P and the remaining solids (on the filter paper, in the bottom of the centrifuge

tube, and left in the beaker) were dried at 30ºC overnight. The solids were scraped off the centrifuge tubes, filter paper and beaker from each replicate of each treatment and were recombined and thoroughly mixed. A subsample of air-dried solid material (750 g) was then extracted with 15mL of $NaHCO_3$ at pH 8.5 for 20 min (Olsen et al. 1954) then centrifuged at 3,500 rpm and filtered (Whatman No. 42). A further 2 g sample was extracted with 10 mL of 0.01 M $CaCl_2$ for 15 minutes, then centrifuged and filtered. The Olsen, $CaCl_2$ and solution extracts were then analyzed for P using the colorimetric method of Murphy and Riley (1962).

RESULTS AND DISCUSSION

The presence of humic acid (HA) completely inhibited the kinetics of P sorption for systems containing only calcite (C), only brushite (P), and calcite together with brushite (C + P) (Figure 1). Even without HA, sorption kinetics were slower for the C, P, and C+P systems than for the system containing ferrihydrite only (F) (Figure 1). Thus, in the C, P, and C+P systems, P solubility was controlled by precipitation/dissolution of Ca phosphate solid phases, and the slower kinetics of Ca phosphate precipitation was subject to greater inhibition by HA. The kinetics of adsorption of P onto F was much faster – faster than the adsorption of HA onto the F surface (Figure 1). Interestingly, when F was present in the C, P, and C+P systems with and without HA, the sorption kinetics followed the behavior of the system containing only F. Iron oxides such as ferrihydrite are ubiquitous in soils, even calcareous soils, thus, iron oxides may play a much more important role than previously thought in regulating P solubility in calcareous soils. This warrants further investigation.

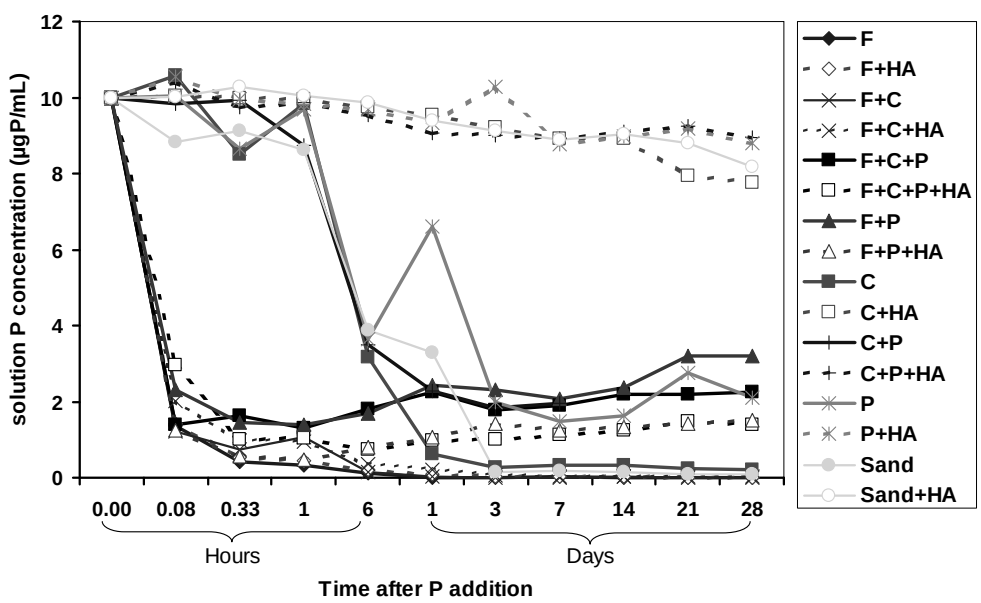


Figure 1. Changes in solution P concentration over time.

When we evaluated the amount of P extracted from the treatment solids using either $NaHCO_3$ (Olsen method), $CaCl_2$, or water we found that very little sorbed P was extracted from F surfaces. The (C) and (P) systems with HA had lower levels of $NaHCO_3$ extractable P than without HA (Table 2). For clarity, it should be noted that Table 2 only lists the amount of P that was extracted from the solids collected at the end of each experiment, and does not list solution data collected during the course of the experiments. The P only systems with HA had lower

levels of water and $CaCl_2$ extractable P than without HA, while the opposite was observed for C and C+P treatments (Table 2).

Table 2. P extracted from treatment solids.

Treatment	P extracted (µgP/g 'soil')		
	Water	$CaCl_2$	$NaHCO_3$
C	4.22	1.06	69
C+HA	16.17	7.87	27
C+P	58.92	7.29	1884
C+P+HA	36.24	11.14	90
P	294.02	47.12	1086
P+HA	81.80	20.81	433

SUMMARY

Humic acid (HA), which acted as an analogue to the soluble organic matter present in organic wastes, inhibited the formation of insoluble calcium phosphates, thus, rendering P more bioavailable. Sorbed HA also decreased the amount of soil test P extracted from Ca phosphate solid phases. Surprisingly, ferrihydrate, with and without HA, was a dominant sorbent of P. Sorption kinetics may be responsible for differences observed between the extractants (water, $CaCl_2$, and $NaHCO_3$) and solid phases responsible for regulating soluble P levels in soils. Care must be taken when determining manure application rates on calcareous soils that are solely based upon $NaHCO_3$ extractable P levels.

REFERENCES

Amacher, M.C. 2001. Soil and sediment characterization methods. Open ended file. USDA For. Serv., Intermountain Res. Stn., Forestry Sci. Lab., Logan, UT.

Amacher, M.C., J. Kotuby-Amacher, E.M. Buselli, and A.W. Nichols. 1995. Phosphorus in stream water and sediments in the central Great Basin. p.336. In: Agron. Abstr. ASA, Madison, WI.

Erich, M.S., C.B. Fitzgeral, and G.A. Porter. 2002. The effect of organic amendments on phosphorus chemistry in a potato cropping system. Agriculture Ecosytems and Environ. 88(1):79-88.

Fixen, P.E., A.E. Ludwick, and S.R. Olsen. 1983. Phosphorus and potassium fertilization of irrigated alfalfa on calcareous soils. 11. Soil phosphorus solubility relationships. Soil Sci. Soc. Am. J. 47:112-117.

Grossl, P.R., and W.P. Inskeep. 1991. Precipitation of dicalcium phosphate in the presence of organic acids. Soil Sci. Soc. Am. J. 55:670-675.

Grossl, P.R., and W.P. Inskeep. 1992. Kinetics of octacalcium phosphate crystal growth in the presence of organic acids. Geochim. Cosmochim. Acta 56:1955-1961.

Harris, W.G., H.G. Wang, and K.R. Reddy. 1994. Dairy manure influence on soil and sediment composition: Implications for phosphorus retention. J. Environ. Qual. 23:107 1 - 1081.

Hesketh, N., and P.C. Brookes. 2000. Development of an indicator for risk of phosphorus leaching. J. of Environ. Qual. 29:105-110.

Inskeep, W.P., and J.C. Silvertooth. 1988. Inhibition of hydroxyapatite precipitation in the presence of humic, fulvic, and tannic acids. Soil Sci. Soc. Am. J. 52:941-946.

James, D.W., J. Kotuby-Amacher, G.L. Anderson, and D.A. Huber. 1996. Phosphorus mobility in calcareous soils under heavy manuring. J. Environ. Qual. 25:770-775.

Jones, C.A., J.S. Jacobsen, and A. Mugaas. 2007. Effect of low-rate commercial humic acid on phosphorus availability, micronutrient uptake, and spring wheat yield. Commun. Soil Sci. and Plant Analysis 38:921-933.

Lindsay, W.L. 1979. Chemical equilibria in soils. J. Wiley & Sons, New York.

Lopez-Hernandez, D., G. Siegart, and J.V. Rodriquez. 1986. Competitive adsorption of phosphate with malate and oxalate by tropical soils. Soil Sci. Soc. Am. J. 50:1460-1462.

Maughan, T. 2002. Nutrient leaching in intensively managed irrigated pastures in northern Utah. MSc Thesis, Utah State University, Logan.

Murphy, J. and Riley, J.R. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27, 31-36.

Nagarajah, S., A.M. Posner, and J.P. Quirk. 1970. Competitive adsorption of phosphate with polygalacturonate and other organic acids on kaolinite and oxide surfaces. Nature (London) 228:83-85.

O'Connor, G.A., K.L. Knudtsen, and G.A. Connel. 1986. Phosphorus solubility in sludge-amended calcareous soils. J. Environ. Qual. 15:308-312.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939. p. 1-19. U.S. Gov. Print Office, Washington D.C.

Sharpley, A.N., and R.G. Menzel. 1987. The impact of soil and fertilizer phosphorus on the environment. Adv. Agron. 41:297-324.

Siddique, M.T, and J.S. Robinson. 2003. Phosphorus sorption and availability in soils amended with animal manures and sewage sludge. J. Environ. Qual. 32:1114-1121.

Stumm, W., and J.J. Morgan. 1981. Aquatic chemistry. An introduction emphasizing chemical equilibria in natural waters. 2nd ed. John Wiley and Sons, New York.

Traina, S.J., G. Sposito, D. Hesterberg and U. Kafkafi. 1986. Effects of organic acids on orthophosphate solubility in acidic, montmorillonitic soil. Soil Sci. Soc. Am. J. 50:45- 52.

Violante, A., C. Colombo, and A. Buondonno. 1991. Competitive adsorption of phosphate and oxalate by aluminum oxides. Soil Sci. Soc. Am. J. 55:65-70.

Violante, A., and L. Gianfreda. 1993. Competition in adsorption between phosphate and oxalate on an aluminum hydroxide montmorillonite complex. Soil Sci. Soc. Am. J. 57:1235-1241.

IMPROVING N AND P USE EFFICIENCY WITH POLYMER TECHNOLOGY

Dr. Larry Murphy, Murphy Agro, 2805 Claflin Road, Suite 200
Manhattan, KS 66502 phone: 785-776-6623 fax: 785-776-8347
e-mail: murphyagro@cs.com
Dr. Larry Sanders, Specialty Fertilizer Products, 134 Cherry Hill
Drive, Belton, MO 64012, phone: 816-322-7200, fax: 816-322-7207
e-mail: jlarrysanders@specialtyfertilizer.com

Abstract

The microenvironment surrounding a P fertilizer granule or within a fluid P fertilizer band is subject to a series of primary and secondary reactions which substantially impact nutrient availability to plants. Influencing or slowing these reactions is a means of improving applied P use efficiency, improving yields and profitability with positive implications for environmental concerns. It is well recognized that even under the best conditions, only 5 to 25% of fertilizer P is taken up by the crop during the first growing season. Thus, the historical problem with the soil chemistry of P fertilizers has been the lack of availability due to fixation. The reported pjolymer technology affects P use efficiency that is economical and profitable. Urea and urea containing N solutions (UAN) are subject to different efficiency-limiting factors. A polymer technology similar in structure to the P polymer has shown good effects in the field. In this case, soil N reactions are being affected, enhancing efficiency of applied N and again positively affecting yields and profitability.

Introduction

The microenvironment surrounding a phosphorus (P) fertilizer granule or within a fluid P fertilizer band is subject to a series of primary and secondary reactions which substantially impact P availability to plants. Influencing or controlling these reactions is of primary importance due to their influence on P fixation and the subsequent plant availability of the nutrients involved.

Phosphorus Fertilizers – The Problem

It has long been understood that even under the best conditions only 20-30% of applied fertilizer P is taken up by the crop during the first cropping season. It is also understood that at high soil pH levels, P is fixed by calcium (Ca) and magnesium (Mg) and at low soil pH levels predominately by iron (Fe) and aluminum (Al). Thus, the historical problem with the soil chemistry of P fertilizers has been lack of availability.

Paper presented at the 2007 Indiana CCA Annual Training Meeting, Indianapolis, IN, Dec. 18-19, 2007.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

Residual P not taken up by the crop (70-80%) and remaining on or near the soil surface has a possible environmental impact through the combined effects of soil erosion and higher P concentrations in run-off water. A P fertilizer product that is more efficient, that produces greater crop responses, has a positive impact on returns to crop producers and leaves less of an environmental footprint is highly desirable.

Phosphorus Fertilizers – The Solution

Specialty Fertilizer Products has developed and patented a family of high charge density dicarboxylic copolymers that affect the availability and plant utilization of applied P fertilizers. These compounds are biodegradable and highly water-soluble. The technology (Avail) can be applied directly to granular P fertilizers as a coating or mixed into liquid fertilizers.

The theory of mode of action is that the high charge density of the polymer (approximately 1500 meq/100 g of polymer) results in adsorption of polyvalent metal cations in soil solution, disrupting and delaying normal P fixation reactions resulting in extended availability of highly water soluble ammonium and calcium phosphates. Results of a laboratory study (Table 1) show the effects of varying concentrations of Avail polymer coated on granular monoammonium phosphate (MAP) which was placed in 100 ppm solutions of Ca, Fe and Al. The resulting P concentrations in solution suggest that the polymer affected the reactions of the three cations with the dissolving MAP allowing more P into solution and ultimately available for plant uptake.

Table 1. Polymer effects on MAP solubility in various solutions.

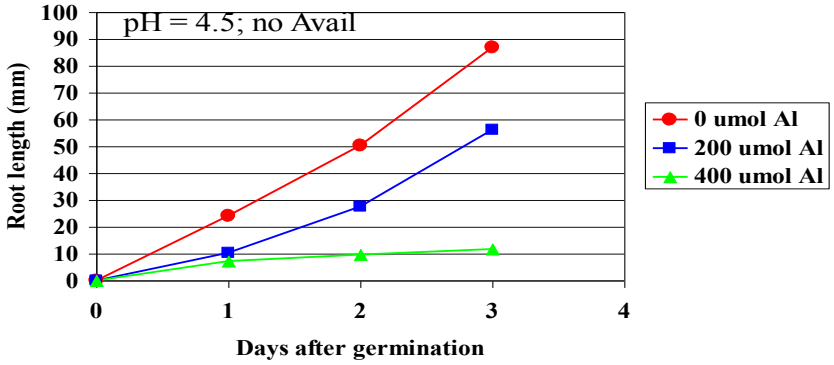
MAP coating % polymer	Cation ppm	Mgm P/Gram MAP	% of Total P in Solution
0.00	Al 100	236.9	45.5
0.25	Al 100	298.4	57.4
0.50	Al 100	284.5	54.7
0.75	Al 100	326.0	62.7
1.00	Al 100	309.4	58.9
0.00	Ca 100	251.5	48.4
0.25	Ca 100	295.8	56.9
0.50	Ca 100	314.1	60.4
0.75	Ca 100	310.4	59.7
1.00	Ca 100	308.2	59.3
0.00	Fe 100	289.9	55.8
0.25	Fe 100	316.7	60.9
0.50	Fe 100	303.5	58.4
0.75	Fe 100	329.2	63.3
1.00	Fe 100	305.2	58.8

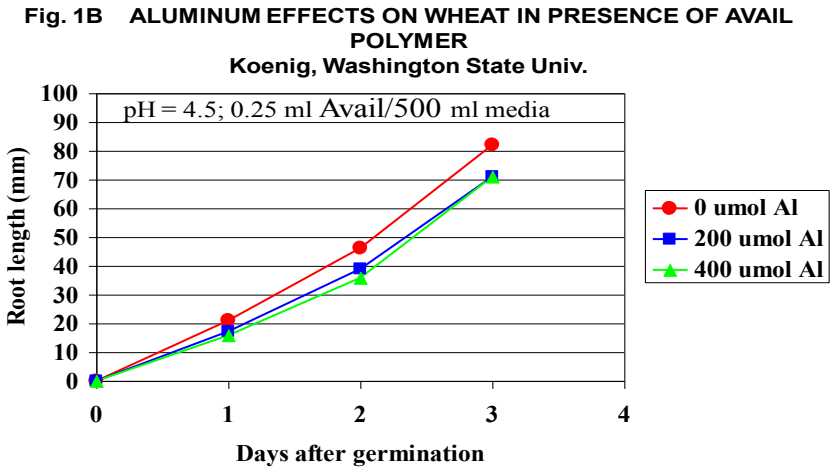
20°C. 24 hours. No stirring. Griffith, Kansas State University

In the soil, the dissolving polymer is theorized to adsorb or sequester the antagonistic cations that react with P in the soil solution of the microenvironment surrounding the fertilizer granule or in the fluid P band. Since P is immobile, once the chemistry of the dissolution area has been modified, the un-fixed P can be taken up by the plant without interference.

An elegant study conducted at Washington State University by Dr. Rich Koenig emphasized the effects of the Avail polymer on the activity of trivalent Al ions in solution. A study of the sensitivity of wheat varieties to Al toxicity was conducted in the lab with three Al concentrations in the growth medium (Fig. 1A). Root length was measured as an indication of plant growth or Al sensitivity. When Avail polymer was introduced into the growth media, the effects of Al disappeared (Fig. 1B).

Fig. 1A. ALUMINUM EFFECTS ON WHEAT GROWTH
Koenig, Washington State Univ.

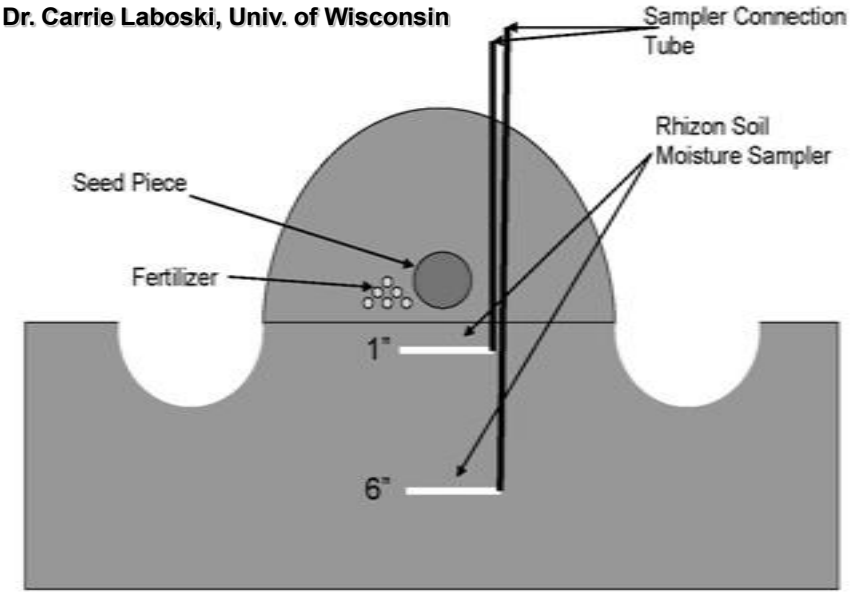




Vertical P Mobility. Enhanced P availability through reduced fixation has been demonstrated to enhance vertical P mobility. Recent studies in Iowa with fluid starter P applications for corn (Kovar) have demonstrated that P mobility vertically in the soil can be considerably increased (10 cm) by the presence of high concentrations of ammonium ions (2:1 N to P_2O_5 ratios) in the same soil retention zone. Those ammonium ions, like the polymer, are assumed to have interrupted normal P fixation reactions through the modification of the microenvironment of the P application zone. University of Wisconsin studies (Laboski, 2007)) of P mobility in the presence of Avail coating (Fig. 2) have shown enhanced concentrations of P in the soil solution with Avail. Quoting the researchers, "At one inch below the seed piece on June 18th(1st flower), July 2nd, and July 16th at Hancock, solution concentrations from MAP + Avail were significantly greater than MAP and control. No difference between treatments at six inches". These results indicate a change in P soil reactions due to the presence of the Avail polymer.

Fig. 2. SAMPLING SOIL SOLUTION FOR P MOBILITY

Dr. Carrie Laboski, Univ. of Wisconsin



Polymer Effects on Plant Responses to Applied P

Phosphorus fertilization effects on plant growth and yields can be influenced by several factors including:

* Methods of P application
* Soil pH
* P application rates
* Type of crop
* Soil test P levels
* Polymer rates

Greenhouse and field investigations have evaluated polymer effects on crop responses to applied P with variables of the factors listed above. Initial greenhouse studies on high P, acidic, P-fixing soils provided the positive impetus (data not shown) for continuing the work in the field. As in any other series of investigations of this type, not all locations have been responsive to polymer coatings on P fertilizers. However, out of all P-responsive sites, polymer coatings have produced positive responses about 80% of the time.

Methods of P Application. University of Arkansas wheat data (Table 2) show that polymer coated MAP was more effective than uncoated MAP. Yields produced by P banded with the seed (starter), P broadcast, and broadcast mixtures of seed and MAP were all significantly increased with Avail coating of MAP. The largest increase was with banded P applications but broadcast P applications, widely recognized as less efficient, were also consistently increased by Avail coating of MAP.

Arkansas Wheat

Table 2. Avail and P application method effects on wheat yields

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

30 lb P_2O_5/A. Low soil P, pH 7 Palmer, University of Arkansas

Wheat data from South Australia (Holloway) show that polymer coated MAP out performed MAP at three different P rates on highly calcareous soils. Although limited by moisture, yields were increased as much as 10% on these high pH (8.3) soils containing approximately 70% free calcium carbonate (data not shown).

Kansas wheat studies on high P testing soil (75 ppm Bray-1) acidic soil also showed a significant yield response of wheat to polymer coated MAP. Although these soils test high for P, they also have a high P fixation capacity due to their very low pH (4.7).

University of Missouri corn data (Table 3) indicate an example of Avail performance with an acid soil pH (5.9), low P soil test combination and with both broadcast and banded P applications. The data indicated no response to untreated MAP, but a significant response to polymer-coated MAP (20 bu/A).

Missouri Corn

Table 3. Corn response to enhanced P availability.

Treatment	Grain Yield bu/A
Control, No P	135
MAP broadcast	132
MAP + Polymer broadcast	151
MAP banded	132
MAP + Polymer banded	157
LSD (0.05)	16

20 lb P_2O_5/A. Soil test Bray P-1: 7 ppm pH: 5.9

Blevins, Univ. of Missouri

Very interestingly, MAP coated with polymer also performed well on medium to high P testing, near neutral soils in Kansas. Irrigated corn yields were increased from 8-20 bu/A over the uncoated MAP by polymer coated MAP applied as a starter (Table 4). Early season plant dry weights, plant P concentrations and P uptake were increased by the enhanced P availability in this 3-year study (data not shown). Soybeans also responded well to banded (starter) polymer-coated MAP with yield increases up to 16 bu/A over uncoated MAP (Table 5) at this same location. Apparently there is still opportunity for P management on soils with good P soil tests and moderate pH levels.

Kansas Corn

Table 4. Enhancing P availability for irrigated corn.

Treatments lb P_2O_5/A	Year 1	Year 2	Year 3
	----------bu/A----------		
Control	172b	119e	169d
20 MAP	192a	142d	192c
20 MAP + Avail	199a	173bc	210a
40 MAP	193a	168c	188bc
40 MAP + Avail	193a	190ab	210a
60 MAP	193a	173bc	195b
60 MAP + Avail	201a	194a	210a

Duncan's multiple range test, 5% level Gordon, Kansas State Univ

P banded at planting.. Soil pH: 6.8. Soil P = 25-38 ppm Bray-1.

Kansas Soybeans

Table 5. Enhancing P availability for irrigated soybeans.

Treatments lb P_2O_5/A	Year 1	Year 2 bu/A	Year 3
Control	52d	32d	60
30 MAP	62c	41c	70
30 MAP + Avail	70b	57a	78
60 MAP	62c	47b	74
60 MAP + Avail	73a	58a	78

Duncan's multiple range test, 5%. P banded beside row. Gordon, Kansas State Univ.
Soil test P: 38 ppm Bray 1. Soil pH: 6.8.

Studies at soil pH values above 7.0 were conducted at the University of Arkansas (wheat shown earlier, Table 2) and at the University of Minnesota with corn (Table 6). All of these studies showed positive responses to MAP and DAP coated with the Avail polymer compared to untreated P materials.

Crops. Phosphate fertilizers coated with Avail polymer have produced increased P uptake and increased yields on a wide range of crops. Experiments with collards, grass, corn, wheat, onions, rice, tomatoes, sweet corn, canola and potatoes have produced positive responses to coated P fertilizer over uncoated P indicating that this is a soil chemistry phenomenon, not associated with species.

Minnesota Corn

Table 6. Enhancing P availability for corn

P Source lb P_2O_5/A	P Uptake V-6 g/12 plants	Yield bu/A
0	1.85	136
25 DAP	1.77	151
25 DAP + Avail	2.72	172
50 DAP	2.17	155
50 DAP + Avail	2.47	175
LSD (0.05)	0,79	22

P broadcast. Soil pH: 7.3 7 ppm Olsen P Randall, Univ. of Minnesota, Waseca

Coating MAP with polymer has also been effective on acidic, P-fixing soils for cool season grass forages in Kansas and Missouri. Data in Table 7 indicate how broadcast P applications with Avail coating during the dormant period enhanced P uptake and yields. These effects also were apparent visually. However, early growth differences in Kentucky on fescue did not result in yield increases.

Kansas and Missouri Cool Season Grasses

Table 7. Enhancing P availability for bromegrass and tall fescue.

Treatments	Bromegrass Miami Co., KS	Bromegrass Miami Co., KS	Fescue Lawrence Co., MO
	----------lb/A----------		
No P	5100	3210	3096
MAP	5290	4160	4392
MAP + Polymer	6010	4710	4724
LSD (0..10)	570	810	782

Low P, pH soils. 20 P_2O_5/A. MO 90 N, KS 100 N/A Lamond, Kansas State Univ. Massie, U of Missouri

University of Idaho potato data (Table 8) also show the effects of the polymer coated MAP at varying rates over MAP compared to untreated MAP on a high pH soil (7.9). Yields were increased at both the 60 and 120 pound P_2O_5 rates by the polymer coating. When polymer coated MAP was applied at both rates, significant increases in yields and dollar returns resulted. The higher coated MAP rate (120 lb/A) gave the best yields and profits. The coated MAP increased US No. 1 yields by 14% and gross returns by $200/A at the higher P rate.

Idaho Potatoes

Table 8. Potato yield and return responses to enhanced P availability.

Treatment lb P_2O_5/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 + Avail	339 ab	0.288 ab	1575
120 MAP	344 bc	0.275 bc	1591
120 MAP + Avail	369 c	0.308 a	1791

Declo sandy loam, pH 7.9; Olsen P 23 ppm--Stark, Univ. of Idaho
Duncan's multiple range test, 5%.

Polymer Rate Effects. Initial studies of polymer rates with solid P fertilizers involved coatings of up to 1 percent polymer formulation. However, subsequent greenhouse and field studies indicated that much lower rates could be utilized. Data in Table 9 indicated that rates could be reduced to 0.25 percent without loss of efficacy. That rate is currently recommended for all solid P fertilizers (MAP, DAP, TSP).

Table 9. Avail polymer rate effects on corn.
Kansas

Treatments	V-6 Dry Wt lb/A	V-6 P uptake lb/A	Yield bu/.A
No P control	380	0.91	103
MAP	501	1.34	121
MAP + 1% AVAIL	592	1.61	138
MAP + 0.75% AVAIL	585	1.58	136
MAP + 0.5% AVAIL	620	1.73	140
MAP + 0.25% AVAIL	601	1.65	137
$LSD_{.10}$	32	0.21	13

P banded 30 lb P205/a. Bray P-1 9 ppm, pH 7.4 Lamond, Kansas State Univ.

Polymer in Fluid Fertilizers

Polymer effects in P-containing fluid fertilizer formulations have also been evaluated but in fewer trials than with solid P fertilizers. Recognizing that fluid bands would have a much less defined geometry than the coating of polymer on a solid particle, polymer rates were increased beginning at 1% polymer by weight, the initial concentration of polymer coated on solids. Rates of 1 and 2% polymer were initially evaluated in field strip trials with a complete mixed fluid starter for corn in Indiana. These trials were replicated over years were harvested with a yield monitor. Initial results were encouraging (Table 10) but indicated that higher rates needed to be evaluated.

Indiana Corn

Table 10. Enhancing fluid starter responses with polymer

Treatments	Corn yields, bu/A		
	Year 1	Year 2	Year 3
Starter only	171	185	189
Starter + 1% polymer	171	190	202
Starter + 2% polymer	179	194	209

7-22-5 starter, 150 lb/A Anderson Fertilizer, Romney, IN

Replicated evaluations of polymer rates in fluid starter for irrigated corn were conducted in Kansas on high P testing, neutral pH (6.8) soil with high N:P ratio formulations which had been shown to enhance P responses under such soil conditions in reduced tillage production systems. Several polymer rates were evaluated in a 15+15+5 starter application placed 2 inches to the side and 2 inches below the seed (Table 11).

Further work with polymer in fluid starter with corn using various rates and a modified formulaltion established the current recommendation for 0.5% concentration

(volume/volume) of Avail SD in side banded fluid starter and 1.5% Avail OS in pop-up starters.

Table 11. Enhancing P Availability in Fluid Starter
2002 - Kansas

Treatments				Corn Yield
N	P_2O_5	K_2O		bu/A
----------lb/A----------				
No starter				133 d*
15	15	5	No polymer	152 c
15	15	5	1% polymer	167 b
15	15	5	2% polymer	186 a

Soil pH = 6.8. Soil test P – 35 ppm Bray P-1. Kansas State Univ.
Means separated by Duncan's multiple range test, 5% level.

Nitrogen

The problems associated with the use of urea or urea-containing solutions prompted examination of potential effects of another dicarboxylic polymer on N use efficiency. This polymer has a similar charge density to Avail but with significantly different formulation characteristics. Initial trials with the material showed some depression of ammonia volatilization, later was shown to have the ability to slow urea hydrolysis through effects on urease and shows effects on nitrification. This multi-functional material has a very high charge density, around 1800 meq/!00 grams of polymer. That characteristic is believed to have effects on metalloenzymes such as urease and soil N oxidation enzymes of *Nitrosomonas* and *Nitrobacter* Each of these enzymes depends upon a specific multi-valent metallic cofactor, respectively Ni, Cu and Fe. The polymer labeled Nutrisphere-N is theorized to sequester or compromise the activities of these metals with resulting slowing of the respective reactions.

Field research begun in 2004 continues to produce positive results with polymer concentrations of 0.25% coated on urea and 0.5% concentrations in UAN. Field conditions of high amounts of surface residues where urea has traditionally experienced problems with N use efficiency were chosen for evaluation of Nutrisphere-N.

Data in Table 12-15 indicated consistent Nutrisphere-N effects both in urea and in UAN applied to no-till corn. Table 16 shows how Nutrisphere-N performed on tall fescue. Those data plus similar results from N fertilization trials with bermudagrass in TX and AR and rice in MO indicate that this is a technology which allows urea to perform at a level equal to ammonium nitrate.

Table 12. NUTRISPHERE-N EFFECTS ON UREA
No-till Corn—Kansas 2004

Treatment lb N/A	% N	Corn Yield bu/A
0	1.77	154
80 Urea	2.00	176
80 + NSN	2.20	198
160 Urea	2.08	192
160 + NSN	2.32	210
240 Urea	2.22	230
240 + NSN	2.46	254
LSD .05		9

Broadcast N, no-till corn — Gordon, KSU
NSN = Nutrisphere-N

Table 13. NUTRISPHERE-N EFFECTS ON UREA
No-Till Corn—Kansas 2005

N Rate lb/A	Ear Leaf N %	Corn Yield bu/A
0	1.78	139
80 Urea	2.79	167
80 Urea + NSN	2.90	184
160 Urea	2.90	183
160 Urea + NSN	3.07	216
240 Urea	2.95	192
240 Urea + NSN	3.09	215
LSD.05		6

Soil pH = 7.0 — Gordon, Kansas State Univ.
NSN = Nutrisphere-N

Table 14. NUTRISPHERE-N POLYMER EFFECTS

No-Till Corn, Kansas--2006

N Rates	Urea		UAN	
lb/A	Polymer	None	Polymer	None
0		138 bu/A		
80	166	152	170	157
160	188	169	192	167
240	197	188	196	181
LSD.05		6		

All N broadcast, Crete silt loam Gordon, KSU
Soil pH: 7.0

Table 15. IMPROVING N USE EFFICIENCY WITH *NUTRISPHERE-N*

***Ohio*--2006**

Treatment		Corn Yield
lb N/A	**Broadcast**	**bu/A**
0		**94**
100	**Urea**	**165**
100	**Urea + Nutrisphere-N**	**178**
100	**UAN**	**159**
100	**UAN + Nutrisphere-N**	**169**
LSD .10		**23**

No-till corn **Mullen, Ohio State Univ.**

Table 16. NUTRISPHERE-N FOR FESCUE

Missouri – Spring 2007

N Source	Bradford	Mt. Vernon
Spring	Yield, lb/A	
No N	2167	1666
Urea	4717	3140
Urea + NSN	5254	3788
Am. nitrate	4827	3648
LSD.05	550	416

75 lb N/A Kallenbach, Univ. of Missouri

Conclusions

Influencing or controlling reactions in the microenvironment around fertilizer granules or in a fluid band or droplet has been shown to have significant benefits to the fate and availability of applied nutrients and subsequent plant response to applied P and N. The objective of agricultural producers has always been to provide the quantity of available nutrients to achieve the maximum economic yield for crops' genetic potential. With this polymer technology, research shows that modification of the microenvironment around fertilizer N and P particles affects nutrient absorption and utilization by a wide spectrum of crops at normal fertilization rates. This technology not only has the potential to improve crop yields and farmer profits but also has positive implications on possible environmental footprint of fertilizer use.

Enhanced Efficiency Fertilizers

MONTANA STATE UNIVERSITY
EXTENSION

EB0188 July 2009

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

Slow release
Controlled release
Volatilization inhibitor
Stabilized
Protected
Nitrification inhibitor

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

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. For a discussion on management of conventional urea fertilizer to minimize losses, see MSU Extension publication EB0173, *Management of Urea Fertilizer to Minimize Volatilization*. 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 *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.

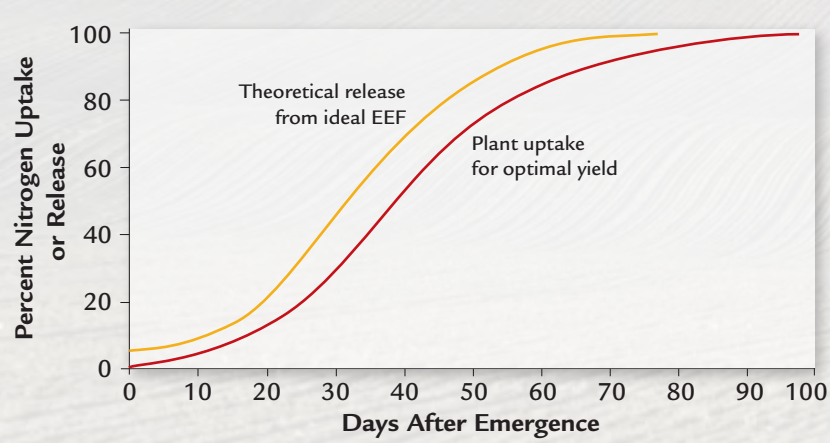


FIGURE 1. Theoretical plant uptake of N during the growing season and matching release of N from an ideal EEF.

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 modify nutrient release. The Appendix on page 12 presents the more common EEFs found in our region. It is not an exhaustive list. With new developments in available products, 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 10-14 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, ½ 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)*.

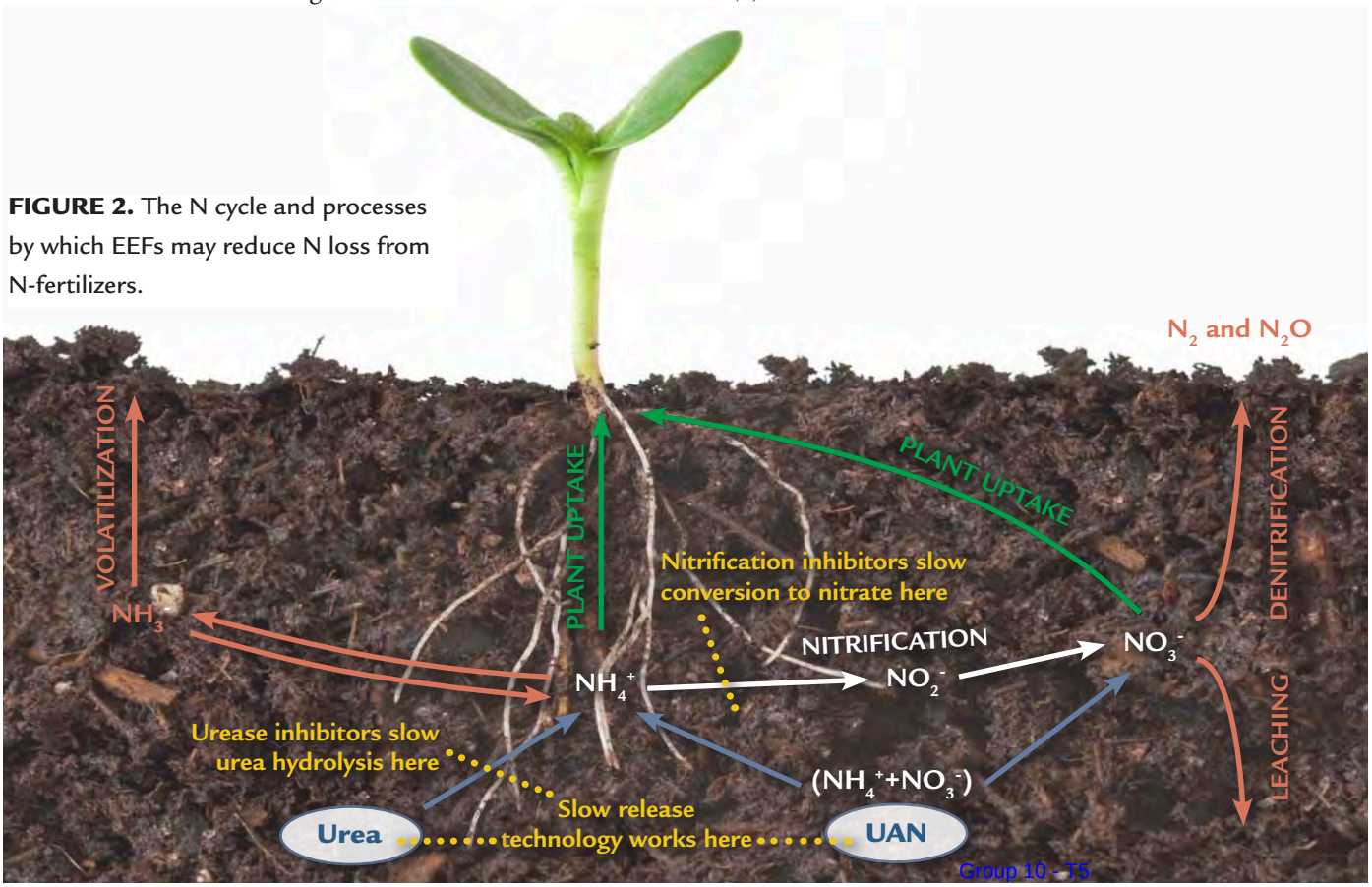


FIGURE 2. The N cycle and processes by which EEFs may reduce N loss from N-fertilizers.

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 ½ 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.

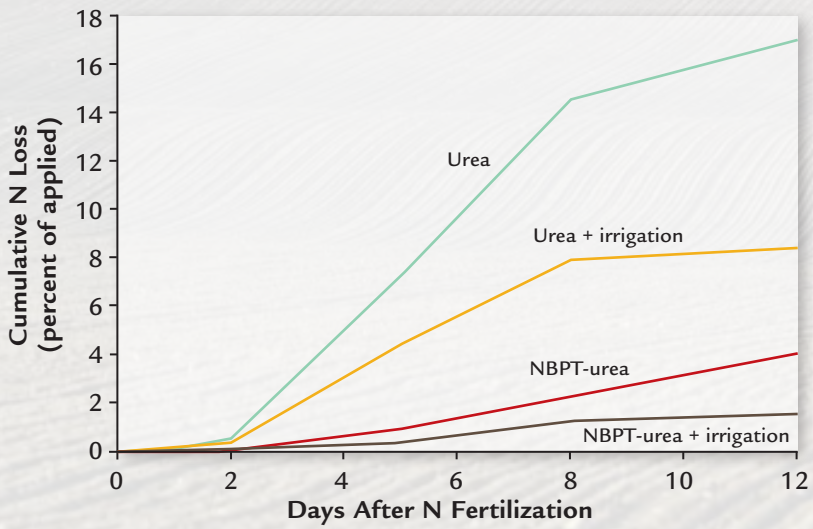


FIGURE 3. Cumulative ammonia loss from 89 lb N/acre urea and NBPT-urea applied in May on a field in Manitoba on clay loam soil with irrigation (0.79 inches on days 2 and 8) and without *(3)*.

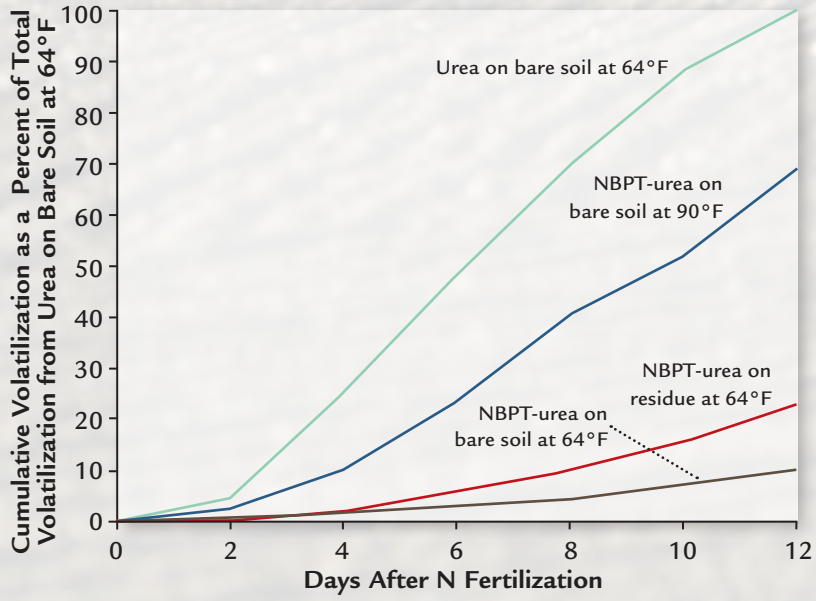


FIGURE 4. Relative cumulative ammonia volatilization from urea and NBPT-urea under lab conditions at different temperatures, on bare soil and on soil with plant residue. Volatilization is expressed as percent of total cumulative loss by urea on bare soil at 64°F *(7)*.

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 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 through coatings or additives. Sulfur coated and polymer-coated urea (PCU) are made at the manufacturing plant. Urea-aldehyde products are mixed with liquid or granular fertilizer at the point of manufacture or at the blending plant.

Sulfur coatings delay urea release from the granule. Individual granules release N at different times to achieve N supply over time. 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. In contrast, urea-aldehyde reaction products slowly decompose in soils by chemical and/or biological processes. Solubility and N release can be varied by altering the chemical composition of the aldehyde additive *(9)*.

There are several products with different polymer coatings. For simplicity we will use PCU to represent all of them. Like NBPT, PCUs are very effective at reducing ammonia volatilization losses. 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 *(10)*.

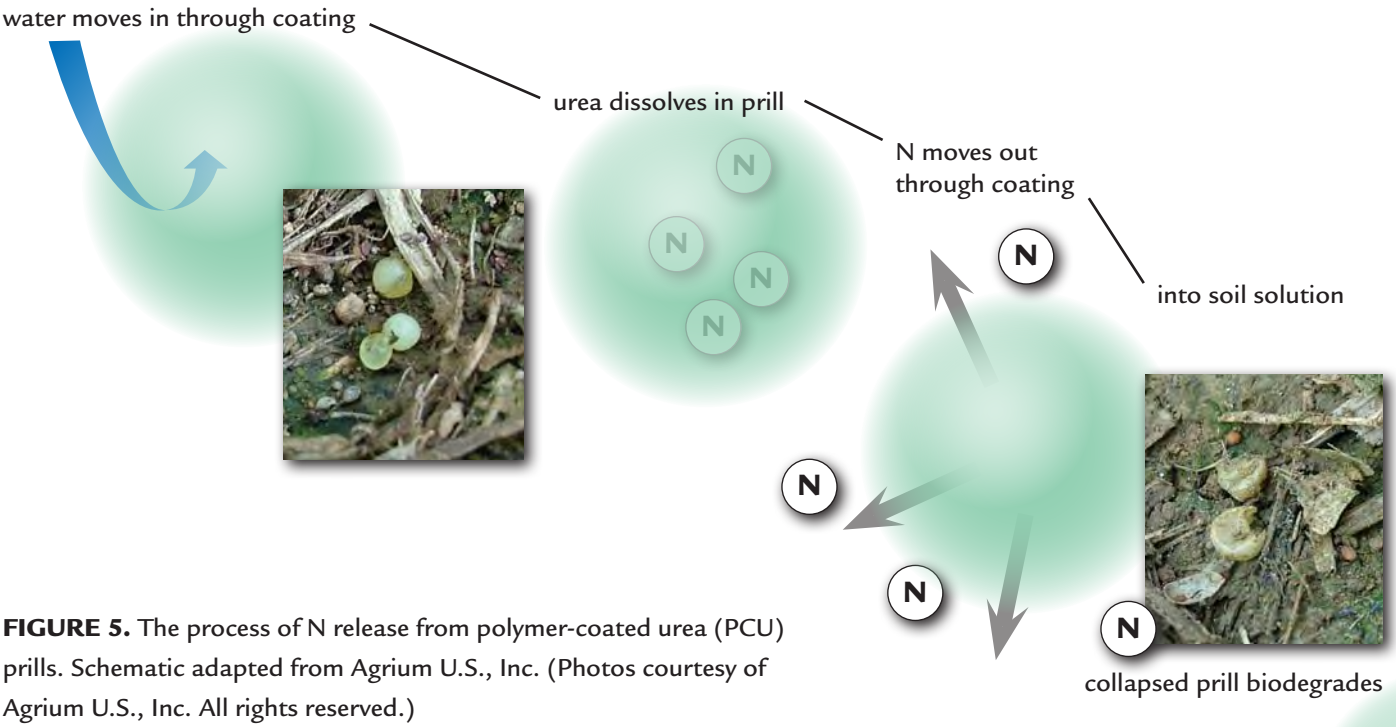


FIGURE 5. The process of N release from polymer-coated urea (PCU) prills. Schematic adapted from Agrium U.S., Inc. (Photos courtesy of Agrium U.S., Inc. All rights reserved.)

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 *(11)*. 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 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 *(12)*. 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 1-inch below the surface is below 50°F *(13)*, 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 4-6 weeks earlier than for

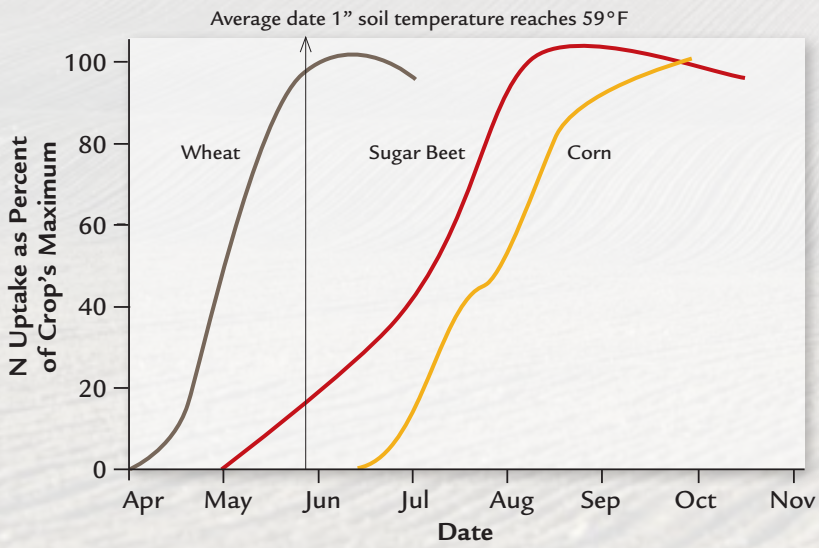


FIGURE 6. Nitrogen uptake by corn *(14)*, wheat *(15)*, and sugar beet *(16)*, over time, as a percent of their maximum N uptake. The date when soil temperature at 1-inch depth reached 59°F comes from Moccasin, Montana in 2006 *(13)*. Corresponding air temperatures that year were close to the 1971-2000 average air temperatures (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt5761). In the lab, buried PCUs release 30% of N by day 40 at soil temperatures of 59°F *(12)*.

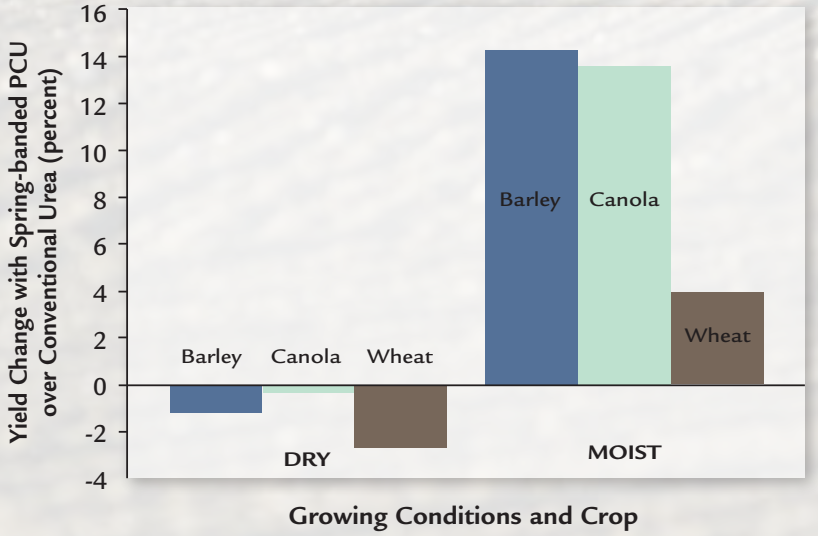


FIGURE 7. Barley, canola, and wheat yield as affected by spring-banded applications of PCU compared to conventional urea under relatively dry conditions at Beaverlodge, Lacombe, Melfort, and Swift Current, and relatively moist conditions at Beaverlodge, Brandon, and Swift Current, Canada *(8)*. Moist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

conventional urea. 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. 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.

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.

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.

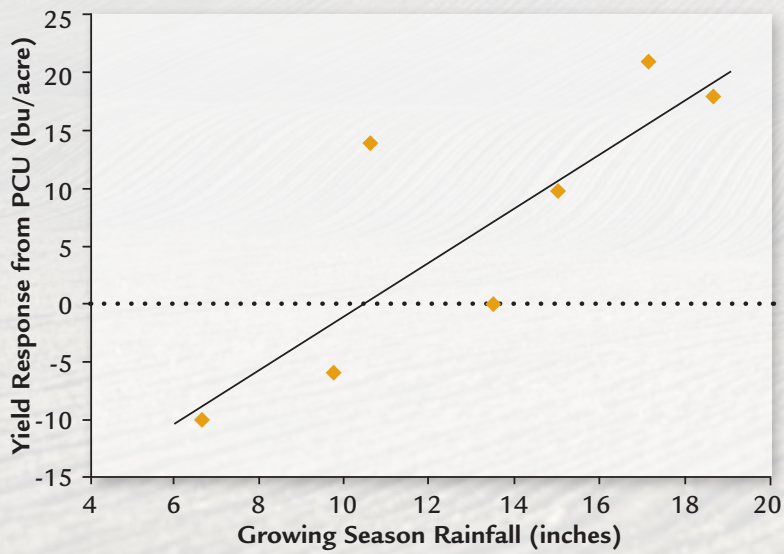


FIGURE 8. Corn yield response to PCU over conventional urea as affected by growing season rainfall in Illinois, 2003-2005. Points above zero denote greater yield with PCU than with conventional N sources. Line shows best fit of the data and illustrates trend *(20)*.

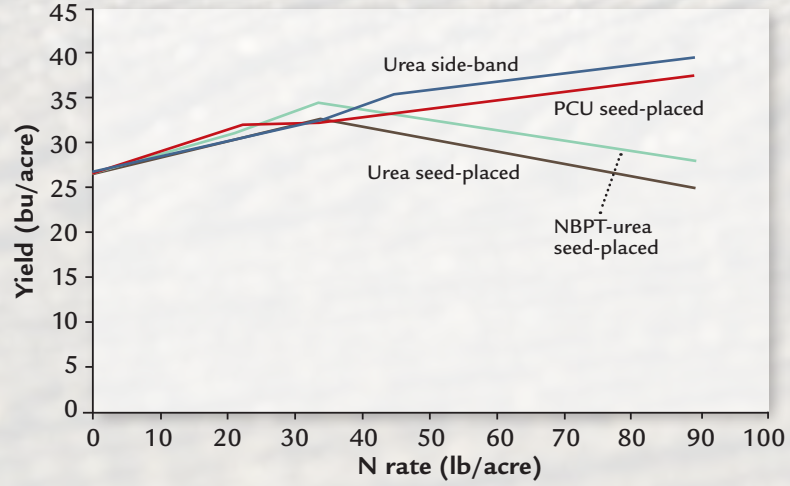


FIGURE 9. Dryland spring wheat yield as affected by seed-placed PCU, NBPT-urea, and conventional urea, and side-banded conventional urea as a control *(24)*.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

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 (EB0161, *Fertilizer Guidelines for Montana Crops*). If there is at least ½ 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 out-performed 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 30-40 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 0.4-0.9 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 *(12)*.

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.

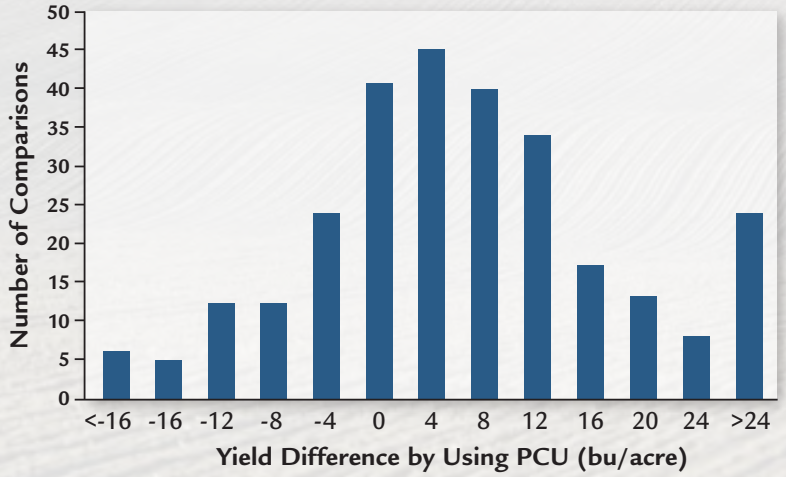


FIGURE 10. Frequency distribution of corn-yield response for pre-plant PCU compared with pre-plant conventional N fertilizer at equal N rates (U.S. corn-belt, 2000-2004). Positive numbers denote greater yield with PCU than with conventional N sources *(9)*.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

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 increase 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)*.

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® (3-9 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 (1.3-10 percent calcium carbonate). The U.S. No. 1 potato yields were 0.6-1.5 tons/acre higher and total yields were 1.5-2.1 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.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

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. The common EEFs in our region, their common name 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)		"
4-amino-1,2,4-trizole hydrochloride (ATC)		"
N-butyl-thiophosphoric triamide (NBPT)	Agrotain®	Volatilization
Malic+ itaconic acid co-polymer with urea	Nutrisphere-N® (NSN)	Nitrification
Controlled- and Slow- Release		
Polymer-coated (PCU)	ESN®, Polyon®, Duration®	Release
Sulfur-coated	SCU	"
Polymer + sulfur-coated	Tricote, Poly-S®	"
Urea formaldehyde	Nitroform®	"
Methylene urea	Nutralene®	"
Triazone	N-Sure®	"
Blends		
NBPT + DCD	Agrotain®Plus, SuperU®	Nitrification, Volatilization
Methylene urea + triazone	Nitamin®, Nitamin Nfusion®	Release
Other		
Malic+ itaconic acid co-polymer with MAP	Avail®	Decreased P mineral precipitation

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. Koenig, R. Professor. Dept. Crop and Soil Sciences, Washington State University, Pullman, Washington.

11. Blaylock, A. Senior Agronomist. Agrium U.S., Inc. Denver, Colorado.

12. Golden, B. Senior Graduate Assistant. Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville, Arkansas.

13. Chen, C. Scientist. Associate Professor. Central Agricultural Research Center, Moccasin, Montana.

14. Heard, J. 2004. *Nutrient accumulation and partitioning by grain corn in Manitoba*. http://www.gov.mb.ca/agriculture/msss/2004/mss601.pdf

15. 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.

16. Cariolle, M. and R. Duval. 2006. *Nutrition-Nitrogen*. p.169-183. In: A.P. Draycott (ed.). Sugar Beet. World Agriculture Series. Blackwell Publishing.

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. S*low-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.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

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/sf714w.htm

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.

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/cm

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, 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

Management of Urea Fertilizer to Minimize Volatilization (EB 173). Free. http://msuextension.org/publications/AgandNaturalResources/EB0173.pdf

Fertilizer Guidelines for Montana Crops (EB 161). Free. http://msuextension.org/publications/AgandNaturalResources/EB0161.pdf

Nutrient Uptake Timing by Crops: to assist with fertilizing decisions (EB0191). Free. http://msuextension.org/publications/agandnaturalresources/EB0191.pdf

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

MONTANA STATE UNIVERSITY EXTENSION

Copyright © 2009 MSU Extension

The U.S. Department of Agriculture (USDA), Montana State University and Montana State University Extension prohibit discrimination in all of their programs and activities on the basis of race, color, national origin, gender, religion, age, disability, political beliefs, sexual orientation, and marital and family status. Issued in furtherance of cooperative extension work in agriculture and home economics, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Douglas L. Steele, Vice Provost and Director, Montana State University Extension, Bozeman, MT 59717.

PROC. 2008 GREAT PLAINS SOIL FERTILITY CONFERENCE, 12:67-70
MAR. 4-5, 2008. DENVER, CO

NITROGEN MANAGEMENT FOR NO-TILLAGE CORN AND GRAIN SORGHUM PRODUCTION

W.B. Gordon
Professor of Agronomy
Kansas State University

SUMMARY

No-tillage production systems are being used by an increasing number of producers in the central Great Plains because of several advantages that include reduction of soil erosion, increased soil water use-efficiency, and improved soil quality. However, the large amount of residue left on the soil surface can make nitrogen management difficult. Surface applications of urea containing fertilizers are subject to volatilization losses. Leaching can also be a problem on course textured soils when N is applied in one preplant application. Slow-release polymer coated urea products are beginning to become available for agricultural use. The polymer coating allows the urea to be released at a slower rate than uncoated urea. The use of urease inhititors applied with urea-containing fertilizers can reduce volatilization losses. Recently, a new product that is a co-polymer of maleic and itaconic acids has become available (Nutrisphere-N) and has shown potential in reducing urea-N losses. Two studies were conducted, one with irrigated corn the other with dryland grain sorghum. The irrigated corn study compared urea (46% N), UAN (28%) a controlled release polymer coated urea (ESN), Agrotain, Agrotain Plus+, Nutrisphere –N[1] and ammonium nitrate at 3 nitrogen (N) rates (80, 160, and 240 lbs/a). A no n check plot also was included. The grain sorghum study consisted of untreated urea, ammonium nitrate, ESN, and urea treated with Agrotain or Nutriphere-N. Nitrogen rates included were 40, 80, and 120 lb N/acre as well as a no-N check. Both studies were conducted on Crete silt loam soils. In both the corn and grain sorghum experiments, the treated urea products yielded better than the untreated urea, and were similar to ammonium nitrate. There were no significant differences in yield of ESN, Agrotain, or Nutrisphere-N. In the corn experiment that included UAN (28%), yield of UAN treated with Agrotain Plus or Nutrisphere-N was greater than that of untreated UAN. If producers wish to broadcast urea-containing fertilizer on the soil surface in no-tillage production systems there are several products available that are very effective in limiting N losses and increasing N–use efficiency.

INTRODUCTION

Conservation tillage production systems are being used by an increasing number of producers in the Great Plains because of several inherent advantages. These advantages include reduction of soil erosion losses, increased soil water-use efficiency, and improved

[1] Mention of a specific trade name is for reader information and does not imply endorsement by the author or Kansas State University.

soil quality. The large amount of residue left on the soil surface in no-tillage systems can make N management difficult. Surface application of N fertilizers is a popular practice with producers. N losses due to volatilization from broadcast urea-containing fertilizers in no-tillage production systems can be significant. Depending on conditions, losses can be 10-20% of the applied N. Nitrogen immobilization can also be a problem when N fertilizers are surface applied in high residue production systems. Nitrogen leaching can be both an agronomic and environmental problem on course-textured soils. Polymer coated urea, long used in turf fertilization, has the potential to make N management more efficient when surface applied in no-tillage agricultural systems. The urea granule is coated, but allows water to diffuse across the membrane. N release is then controlled by temperature. A polymer-coated urea product is now available for crop use and is marketed under the name of ESN. The use of urease inhititors applied with urea-containing fertilizers can reduce volatilization losses. In the soil urea is hydrolyzed relatively quickly by the soil enzyme urease. Agrotain, a commercially available urease inhititor, and has in numerous studies proven to be effective in reducing N losses due to volatilization. Agrotain Plus is a product that contains both a urease inhibitor and a nitrification inhibitor (DCD). Recently, a new product that is a co-polymer of maleic and itaconic acids has become available (Nutrisphere-N) that has shown potential in reducing urea-N losses. The cation nickel is essential for the action of urease, Nutisphere-N is thought to sequester or inactivate the nickel ions rendering urease inactive. The objective of these experiments were to evaluate N efficiency from surface broadcast applications of urea-containing N and to try to reduce N loss and improve efficiency with the use of products designed to limit N volatilization and loss.

METHODS

Two experiments were conducted at the North Central Kansas Experiment Field on a Crete silt loam soil. An irrigated corn experiment was conducted at Scandia, KS and a dryland grain sorghum experiment was located at Belleville, KS. At the irrigated site, soil pH was 7.0; organic matter was 2.8%; Bray-1 P was 28 ppm, and exchangeable K was 240 ppm. The previous crop was corn. The corn hybrid DeKalb DKC60-19 was planted without tillage into corn stubble on April 20, 2006 and April 22, 2007 at the rate of 31,000 seeds/acre. Nitrogen was applied on the soil surface immediately after planting. Treatments consisted of controlled released polymer-coated urea (ESN), Nutrisphere-N coated urea, Agrotain coated urea, urea, and ammonium nitrate applied at 3 rates (80, 160, and 240 lbs/a). A no N check plot also was included. Additional treatments included UAN (28%), Agrotain treated UAN, Agrotain Plus+ treated UAN, and Nutrisphere-N treated UAN. The experimental area was adequately irrigated throughout the growing season. Plots were harvested on October 20, 2006.

At the dryland site, soil pH was 6.5; organic matter was 2.5%; Bray-1 P was 38 ppm and exchangeable K was 450 ppm. The previous crop was corn. The grain sorghum hybrid Pioneer 85G01 was planted at the rate of 62,000 seed/acre on May 20, 2006. and June 3, 2007. Nitrogen was broadcast on the soil surface immediately after planting. Treatments consisted of urea, ammonium nitrate, ESN, urea treated with Nutrisphere-N, and Agrotain treated urea applied at 40, 80 and 120 lbs/N/acre.

RESULTS

Grain yield of irrigated corn plots receiving untreated urea were lower than plots receiving urea treated with Agrotain, ESN or Nutrisphere-N at all levels of applied N (Table 1). Yields achieved with Agrotain, ESN, and Nutrisphere were equal to those of ammonium nitrate. Yield of UAN (28%) was also lower than those of UAN treated with Agrotain, Agrotain Plus+, or Nutrisphere-N. When averaged over N-rates, yields of all treated N products were greater than untreated urea or UAN (Table 2). There were no significant differences in yields of Agrotain, Agrotain Plus+, ESN, and Nutrisphere. The lower yields with urea and UAN indicate that volatilization of N may have been significant problem. The dryland grain sorghum study results were similar to the irrigated corn experiment. Yield of plots receiving untreated urea was significantly lower than plots receiving urea treated with Agrotain, Nutrisphrere-N or ESN (Table 2). There were no differences in yield of the three products tested.

Results of this study suggest that the efficiency of surface broadcast urea-containing fertilizers in no-tillage production systems can be improved by use of several products that are effective in reducing N volatilization losses.

Table 1. Effects of N source and rate on corn grain yield, earleaf N, and grain N, Scandia, (2-Year average).

N Source	N-Rate	Yield	Earleaf N	Grain N
	lb/acre	bu/acre	%	%
	0-N check	152.2	1.72	1.13
Urea	80	152.0	2.30	1.22
	160	169.3	2.65	1.26
	240	183.1	2.68	1.30
ESN	80	171.6	2.89	1.28
	160	186.6	2.95	1.32
	240	196.9	3.05	1.40
Nutrisphere-N	80	165.8	2.89	1.29
	160	187.7	2.94	1.36
	240	196.9	3.06	1.41
Urea+Agrotain	80	171.6	2.91	1.30
	160	179.7	2.96	1.36
	240	196.6	3.04	1.38
UAN (28%)	80	156.6	2.45	1.24
	160	167.0	2.69	1.28
	240	180.8	2.74	1.27
UAN+Agrotain	80	170.5	2.88	1.30
	160	191.2	2.98	1.35
	240	195.8	3.03	1.39
UAN+Agrotain Plus+	80	168.2	2.90	1.31
	160	185.4	2.99	1.38
	240	195.8	3.08	1.42
UAN+Nutrisphere-N	80	170.5	2.87	1.30
	160	192.0	3.01	1.38
	240	195.8	3.04	1.41
Ammonium Nitrate	80	173.9	2.86	1.30
	160	187.8	2.96	1.35
	240	195.8	3.05	1.40
Average(not including check)		181.1	2.88	1.33

Table 2. Effects of N source (averaged over rate) on corn grain yield, earleaf-N and grain-N, Scandia (2-year average).

Treatment	Yield,bu/acre	Earleaf-N, %	Grain N, %
No N check	152.0	1.72	1.13
Urea	168.1	2.52	1.26
ESN	185.0	2.96	1.33
Nutrisphere-N	183.5	2.96	1.35
Urea+Agrotain	182.6	2.97	1.35
UAN	168.1	2.62	1.26
UAN+Agrotain	185.8	2.96	1.35
UAN+Agrotain Plus+	183.1	2.99	1.37
UAN+Nutrisphere-N	186.1	2.97	1.36
Ammonium Nitrate	185.8	2.96	1.35
LSD (0.05)	6.2	0.09	0.04
CV%	6.8	4.5	4.9

Table 3. Effects of N source and rate on grain sorghum yield, Belleville (2-year average)

Treatment	N-Rate, lb/acre	Yield, bu/acre
Check	--------	71
Urea	40	108
	80	122
	120	128
ESN	40	120
	80	130
	120	132
Urea+Agrotain	40	116
	80	129
	120	133
Urea+Nutrisphere-N	40	120
	80	133
	120	132
Ammonium Nitrate	40	118
	80	131
	120	133
N-Source Treatment Means		
Urea		119
ESN		127
Agrotain		126
Nutrisphere-N		128
Ammonium Nitrate		127
LSD(0.05)		5

CV%	6

2009 Greenhouse Gas Emissions with different N Sources in Hard Red Spring Wheat Production

By

Katy E. Smith

University of Minnesota-Crookston, Department of Math, Science and Technology

Experimental Conditions:

The experiment was conducted at one location on a Glyndon vfsl. The experimental design was a RCBD with four blocks (replications). The previous crop at both sites was soybean. Residual soil nitrate-N was 24 lbs. N A^{-1}. Knudson HRSW was planted at 1.6 million seed A^{-1}. Individual plot size was 25-ft long and 5-ft wide accommodating 10 seed rows spaced 6-inches apart. Plots were sampled for gas emissions weekly initiating after the spring fertilizer application and wheat planting and continued until harvest. Estimating fluxes of greenhouse gases involved placing bases in each plot that stayed in that location for the remainder of the growing season. On each sampling date chamber tops were placed on the bases and air samples were pulled at 15 minute intervals for 45 minutes. These samples were placed in gas tight vials using a syringe. Once collected, the concentration of the greenhouse gases in the sample was quantified using a gas chromatograph (GC) equipped with a thermal conductivity detector (TCD), flame ionization detector (FID), and an electroconductivity detector (ECD). The TCD detector detects the CO_2, the FID detector detects the CH_4, and the ECD detector detects gaseous N as N_2O. Concentration of these gases was quantified by comparison to standards which are also analyzed using the GC. Flux rate was determined by the change in gas concentration over time and fitting the data to either a linear or curvilinear model. This procedure is used by a GRACeNET, a group of USDA ARS scientists monitoring greenhouse gas emissions across the country

Treatments were four N sources at two N rates plus a 0-N control. The two N rates were 60 and 120 lbs N A^{-1} representing half and full recommended rates for a 65 bushel yield goal. The four N sources were commercially available urea, environmentally smart nitrogen (ESN), Nutrisphere (NSN), and SuperU.

Statistical analysis was done using the general linear model of SAS. The results of CO_2 and CH_4 did not show a significant interaction between our main effects; however the N_2O data had a significant interaction between the N source and the N rate; therefore graphs of CO_2 and CH_4 data are averaged across rate, whereas graphs of N_2O data are not. Means were identified as different using the least significant difference test at an alpha level of 0.05.

Results:

General:

The 2009 growing season tended to have adequate moisture. Temperatures were below normal for the majority of the growing season. The cool temperatures along with the spring flooding (causing a delay in planting) did delay physiological development and maturity resulting in delayed harvests. The plots were harvested on September 1, and the final gas sampling date was August 24.

Soil CO_2 Flux:

When averaged across the growing season, N source and N rate did not significantly impact soil CO_2 flux. Significant differences were found on only 2 of the 15 sampling dates (7/27 and 8/4) between N fertilizer sources. On the two dates that showed significant differences, the ESN treated plots had significantly higher soil CO_2 flux than some of the other treatments, but not the control. This is most likely because the ESN is a slow release fertilizer and would have had still been releasing nitrogen at this point in the season which would have stimulated microbial mineralization of soil organic matter and thus resulted in a slightly higher, yet significantly different, soil CO_2 flux. Although the difference between treatments on these dates was significantly different, the magnitude of the difference was relatively small (Figure 1) and thus did not impact the overall results indicating that N source did not significantly impact soil CO_2 emissions during the season.

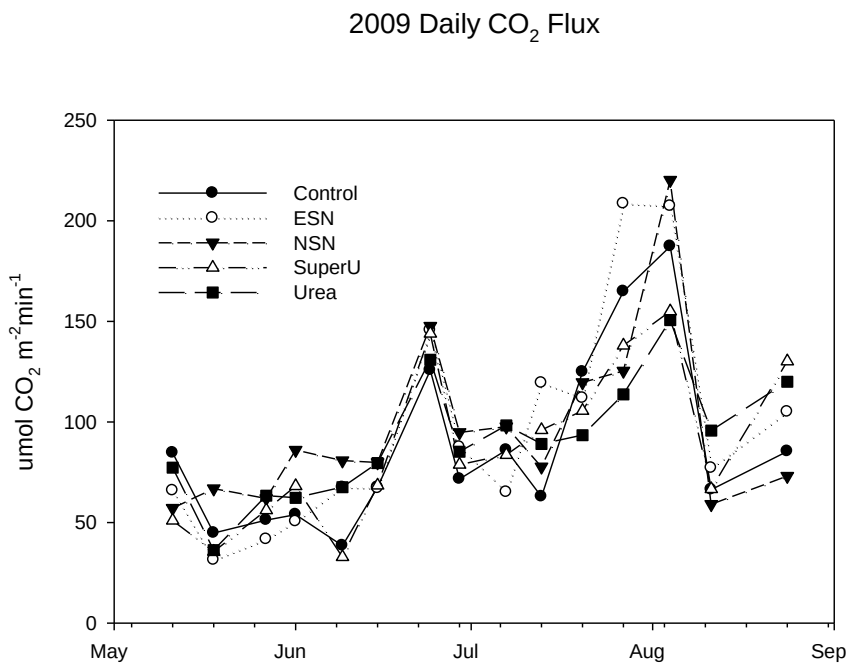


Figure 1. 2009 Daily CO_2 Flux. Control= no treatment; ESN=environmentally smart nitrogen; NSN-nutrisphere N; SuperU=Urea with agrotain mixed in a pelletized form; Urea

Soil CH_4 Flux:

When averaged across the growing season, neither N source or N rate significantly impacted soil CH4 emissions. As with the soil CO_2 flux, there were two sampling dateswith significant differences (7/7 and 7/27). The trend of significance was not the same on the two dates with urea having significantly higher CH_4 flux than all other treatments on 7/7 and with the Control having a significantly higher CH_4 flux on 7/27 (Figure 2). In all cases, the emissions of CH_4 across treatments was very low and often negative indicating the CH_4 emissions had very little impact on the global warming potential of this system regardless of N source of N rate.

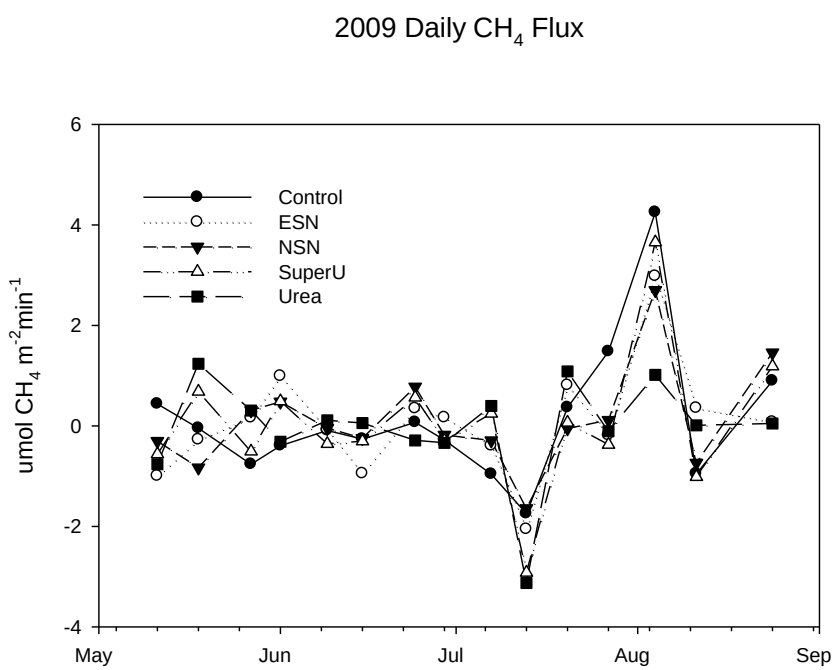


Figure 2. 2009 Daily CH_4 Flux. Control= no treatment; ESN=environmentally smart nitrogen; NSN-nutrisphere N; SuperU=Urea with agrotain mixed in a pelletized form; Urea

Soil N_2O Flux:

When averaged across the entire growing season; N source, N rate and the interaction between N source and N rate showed significant differences in soil N_2O flux. Data showed that when the urea was used as the N source, it had significantly higher (0.08686 umol $m^{-2}min^{-1}$; $p<0.05$) than the Super U (0.02596 umol $m^{-2}min^{-1}$), Control (0.00636 umol $m^{-2}min^{-1}$), and ESN (0.00558 umol $m^{-2}min^{-1}$) treatments, but was not significantly different from the NSN (0.04041 umol $m^{-2}min^{-1}$ treatment). N rate also showed significant differences in soil N_2O flux with the 120 lbs N A^{-1} showing significantly higher (0.06144 umol $m^{-2}min^{-1}$; $p<0.05$) than the 60 lbs N A^{-1} and the control. In addition, the interaction between N source and N rate was significant with the Urea applied at the full recommended rate being significantly higher than all other treatments.

Several statistically significant differences existed throughout the growing season. Significant differences were found on 10 of the 15 sampling dates. These differences were found in the first 8 sampling dates (5/18, 5/27, 6/1, 6/9, 6/15, 6/24, 6/29, 7/7) and again later in the growing season (7/20, 7/27) (Figure 3). The majority of the sampling dates early in the season showed the Urea 100 (Urea applied at 100% of recommended rate) to have the highest soil N_2O flux followed by the NSN 100 (Nutrisphere nitrogen applied at 100% of the recommended rate). The trend on 7/20 was not consistent with the other sampling dates in that the ESN treatment showed significantly higher soil N_2O flux; although the magnitude of this difference was very small. The lsd on this date was 0.0025. So, the ESN 100 flux was 0.004892 umol $m^{-2}min^{-1}$ and the control was 0.01559 umol $m^{-2}min^{-1}$. These differences cannot be seen in Figure 3 due to the small magnitude of the difference. In addition, significant differences were observed on 7/27 with the NSN 50 having significantly higher N_2O flux than any other treatment. This trend is also not consistent

with results observed earlier in the season in that typically the treatments at the 100% of the recommended rate had higher soil N_2O flux.

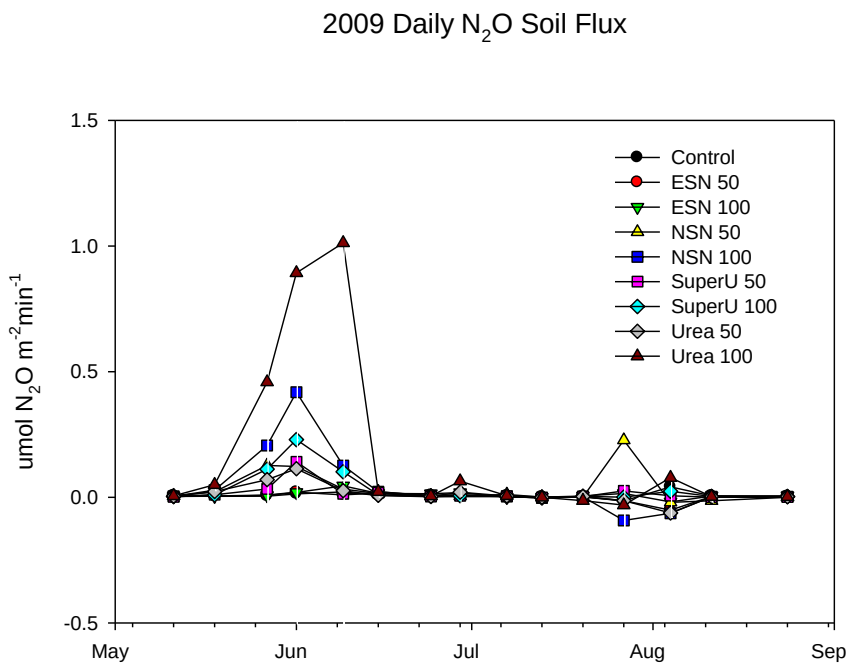


Figure 3. 2009 Daily N_2O Soil Flux. Control= no treatment; ESN=environmentally smart nitrogen; NSN-nutrisphere N; SuperU=Urea with agrotain mixed in a pelletized form; Urea.

Cummulative N_2O fluxes for the 2009 growing season were calculated using linear interpolation between adjacent sampling dates and stepwise adding consecutive dates (Figure 4). As can be seen in this Figure, despite the significantly higher fluxes of non-consistent treatments later in the season, the cumulative flux shows that the urea applied at 100% of the recommended rate showed significantly higher seasonal soil N_2O fluxes than all other treatments. The environmentally friendly products all showed reduced soil N_2O emissions. Within the environmentally friendly products, the NSN showed the highest N_2O emissions, followed by Super U and finally the ESN product.

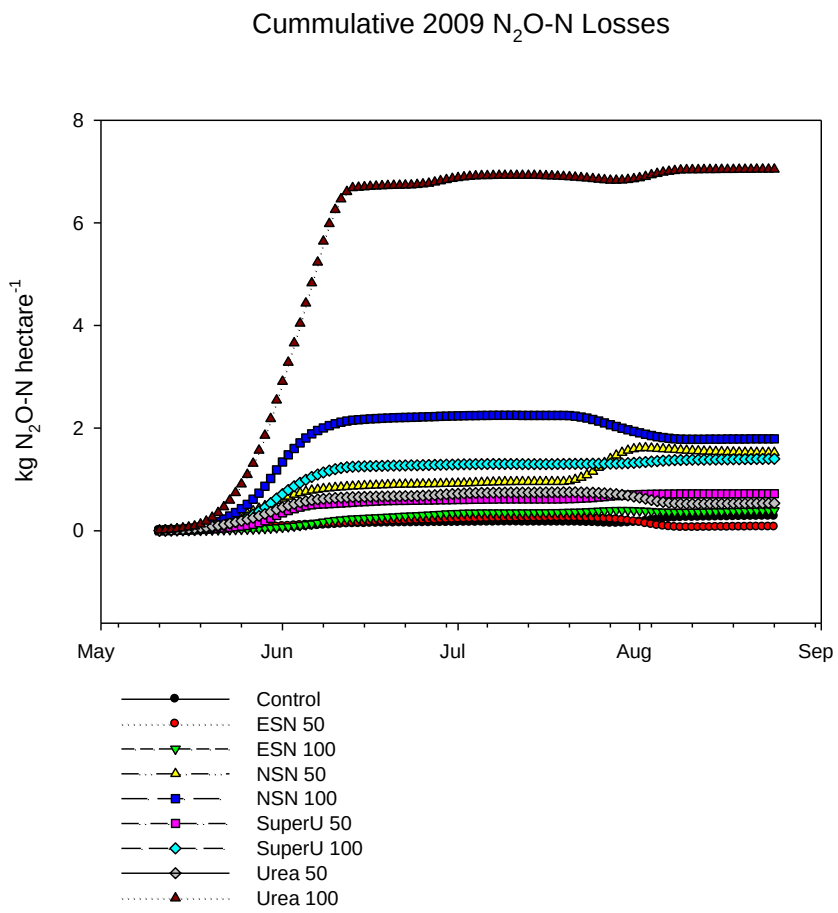


Figure 4. Cummulative soil N_2O-N losses in the 2009 growing season. . Control= no treatment; ESN=environmentally smart nitrogen; NSN-nutrisphere N; SuperU=Urea with agrotain mixed in a pelletized form; Urea.

Preliminary Conclusions:

Data from the 2009 growing season suggest that N source and N rate can significantly impact N_2O emissions, and thus the global warming potential of the agronomic system. This is encouraging considering that wheat yield was not significantly different between the different N sources in the 2009 growing season (see progress report by Albert Sims). In addition to showing reduced N_2O emissions and equal yield with the environmentally friendly fertilizer products one of the environmentally friendly products (ESN) actually showed a significantly higher protein content in the grain in the 2009 growing season (see progress report by Albert Sims). Taken together, data from 2009 indicate that we can reduce emissions of greenhouse gases while maintaining yield and actually achieving higher grain protein content. While these results are encouraging, we are cautious as the 2009 growing season was unusually wet and cool and field data can be variable depending upon environmental conditions. It will be interesting to continue this study in 2010 to determine the impact of these environmentally friendly N products on greenhouse gas emissions, wheat yield and protein content in a different growing season.

Humic Materials for Agriculture

By R.L. Mikkelsen

Humic materials...very large and complex molecules extracted from organic matter...have been used in many ways for plant production. There are numerous reports of plant response and also of no response to these materials. This article reviews their use in agriculture and points to consider before using humic materials.

Few agricultural products have been subject to more confusion and conflicting information than humic-type additives. The scientific literature is full of reports where humic additives have directly or indirectly stimulated plant growth. There are also many reports where no response was found following the use of humic substances.

Unlike fertilizer, which has a long history of documented research and university recommendations, humic acid is widely sold and used without as much detailed research. This brief review will cover the nature of humic substances and how they are currently being used in crop production.

Humic material can be extracted from soft brown coal-like deposits called leonardite, found with lignite coal.

What Are Humic Substances?

There is no one single chemical known as humic acid, since the chemical structure has never been completely defined. These materials are composed of complicated organic mixtures which are linked together in a random manner, resulting in extraordinarily complex materials (**Figure 1**). It has been suggested that no two molecules of humus are exactly the same. The special properties of humic materials result from this extreme heterogeneity and their high chemical reactivity.

Humic materials have an abundance of carboxyl groups and weakly acidic phenolic groups, which contribute to their complexation and ion-exchange properties. They exhibit both hydrophobic and hydrophilic characteristics and can bind to soil mineral surfaces.

Over the years, many methods have been used to extract humic acids from stable organic matter. Most commercially

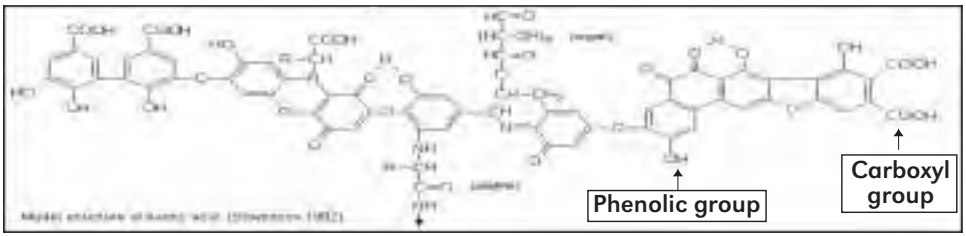


Figure 1. A simplified example of the structure of humic acid extracted from soil.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Data

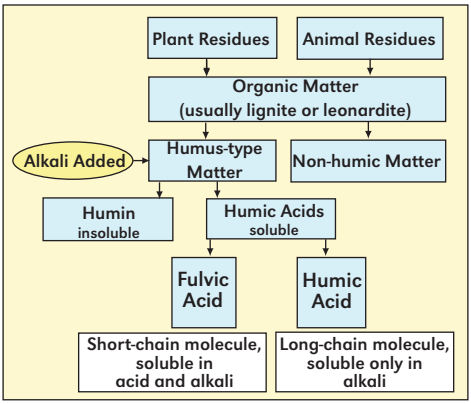


Figure 2. Common chemical extraction technique for extracting organic materials into various fractions commonly applied for crops.

available humic material is extracted from soft brown coal-like deposits with an alkali solution (**Figure 2**). Following extraction, it may be subjected to many secondary processes for stabilization and enhancement, including addition of nutrients. Given the wide range of extraction methods and processes used to produce commercial products, it is frequently difficult to compare specific materials.

With their high pH-dependent charge, when the cation exchange sites are filled primarily with hydrogen (H) ions, the material is considered an acid and is called humic acid. This material has no great effect on soil pH because this acid form is insoluble in water. When a cation other than H dominates the exchange sites, the material is technically called humate (a salt of humic acid). **Humic materials are not fertilizers, since they contain only small amounts of plant nutrients, but their potential usage has been classified as providing soil physical, chemical, and biological benefits.**

Use of Humic Substances

Physical benefits—The conditioning value of high rates of organic matter added to soil has long been known. Both fresh and stable organic matter provide benefits such as improved tilth, water retention, and a nutrient reservoir. However, consider that a soil containing just 1% organic matter has over 20,000 lb/A of organic matter.

Clearly, massive amounts of organic matter addition are required to make significant changes in this soil property, and usually this is a very long-term process. However, it may be feasible to make important changes in localized soil zones, such as the seedbed or in a fertilizer band.

Soil chemical benefits—Humic materials are able to complex various cations (pseudo-chelation) and serve as a sink for polyvalent cations in the soil. They have a negative surface charge at all pH values where crop growth occurs. Reports of improved cation availability following addition of humic materials are common. Detailed reviews of this phenomenon have been published elsewhere.

Essential micronutrient cations that might normally be expected to precipitate at pH ranges found in most soils are maintained in solution through complexation with many organic compounds. Enhanced plant growth following addition of humic materials has sometimes been related to increased micronutrient availability… especially iron (Fe) and zinc (Zn). There are also numerous reports of metal concentrations being reduced to non-toxic levels following addition of complexing organic matter.

Organic substances have been demonstrated to enhance the solubility of soil phosphorus (P) through complexation of Fe and aluminum (Al) in acid soils and calcium (Ca) in calcareous soils. For example, researchers at the University of Idaho showed positive yield and quality responses of potatoes to humic acid added to band-applied P in a calcareous soil. Other researchers have noted similar increases in nutrient availability for plants following the use of humic substances, although there is still much to learn about these reactions.

Biological benefits—-Numerous reasons have been proposed for the stimulatory plant responses sometimes seen following addition of humic materials.

(continued on page 10)

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Order

Figure 3. Cultivar differences in canopy appearance at 114 days after planting in 2004 at Jackson, Tennessee.

remobilization of carbohydrates in these cultivars, to improve their efficiency.

In short season environments like Tennessee, the likelihood of a satisfactory cotton crop is promoted by planting well-adapted, early maturing cultivars and managing them for earliness. **An important element in earliness management is a K fertility maintenance program based on annual soil test results and local extension recommendations.** BC

Dr. Gwathmey is Associate Professor of Crop Physiology in the Plant Sciences Department, University of Tennessee Agricultural Experiment Station, 605 Airways Blvd., Jackson, TN 38301; e-mail: cogwathmey@utk.edu.

Acknowledgment

Donation of planting seed by Delta and Pine Land Co. is appreciated.

PPI/FAR Research Project TN-19F

Humic Materials...from page 7

However, there is currently not enough research to explain possible mechanisms and accurately predict when humic materials might prove beneficial. There are reports of growth and yield responses from various conditions...from soil and foliar application...banded, broadcast, and fertigated applications...and solid and liquid humic formulation. Thus, defining the positive effect is difficult.

A benefit sometimes mentioned regarding humic material is that it can provide a carbon (C) source for soil microorganisms. This mechanism does not appear to be likely, since a typical application of 5 to 20 gal/A of humic material will supply only 3 to 15 lb C/A. Compare this with more than 4,000 lb of C/A returned in the residue of a typical corn crop. The hormonal effect of humic materials on plant growth has also been carefully studied and largely negated. Humic acids have been shown to function as a urease inhibitor and a nitrification inhibitor in some circumstances. The search for a biological explanation for the plant responses to humic materials will continue and will not be simple.

The use of humic materials in production agriculture continues to grow. There are numerous reports of both successful and unsuccessful use of these materials. Due to the wide variation in their raw materials and processing methods, it is difficult to accurately compare the efficacy of specific commercial products without careful study. Due to the range of recommendations for use, it is not easy to define a mode of action that can be applied across many crops, soils, and growing conditions.

Users of humic materials should keep careful records and conduct on-farm field trials to determine product effectiveness. Research organizations should continue to study the value of this expanding agricultural input. Remember that no additive will compensate for poor management and inadequate crop nutrition. BC

Dr. Mikkelsen is PPI West Region Director, located at Davis, California; e-mail: rmikkelsen@ppi-far.org.

Group 10 - T5
May 12, 2010 Workshop
Preliminary Draft Agricultural Data