TECHNICAL NOTE

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Boise, Idaho

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NITROGEN ASSIMILATION BY PLANTS
IMPORTANTS OF N TIMING
IN IDAHO'S SMALL GRAIN CROPS

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In Tech Note 6 we discussed the N Cycle and the different processes that N (N) undergoes within this natural cycle and the impact it has on Idaho's environment.

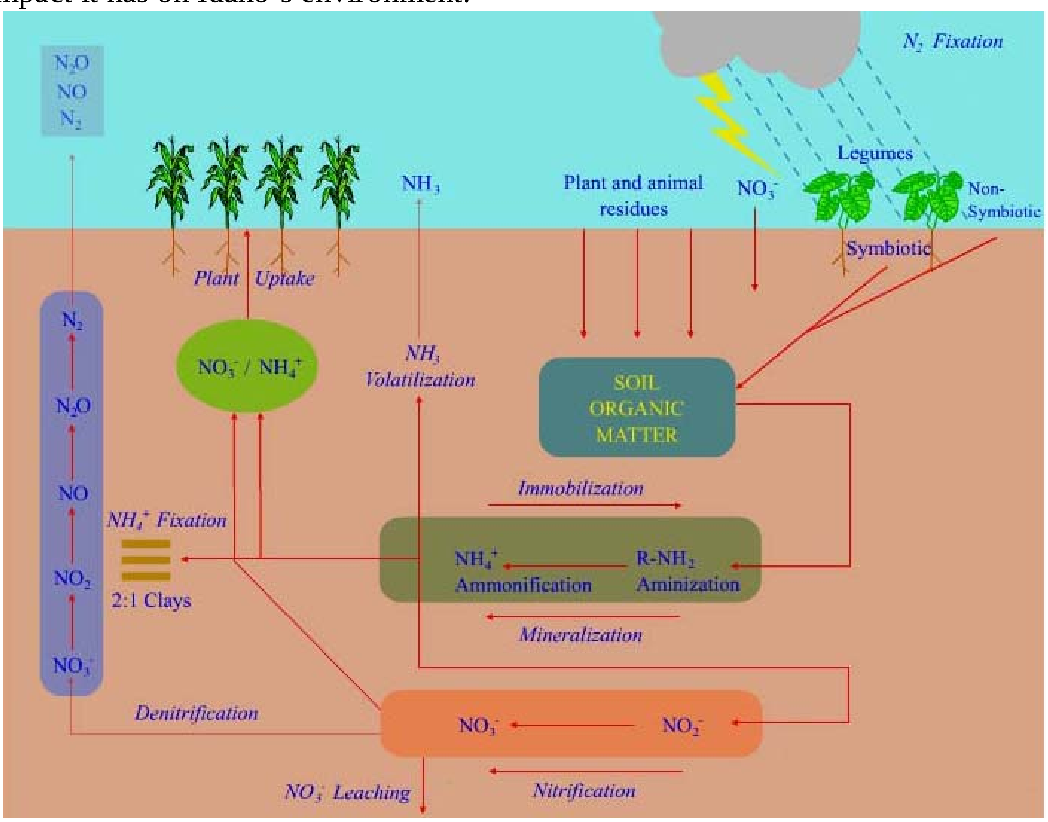


Figure 1. The N Cycle (**N** - Vision **Ag** Home)

This discussion will center on N Assimilation by plants and the importance of N timing in adopting the new National Nutrient Management Strategy of the 4R's: **Right Source of Nutrients; the Right Time of Application, the Right Rate, and the Right Method of Application.** Our National Nutrient Management Strategy of the 4R's is a strategy of assisting the producer in managing the application of N in meeting the Practice Specifications as outlined in the Idaho 590 Nutrient Management Standard, its option jobsheets and program guidelines. This emphasis is designed to address the need for a higher level of nutrient management using the 4R's to meet our National Water Quality objectives. This emphasis is a change in how we look at N management, a change from looking at increasing N use efficiency by increase yields or production economics to one that looks at the fact that as N rates increase there is a corresponding increase in risk to the environment.

N ASSIMILATION BY PLANTS

Cumulative biomass accumulation

N uptake by the typical crop in Idaho varies throughout its growing period. The following graph (Figure 1a) shows the cumulative biomass accumulation by the crop during the growing season (PNW 513). The sigmoid, or S-shaped, crop growth curve can be divided into three parts (designated by dotted lines):

- Slow growth early in the season (exponential)
- Rapid growth during midseason (linear)
- Slow growth (approaching a plateau) late in the season as the crop matures.

For most crops, the shift from vegetative growth (leaves, stems) to reproductive growth (seeds, tubers) occurs shortly after the crop attains maximum leaf area. Some crops (wheat, grass seed, potatoes) are harvested at plant maturity. Other crops (alfalfa, peppermint) are harvested during the period of rapid, linear growth.

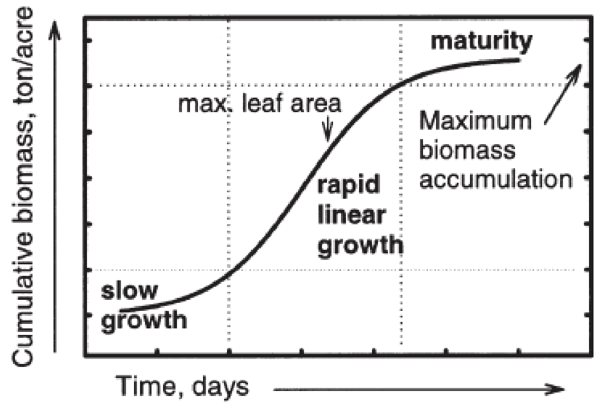


Figure 2a.—Example biomass curve.

Cumulative N uptake

This graph (Figure 2b) shows the cumulative above ground N uptake by the crop during the growing season. Cumulative N uptake also follows a sigmoid curve over the growing season. This sigmoid curve is divided into three phases:

- Phase I: Slow N uptake corresponding to slow early growth
- Phase II: Rapid N uptake as the crop grows rapidly, increasing its leaf area
- Phase III: Slow or no crop N uptake.

During Phase III, N is redistributed within the plant from leaves to stems or reproductive structures (tubers, seeds). Biomass continues to accumulate.

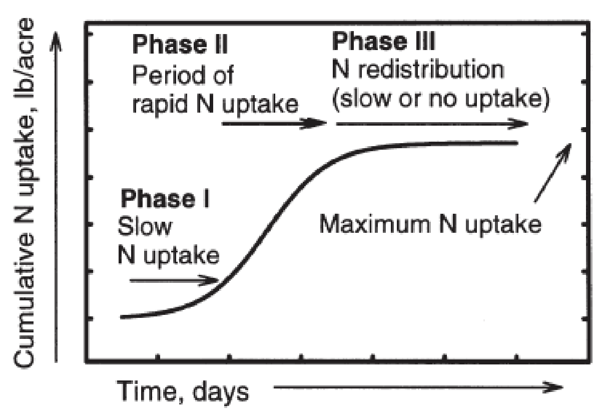


Figure 2b.—Example cumulative N uptake curve.

The period of rapid N uptake begins about the time of rapid biomass accumulation (see Figure 2a); it is complete long before the crop reaches maturity. The maximum amount of above-ground crop N is called "maximum N uptake." For crops that are not grown to maturity, maximum N uptake is the N uptake at harvest.

N uptake rate

The N uptake rate curve in this graph (Figure 2c) is mathematically derived from the cumulative N uptake graph (Figure 1b). N uptake rate is the slope of the cumulative N uptake curve at any point in time. The maximum N uptake rate gives an indication of how rapidly the crop utilizes N during the period of rapid N uptake.

General Principles

The assimilation of N in field crops is primarily through the roots of the plant, the exception being foliar application of urea-N with absorption through the leaf. Early in the physiological stages of a plant, both ammonium and nitrate are taken up by the plant. Often ammonium is taken up early in the development of the plant roots due to early root activity in the organic enriched surface soil and dominance of ammonium early in the spring prior to spring warm-up and increased nitrification. This uptake takes place through the root cap area (zone of division and elongation) and is dependent on the root growth. Later as the weather warms, transpiration in the plant increases, surface soil warm and increased nitrification, then nitrate-N becomes the major N assimilated. We use this fact to develop method of evaluating N in the plant and to determine what part of the plant to sample. This will be discussed later.

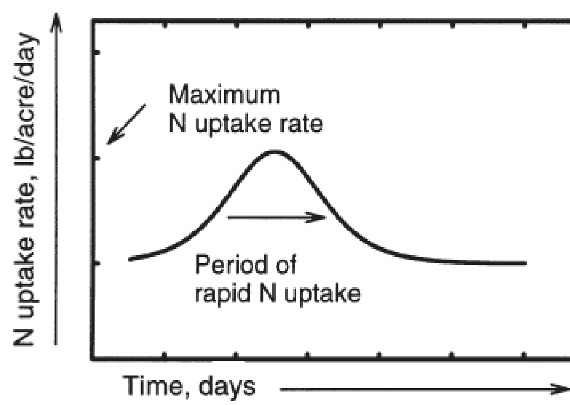
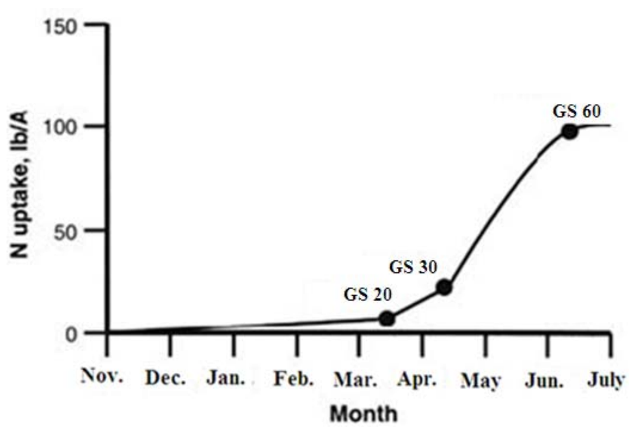


Figure 1c.—Example N uptake rate curve.

To discussion N assimilation in the crop, I am using winter wheat as the example. Winter wheat was chosen because of it is produced throughout the state. N management and efficient N (N) fertilization is crucial to the economics of wheat production and the timing of N application has a significant impact on ground and surface water resources throughout the state. Excessive plant-available N produces a crop, in the case of winter wheat, that is susceptible to lodging and disease with resulting decreased yields and increased input costs. The potential for enrichment of ground and surface waters with nitrates also increases with excessive N fertilizer applications. However, insufficient N availability to wheat plants results in low yields and significantly



reduced profits compared to a properly fertilized crop. N fertilizer rate and timing are the major tools available after planting to manipulate wheat to produce higher yields per acre with increase N use corn, sugar beet or potatoes. Table 3. lists several crops from the Pacific NW showing the typical data of

Table —Examples of crop N uptake during the period of rapid N uptake (Phase II).[a]

Crop	Location[b]	Phase II period dates	Phase II period growth stage		Maximum N uptake rate (lb N/a/day)	Phase II N uptake (lb N/a)
Winter wheat (soft white)	WV	1 Mar to 30 Apr	jointing	heading	2 to 3	60
Tall fescue and perennial ryegrass for seed	WV	1 Apr to 30 Apr	jointing	heading	2 to 3	70
Hops	WV	10 Jun to 10 July	vegetative	cone initiation	3 to 4	80
Peppermint (unflamed)	WV	10 May to 1 Aug	3 to 6 in high	harvest	1 to 2	80
Peppermint (flamed)	WV	1 June to 1 Aug	3 to 6 in high	harvest	2 to 3	160
Potatoes (Russet Burbank)	CB	40 to 100 days after planting	late vegetative Growth Stage I	middle of tuber Growth Stage III	4 to 5	150
Onions (dry bulb)	TV	1 July to 15 Aug	6 to 8 leaf	tops down	1 to 2	70

[a] Example data are derived from crop N uptake curves presented in Figures 2–10. Crop N uptake rate varies with cultivar, plant population, cultural practices, and climate.

[b] Locations: WV = Willamette Valley, OR; CB = Columbia Basin, WA; TV = Treasure Valley, ID.

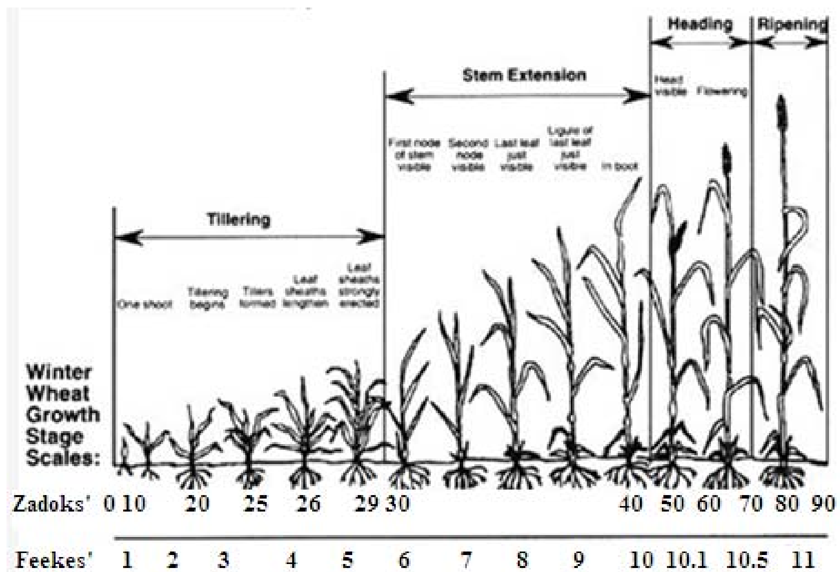
Phase II (rapid uptake) and the maximum N uptake rate in lb-N/ac/day. The data shows the importance of having positional N in the soil at or during this period.

The winter wheat plant has a generalized N uptake pattern that is depicted by the following curve. A crop that is planted on time for a particular location germinates, emerges, and tillers prior to the dormancy period that generally begins in Mid-November. Dry matter production and thus N requirement is rather low during the autumn, but N is required to establish the crop and promote the production of fall tillers. Fall tillers are those that will begin growth first in the spring, and generally produce heads with more kernels. The Root systems are also developed in the autumn, and are generally larger than the top growth. Well-developed roots reduce winter-kill and prepare the plant to efficiently utilize nutrients and moisture from the soil. N fertilization in excess of the amount which the plant can utilize prior to dormancy creates the potential for leaching losses of the N. Plants with excessive fall growth are also more susceptible to disease infection and winter-kill. Hence, a moderate amount (15-30 lbs. of N/acre) is all that is needed for establishing a timely-planted winter wheat crop.

The wheat crop utilizes very little N during winter dormancy. N applied early in the dormancy period is subject to leaching and/or run-off losses. Applying large amounts of N on frozen and snow covered ground, and expecting this N to be available for producing grain in April and May, is not reasonable because of climatic conditions, potential for ammonia volatilization from applied urea, and the growth pattern of wheat. However, there are situations, particularly on very sandy soils in Southern Idaho, in which a small N application in March may be beneficial. Such conditions might warrant an application of 30 lbs. of N per acre to encourage tillering and root growth. However, potential losses to the environment are great with such applications, and they should be made only after careful consideration of the specific field conditions, and the N application should not exceed 30 lbs. N/acre.

The wheat crop typically breaks dormancy in late March/early April in most areas of Idaho. As growth begins so does the crop's requirement for N. Late winter/early spring growth is characterized by further tillering of the crop prior to stem elongation. Since the initial growth is usually rather slow because of cool temperatures, the initial N fertilizer application should be as near to the initiation of growth as it is possible to estimate for important, however, to realize that fields with low tiller numbers should receive spring top-dress on N so that tiller production is not delayed due to a lack of plant-available N.

The N uptake curve shows that N uptake is usually not great during the period of mid-February to mid-April. Again, this closely matches the growth or dry-matter production pattern for the crop.



Excessive N applications during the early-spring tillering phase can result in spindly plants that are more likely to lodge and be susceptible to diseases such as powdery mildew. The leaf sheath erection growth phase, Zadoks GS 30, signals the beginning of stem elongation and the most rapid phase of wheat growth. Two important factors are occurring during this time. First, the potential number of kernels per head is being established during the embryonic formation of the head. Second, rapid N uptake begins. Management must now be directed to maintaining developing heads. Inadequate available N causes tiller abortion with resulting lowered harvest population. Some tillers will always be lost. However, stands with marginal populations at the end of tillering are likely to have lower yields due to low numbers of heads/sq. ft. at harvest. The initial phase of head development is occurring at GS 30. The late winter/early spring N application should be adequate to develop the embryonic head.

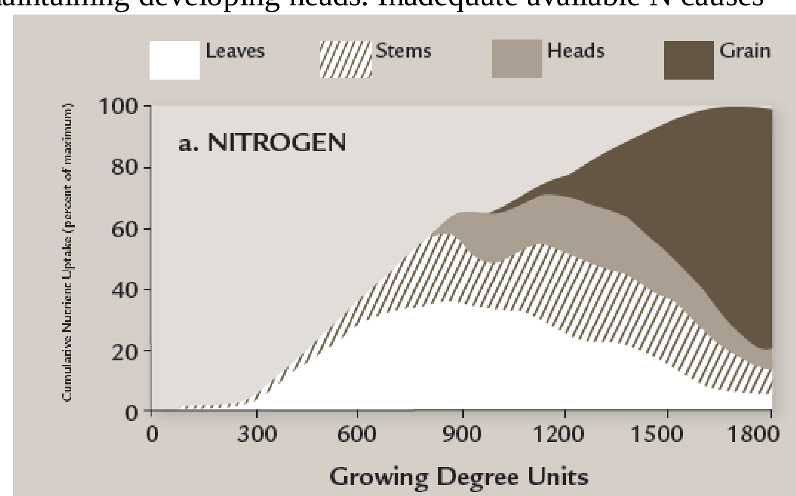


FIGURE 2. Nutrient accumulation in leaves, stems, head and grain of irrigated hard red spring wheat as a percent of each nutrient's maximum. Growing Degree Units are cumulative average daily temperature as defined in the text. This figure was modified from its original *(4)*.

Nutrient Uptake Timing by Crops to assist with fertilizing decisions EB0191

Visually, the crop should have a medium to dark green color and be vigorously growing by GS 30. If the crop is beginning to show signs of chlorosis (yellowing), then the application of N at this stage is critical for the development of adequate head size. Priority should be given to N treatments for crops showing a lack of adequate N at this stage of growth. The question of N fertilizer amounts at this growth stage will be discussed in a later section of this report.

Finally, GS 30 indicates that the wheat plant is about to embark on it's most rapid period of vegetative growth in order to build a structure for producing carbohydrate to fill the grain. The largest period of N uptake beginning Mid April through the first two weeks of June (flowering) for a well-fertilized crop grown under Idaho climatic conditions. This is where it all comes together and based on whether the crop is produced under non-irrigation or irrigation will be measured how well the producer has managed N.

For the dryland or non-irrigated producer, it's knowing the fields, their soils and second guessing the weather, particularly, winter and early spring moisture. The key is when to apply the N and applying the right form of N that will be available to the crop following GS 30, when the greatest N amount is required by the crop. The timing of N application is going to be dependent on the form and method of application that a producer can used, which makes it difficult for development of program policy under Idaho's climatic conditions. One program may not fit all precipitation zones across Idaho. For the farmer who has the privilege of irrigation, it's easier to management N timing and rates, with the exception when weather delays irrigation and the ability to apply water-run or fertigation N. Under both scenarios, knowing the growth stage of the crop and managing N to assure optimum yields is critical in N use efficiency and reduction of having N get away from the crop and into the environment. The key is working with the producer and making the best fit decision.

During the post GS 30 to GS 60 period, fertilizer management must provide for the crop requirement during this phase in order to have adequate leaf area for producing profitable yields. An important consideration to think about when discussing N management options with the producer is that during the post GS 30 to GS 60 period (Stem Extension and Heading) there is very little chance for leaching loss of N fertilizer when applied near the beginning of this growth phase due to the extensive growth of the wheat root system by GS 30 and the relatively high rates of evapotranspiration provides an major sink for nitrate-N uptake by the crop during this time period.

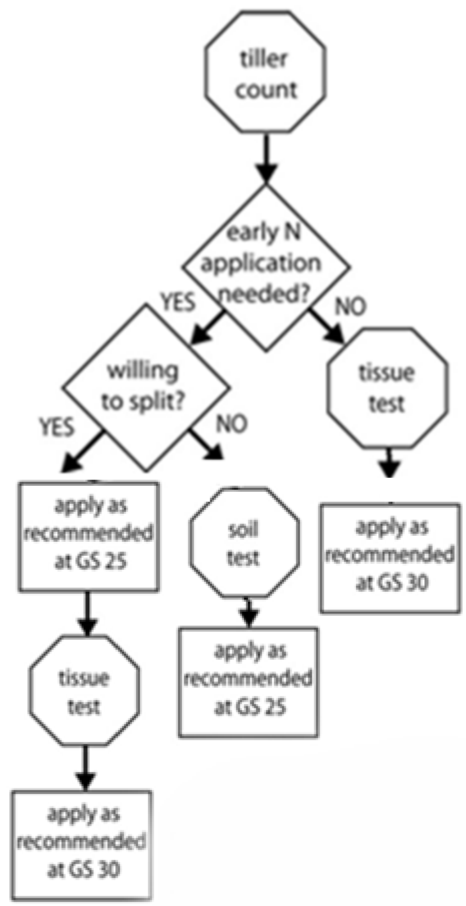
N uptake during the grain-fill period (early June through July) is relatively low compared to uptake during the stem elongation phase of growth. Plant tissue N is mobilized and translocated to the grain during this period with only small additions coming from available soil N. Research has shown no yield increases from N fertilizer applications at or after flowering. Foliar applications (10 to 20 lbs. N/acre) of urea at this growth stage have been shown to increase grain protein but not yield. If such applications are made, they should be made in sufficient volumes of water (20 to 30 gallons/acre) to reduce the potential for foliar burn.

Seedbed Considerations

Plant available N is needed in the surface soil during the germination and development of the wheat seedling in order to promote tillering and root development. Our difficulty is the FGs are based on foot increments for soil sampling for development of the N budget. In this new approach, the seedbed sample is the top 6 inches of soil. The reason for this is research has shown that if soil nitrate levels are less than 10 ppm NO_3^--N in the top 6 inches of soil, the emerging seedlings and developing tillers are likely to exhibit N deficiency symptoms. Extractable nitrate-N levels of 30 ppm NO_3^--N in the surface 6 inches of soil indicate a high level of N availability and no fertilizer N application is required. Research has also shown that applying 15 to 30 lbs-N/acre just before planting and prior to tillering GS 20 will stimulate tillering and root development in those situations where residual N availability is less than the desired 10 ppm NO_3^--N. If the N fertilizer is applied pre-plant the N fertilizer should be incorporated in the surface 2 to 4 inches for conventional tillage systems. Surface applications have been found to be adequate for no-till.

Early Spring Consideration (Split N Applications)

The flow chart on the next page summarizes an approach to determining the optimum economic late winter/early spring N rates for winter wheat. The system relies on tests which are field specific and is flexible to be able to be used by growers who will split their late winter/early spring N applications as well as those growers who choose not to split their N fertilizer application. As shown in the chart, all growers, whether they plan to split their N or not, should start by making tiller counts to determine whether an early N application is needed to stimulate tiller development. The rate of the first application of a split is based on a tiller count and the rate of the second application is based on a tissue test.



For growers not willing to split, when tiller numbers are low a single application should be made at growth stage GS 10 with rate based on a soil nitrate test; and when tiller numbers are adequate a single application should be made at GS 30 with rate based on a tissue test. The growers that are not encouraged to utilize an N inhibitor, or slow or controlled release N source. If the producers are top-dressing using a fertilizer containing urea form of N they should be encouraged to use a urease inhibitor. The flow chart shows how to obtain field-specific N rate recommendations for late winter/early spring N applications. A tiller count should be the first step in all fields, regardless of whether spring N applications will be split or not; then

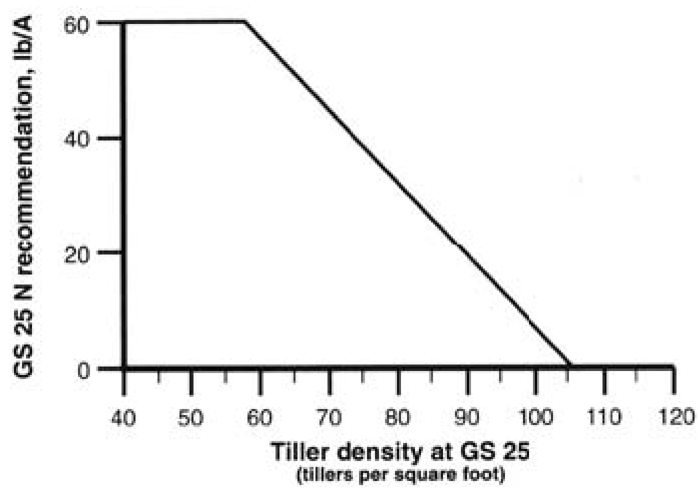
follow the arrows. The first application in a split is made when the wheat crop breaks dormancy and begins active growth. This usually occurs in late March, and is also known as "spring greenup." As a side note, this corresponds closely to 450-500 Spring Growing Degree Days based on 32°F ($GDD_{(32°F)}$).
Where $GDD_{(32°F)} = (T_{max}-T_{min})/2-32$. Another way to determine this awakening of the dormant wheat plant is the presence of “white fuzzy root” on the seminal lateral tiller roots. The purpose of the first N application in a split is to stimulate formation of additional tillers when such stimulation is necessary to achieve optimum tiller density. The main nutritional needs of the crop will be supplied by the second application in the split.

The rate recommendation for the first application in a split is based on tiller density measurements. To measure tiller density:

1. cut a dowel rod to a 3-foot length,
2. lay the dowel down next to an average-looking row and count **all** tillers with three or more leaves that are found in the 3-foot length, record this number;
3. repeat this count in **at least** five other locations that are well-spaced around the field;
4. average all tiller counts from the field;
5. calculate tiller density (in tillers per square foot) with the following equation:

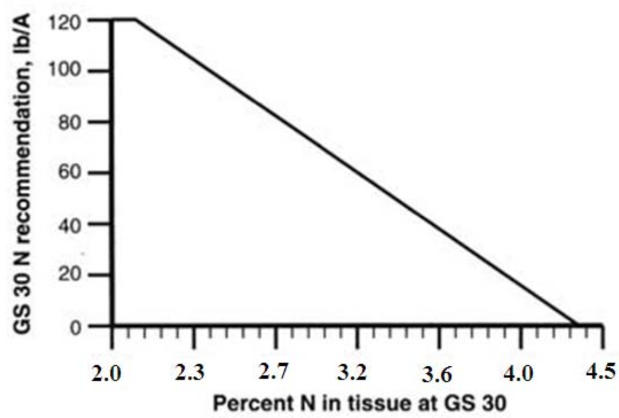
Tiller Density= (Average Tiller Count X 4) / row width (in inches).

Use the graph to the right to get a rate recommendation from the tiller density measurement. If tiller numbers are low, 50/sq. ft. or less, N fertilization at this time is critical for the crop to develop any reasonable yield potential. Fields with low tiller counts should be fertilized before fields with more tillers, if possible. If tiller numbers are high, 100/sq. ft. or more, no N application is needed at this time. When winter precipitation is above average and may have lowered the level of residual soil N, you should consider adjusting the recommendation upward.

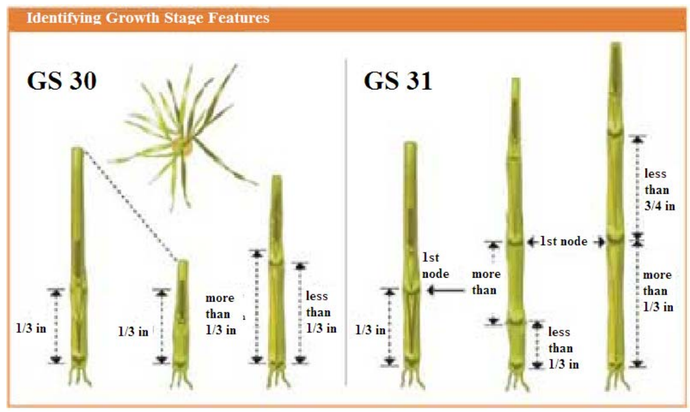


The second application in a split is made just prior to the period of maximum N uptake (GS 30). If you're keeping track of GDD it is about 300 to 600 GDD $_{(32^{o}F)}$. Its purpose is to supply the main nutritional needs of the crop to the extent that they are not already satisfied by soil N and the first N application (if any).

Research on winter wheat has shown that tissue N content at growth stage GS 30 is a reliable indicator of how much additional N fertilizer is needed to ensure that the nutritional needs of the crop are met. Use the graph to the right to obtain a rate recommendation from tissue test results. This data and rates are based on Pacific Northwest Universities (Idaho, Oregon and Washington) Research. A maximum of 120 lbs-N/acre should be the target application at GS 30 if no N was applied at GS 25 (due to high tiller density) and tissue N measured at growth stage 30 is low. Total spring N applications (GS 25 plus GS 30) should not exceed a total of 120 lbs-N/acre in order to avoid problems with lodging and yield loss. For example, if 40 lbs-N/acre was applied at GS 25 and tissue test results give a recommendation of 100 lbs-N/acre at GS 30, only 80 lbs-N/acre should be applied at GS 30.



The first requirement for obtaining a good plant tissue sample for use in estimating N fertilizer requirement at GS 30 is to be certain that the wheat is in growth stage 30. Growth stage 30 is when the leaf sheaths of the wheat are strongly erected and splitting the stem shows a hollow internode area about 1/2 inches in length. GS 31 has been reached when the first node of the stem is visible at the base of the plant. Sampling at the correct stage of growth is very important. Rapid growth during this time results in the N content being diluted by increases in dry matter production. Samples taken earlier than GS 30 will generally show higher concentrations of N than will be found at GS 30. If these higher %N values were used for predicting the N fertilizer needed on a given field, a less than optimum N fertilizer recommendation would result. Samples taken after GS 30 will usually show lower percent N concentrations, which can result in higher than needed N fertilizer recommendations. Thus, proper identification of GS 30 is essential to making good use of this system.



A representative tissue sample from the field is essential for accurately predicting fertilizer N requirement at GS 30. Obtaining a representative tissue sample is similar to obtaining a representative soil sample. Unusual areas of the field should be avoided. If major differences in top-growth and apparent residual N availability are evident in large areas of the field, the areas should be sampled (and fertilized) separately. The sample is taken by cutting a handful of wheat tissue at 20 to 30 representative areas in the field. The top-growth should be cut at approximately 1/2 inch above ground; soil particles clinging to the tissue must be brushed from the tissue; and dead leaf tissue must be removed from the sample. The individual samples should be placed in a paper bag large enough to allow good mixing of the tissue.

After thorough mixing of the tissue sample, take approximately three handfuls of tissue from the mixed sample and place in the sample bag provided by the laboratory, or in a clean paper bag. Samples should go directly to the laboratory. If samples cannot be analyzed within 24 hours from the time they are taken, they must be dried to prevent spoilage. Tissue samples should never be packaged in plastic bags due to condensation that can initiate sample decay.

Table 1. Nutrient sufficiency levels from whole wheat plant tissue samples taken at GS 30.

Nutrient							
S*	P	K	Mg	B	Zn	Mn	Cu
------------%-----------				------ppm--------			
0.25	0.25	2.0	0.10	3	12	20	3
"Sufficient level"							

*An N/S ratio of less than 15 indicates adequate sulfur content in relation to N content of the tissue.

The plant tissue sample taken at GS 30 can also be analyzed for nutrients other than N. These analyses can be useful in detecting nutritional problems which can possibly be corrected at the time of making the GS 30 N application. The following table contains values for sufficiency levels of selected nutrients. These values are considered sufficient based on limited research and numerous observations of data from tissue samples taken at GS 30 in intensive wheat management demonstrations.

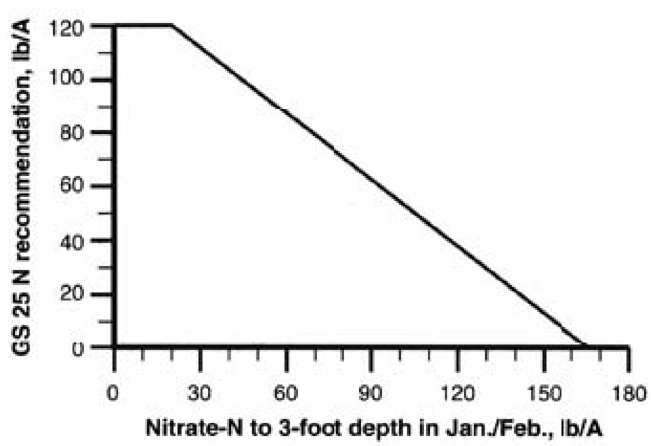
In situations where heavy rains occur during the several weeks prior to taking the GS 30 tissue sample, recommendations should probably be adjusted upward. This is especially true on sandy-textured soils. Situations in which a downward adjustment of the recommendation should be considered include soils that have received manure or sludge applications, soils with high organic matter levels, and clayey-loamy textured soils.

Single-application management

Split spring N applications often produce higher yields than can be produced with any rate or timing in a single application. As we try to improve the efficiency of applied N the ideal situation is to recommend splitting spring N applications wherever possible. However, logistical reasons because of field conditions, climatic conditions, or the fact of too many acres for the level of management required in Split-application management, prompt some growers to make only a single late winter/early spring N application on some or all of their wheat acreage. If this is the case, then there are two choices, if the producer can split on only part of your acreage, splitting is more likely to be beneficial on sandier land or are subject to run-off and potential leaching. For the same reason, it is preferable to make single N applications late (GS 30) rather than early (GS 25). If a field is low in tillers, however, waiting until GS 30 (when tillering has ended) to make a single N application can seriously damage yield potential.

The first step in single-application N management is to determine whether there are an adequate number of tillers in a particular field. Count tillers and calculate tiller density as described in the above section, "First application in a split." If you have 90 or more tillers per square foot, it is recommended to wait until GS 30 and making a single N application then based on a tissue test. With 90 or more tillers per square foot, delaying your single application until GS 30 is beneficial not only because it reduces the chance of N loss by leaching, but because a single early application will result in **too many** tillers, leading to spindly shoots, too many leaves, and increased probability of disease and lodging. In most cases, a single N application at GS 30 is economically superior to a single application at GS 25 when tiller density is between 70 and 90 tillers/square foot at GS 25. How to take a tissue sample and obtain an N rate recommendation for GS 30 are described in the above section, "Second application in a split."

When tiller density at GS 25 is below 70 tillers/square foot, "single-shot" N applications should be made at GS 25. Fields with the lowest tiller densities should be fertilized first, where possible. The rate of N to be applied can be based on a measurement of soil nitrate-N in the top 3-foot soil depth plus the soil ammonium-N in the first foot. This test, while producing recommendations that are economically superior to a fixed rate of 80 lbs-N/acre, is not as reliable as the GS 30 tissue-test. This is another reason why a single late application is



preferable when tiller numbers are adequate.

The samples should be divided into three 1-foot increments to determine the nitrate distribution in the soil profile. Results (in ppm) from each 1-foot layer should be multiplied by 3.5 in Northern Idaho and 4.0 for Southern Idaho to convert to lbs-N/acre.

If soil nitrate levels are very high, i.e. 120 to 150 lbs-nitrate-N per acre, then little if any yield response will be expected from applying additional fertilizer N in a single application program. Such soil nitrate levels are most likely to be found in loam and silt loam soils or soils with sandy surface textures and high levels of clay in the subsoil; tiller numbers for a timely planted crop will generally be high on these soils.

In summary

N Assimilation by plants is an importance of consideration in adopting the new National Nutrient Management Strategy of the 4R's: **Right Source of Nutrients; the Right Time of Application, the Right Rate, and the Right Method of Application.** N uptake by the typical crop in Idaho takes on a sigmoid, or S-shaped, crop growth curve, which can be divided into three parts (designated by dotted lines):

- Slow growth early in the season (exponential)
- Rapid growth during midseason (linear)
- Slow growth (approaching a plateau) late in the season as the crop matures.

For most crops, the shift from vegetative growth (leaves, stems) to reproductive growth (seeds, tubers) occurs shortly after the crop attains maximum leaf area. Some crops (wheat, grass seed, potatoes) are harvested at plant maturity. Other crops (alfalfa, peppermint) are harvested during the period of rapid, linear growth. Cumulative N uptake also follows a sigmoid curve over the growing season. This sigmoid curve is divided into three phases:

- Phase I: Slow N uptake corresponding to slow early growth
- Phase II: Rapid N uptake as the crop grows rapidly, increasing its leaf area
- Phase III: Slow or no crop N uptake. During Phase III, N is redistributed within the plant from leaves to stems or reproductive structures (tubers, seeds). Biomass continues to accumulate. The period of rapid N uptake begins about the time of rapid biomass accumulation; it is complete long before the crop reaches maturity. The maximum amount of above-ground crop N is called "maximum N uptake." For crops that are not grown to maturity, maximum N uptake is the N uptake at harvest. The assimilation of N in field crops is primarily through the roots of the plant, the exception being foliar application of urea-N with absorption through the leaf. Early in the physiological stages of a plant, both ammonium and nitrate are taken up by the plant. Often ammonium is taken up early in the development of the plant roots due to early root activity in the organic enriched surface soil and dominance of ammonium early in the spring prior to spring warm-up and increased nitrification. This uptake takes place through the root cap area (zone of division and elongation) and is dependent on the root growth. Later as the weather warms, transpiration in the plant increases, surface soil warm and increased nitrification, then nitrate-N becomes the major N assimilated. We use this fact to develop method of evaluating N in the plant and to determine what part of the plant to sample.

Winter wheat was chosen to discuss N Assimilation because of it is produced throughout the state. N management and efficient N fertilization is crucial to the economics of wheat production and the timing of N application has a significant impact on ground and surface water resources throughout the state. Excessive plant-available N produces a crop, in the case of winter wheat, that is susceptible to lodging and disease with resulting decreased yields and increased input costs. The potential for enrichment of ground and surface waters with nitrates also increases with excessive N fertilizer applications. However, insufficient N availability to wheat plants results in low yields and significantly reduced profits compared to a properly fertilized crop. N fertilizer rate and timing are the major tools available after planting to manipulate wheat to produce higher yields per acre with increase N use corn, sugar beet or potatoes. Each Phase of nutrient uptake is critical to the crop and how N fertilizer is applied is critical to whether that N is going to have a negative effect on the environment. Winter wheat plant has a generalized N uptake pattern that is depicted by the S-Shaped uptake curve. The crop is planted, germinates, emerges, and tillers prior to the dormancy period over the winter. Dry matter production and thus N requirement is rather low during the autumn and early winter, but N is required to establish the crop and promote the production of fall tillers. Fall tillers are those that will begin growth first in the spring, and generally produce heads with more kernels. N applied early in the dormancy period is subject to leaching and/or run-off losses. Applying large amounts of N on frozen and snow covered ground, and expecting this N to be available for producing grain in April and May, is not reasonable because of climatic conditions, potential for ammonia volatilization from applied urea, and the growth pattern of wheat. The wheat crop typically breaks dormancy in late March/early April in most areas of Idaho. As growth begins so does the crop's requirement for N. Late winter/early spring growth is characterized by further tillering of the crop prior to stem elongation. Since the initial growth is usually rather slow because of cool temperatures, the initial N fertilizer application should be as near to the initiation of growth as it is possible to estimate for important, however, to realize that fields with low tiller numbers should receive spring top-dress on N so that tiller production is not delayed due to a lack of plant-available N.

Growth Stages and Growing Degree Days can be used to assist the planner in when to apply N for optimum N nutrient management. Excessive N applications during the early-spring tillering phase can result in spindly plants that are more likely to lodge and be susceptible to diseases such as powdery mildew. The leaf sheath erection growth phase, Zadoks GS 30, signals the beginning of stem elongation and the most rapid phase of wheat growth. Two important factors are occurring during this time. First, the potential number of kernels per head is being established during the embryonic formation of the head. Second, rapid N uptake begins. Visually, the crop should have a medium to dark green color and be vigorously growing by GS 30. If the crop is beginning to show signs of chlorosis (yellowing), then the application of N at this stage is critical for the development of adequate head size. Priority should be given to N treatments for crops showing a lack of adequate N at this stage of growth. Finally, GS 30 indicates that the wheat plant is about to embark on its most rapid period of vegetative growth in order to build a structure for producing carbohydrate to fill the grain. The largest period of N uptake beginning Mid April through the first two weeks of June (flowering) for a well-fertilized crop grown under Idaho climatic conditions. This is where it all comes together and based on whether the crop is produced under non-irrigation or irrigation will be measured how well the producer has managed N.

For the dryland or non-irrigated producer, it’s knowing the fields, their soils and second guessing the weather, particularly, winter and early spring moisture. The key is when to apply the N and applying the right form of N that will be available to the crop following GS 30, when the greatest N amount is required by the crop. The timing of N application is going to be dependent on the form and method of application that a producer can used, which makes it difficult for development of program policy under Idaho's climatic conditions. One program may not fit all precipitation zones across Idaho. For the farmer who has the privilege of irrigation, it's easier to management N timing and rates, with the exception when weather delays irrigation and the ability to apply water-run or fertigation N. Under both scenarios, knowing the growth stage of the crop and managing N to assure optimum yields is critical in N use efficiency and reduction of having N get away from the crop and into the environment. The key is working with the producer and making the best fit decision. During the post GS 30 to GS 60 period, fertilizer management must provide for the crop requirement during this phase in order to have adequate leaf area for producing profitable yields. An important consideration to think about when discussing N management options with the producer is that during the post GS 30 to GS 60 period (Stem Extension and Heading) there is very little chance for leaching loss of N fertilizer when applied near the beginning of this growth phase due to the extensive growth of the wheat root system by GS 30 and the relatively high rates of evapotranspiration provides an major sink for nitrate-N uptake by the crop during this time period. N uptake during the grain-fill period (early June through July) is relatively low compared to uptake during the stem elongation phase of growth. Plant tissue N is mobilized and translocated to the grain during this period with only small additions coming from available soil N. Research has shown no yield increases from N fertilizer applications at or after flowering. Foliar applications (10 to 20 lbs. N/acre) of urea at this growth stage have been shown to increase grain protein but not yield. If such applications are made, they should be made in sufficient volumes of water (20 to 30 gallons/acre) to reduce the potential for foliar burn. The rate recommendation for the first application in a split is based on tiller density measurements. The second application in a split is made just prior to the period of maximum N uptake (GS 30). If you're keeping track of GDD it is about 300 to 600 $GDD_{(32^{o}F)}$. Its purpose is to supply the main nutritional needs of the crop to the extent that they are not already satisfied by soil N and the first N application (if any).

Research on winter wheat has shown that tissue N content at growth stage GS 30 is a reliable indicator of how much additional N fertilizer is needed to ensure that the nutritional needs of the crop are met.

REFERENCES

Bremner, J.M. 1965. Inorganic forms of N. In C.A. Black et al. (ed.) Methods of soil analysis, Part 2. Agronomy 9:1179-1237. Am. Soc. of Agron., Inc., Madison, WI.

Cabrera, M., J. Molina, and M. Vigil. 2008. Modeling the N cycle. p. 695-730. In N in Agricultural Systems. Agronomy Monograph No. 49. J.S. Schepers and W.R. Raun, eds. ASA-CSSA-SSSA, Madision, WI.

Coyne, M.S. 2008. Biological denitrification. p. 201-254. In N in Agricultural Systems. Agronomy Monograph No. 49. J.S. Schepers and W.R. Raun, eds. ASA-CSSA-SSSA, Madision, WI.

Ferguson, R. G. Slater, and D. Krull. 2009. Encapsulated nitrapyrin study, 2009. University of Nebraska Report.

Franzen, D. 2009. Studies on slow-release liquid fertilizers applied at low rates as a foliar application on North Dakota spring wheat/winter wheat. North Dakota State University, Fargo, ND.

Franzen, D.W., R.J. Goos, R.J. Norman, T.W. Walker, T.L. Roberts, N.A. Slaton, G. Endres, R. Ashley, J. Staricka, and J. Lukach. 2010? Field and laboratory studies comparing Nutrisphere®-N with urea in North Dakota, Arkansas and Mississippi. Journal of Plant Nutrition. Accepted for publication, June, 2010.

Goos, R.J. and B.E. Johnson. 1999. Performance of two nitrification inhibitors over a winter with exceptionally heavy snowfall. Agronomy Journal 91:1046-1049.803-806.

Goos, R.J. 2008. Evaluation of Nutrisphere-N as a soil nitrification and urease inhibitor. p. 89-96. In Proceedings of the North Central Extension-Industry Soil Fertility Conference, 12-13 November, 2008, Des Moines, IA. International Plant Nutrition Institute, Brookings, SD.

Grant, C.A. 2004. Potential uses for Agrotain and polymer-coated products. p. 76-86. Canada Soil Science Conference Proceedings, 2004.

Hendrickson, L.L., L.M. Walsh, and D.R. Keeney. 1978. Effectiveness of nitrapyrin in controlling nitrification of fall and spring-applied anhydrous ammonia. Agronomy Journal 70: 704-708.

Hergert, G.W., and R.A. Wiese. 1980. Performance of nitrification inhibitors in the Midwest (west). p. 89-105. In Nitrification Inhibitors-Potentials and Limitations. ASA-SSSA, Madison, WI.

Huber, D.M., H.L. Warren, D.W. Nelson, C.Y. Tsai, and G.E. Shaner. 1980. Response of winter wheat to inhibiting nitrification of fall-applied N. Agron. J. 72:632-637.

Jones, Clain, Kathrin Olson-Rutz, Courtney Pariera Dinkins, 2009. Nutrient Uptake Timing by Crops. EB0191, Montana State University, Department of Land Resources and Environmental Sciences.

Karow, R.S., E.L. Klepper, R.W. Richman, and R.R. Toll. 1993. Early Growth and Development of Cereals. Oregon State University Extension Service. EM 8542

Kissel, D.E., M.L. Cabrera, and S. Paramasivam. 2008. Ammonium, ammonia and urea reactions in soils. p. 101-156. In N in Agricultural Systems. Agronomy Monograph No. 49. J.S.

Schepers and W.R. Raun, eds. ASA-CSSA-SSSA, Madision, WI.

Norton, J.M. 2008. Biological denitrification. p. 173-200. In N in Agricultural Systems. Agronomy Monograph No. 49. J.S. Schepers and W.R. Raun, eds. ASA-CSSA-SSSA, Madision, WI.

Randall, G.W., J.A. Delgado, and J.S. Schepers. 2008a. N management to protect water resources. p. 911-946. In N in Agricultural Systems. Agronomy Monograph No. 49. J.S.

Schepers and W.R. Raun, eds. ASA-CSSA-SSSA, Madision, WI.

Schepers, J.S., D.D. Francis, and M.T. Thompson, 1989. Simultaneous determination of Total C, Total N, and 15N on Soil and Plant Material. Commun. In Soil Sci. Plant Anal. 20:949-959.

Schmidt, E.L. 1982. Nitrification in soil. p. 253-288. In N in Agricultural Soils-Agronomy Monograph No. 22. F.J. Stevenson, ed. ASA-CSSA-SSSA, Madision, WI.

Schwab, G.J., and L.W. Murdock. 2009. N transformation inhibitors and controlled release urea. University of Kentucky Cooperative Extension Service circular AGR-185.

R.L. Westerman, Editor. 1990. Soil Testing and Plant Analysis, Third Addition, SSSA Book Series 3.

Stark, J. 2008. Evaluation of Nutrisphere-N as a N source for spring malt barley. 2008 Report. Montana State University.

Stark, J. 2009. Evaluation of Nutrisphere-N as a N source for spring malt barley. 2009 Report, Montana State University

Sullivan, D.M., J.M. Hart and N.W. Christensen, 1999, N Uptake and Utilization by Pacific Northwest Crops. A Pacific Northwest Extension publication, PNW 513.

Touchton, J.T., R.G. Hoeft, and L.F. Welch. 1978a. Nitrapyrin degradation and movement in soil. Agronomy Journal 70:811-816.

Touchton, J.T., R.G. Hoeft, and L.F. Welch. 1978b. Effect of nitrapyrin on nitrification of fall and spring-applied anhydrous ammonia. Agronomy Journal 70: 805-810.

Touchton, J.T., R.G. Hoeft, and L.F. Welch. 1979a. Effect of nitrapyrin on nitrification of broadcast-applied urea, plant nutrient concentrations, and corn yield. 71:787-791.

Touchton, J.T., R.G. Hoeft, L.F. Welch, D.L. Mulvaney, M.G. Oldham, and F. E. Zajicek. 1979b. N uptake and corn yield as affected by applications of nitrapyrin with anhydrous ammonia. Agronomy Journal 71:238-242.

Warncke, D. and M. Nagelkirk. 2008. N management for winter wheat in Michigan. Crop and Soil Sciences Information Series, CSSIS #S, Michigan State University Extension Publication, East Lansing, MI.