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Fertilizing Small Grains in Arizona

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Nitrogen

Nitrogen Content of Crop

Nitrogen (N) is the primary fertilizer nutrient required by small grain crops which include wheat, barley, triticale, and oats. A wheat crop at grain harvest contains about 35 pounds of N per 1000 pounds of grain at a grain protein content of 13%. The total amount of N contained in the crop will vary greatly depending on yield level and protein content of the grain (Table 1). The nitrogen content of a winter cereal forage crop such as wheat, barley, triticale, and oats will vary also depending on forage yield and protein (Table 2). If high yields are expected or high protein content is desired, the grower needs to increase N fertilizer rate accordingly. The crop N content and optimum N fertilizer rate are not identical due to contributions of N from the soil and water or losses of N that may occur throughout the season.

Table 1. Nitrogen content of wheat (grain, straw, and roots) at various grain yield and grain protein levels.

	Grain protein (%)		
Grain yield	**12**	**13**	**14**
lb/acre	Crop N (lb N/acre)		
5000	166	176	185
6000	200	211	222
7000	233	246	259
8000	266	281	296

Assumptions: 1) Grain yield on a 7% moisture basis, 2) Grain protein on a 12% moisture basis, 3) Grain N = grain protein/5.7, 4) Grain yield/total above-ground yield = 0.42 (Ottman et al., 2000; Ottman and Pope, 2000), 5) Straw N = 0.34% (Ottman et al., 2000), 6) Root yield = 0.2 x total above-ground yield (Rajala and Peltonen-Sainio, 2001), and 7) Root N = 1.5% (Hicks, 1928).

Table 2. Nitrogen content of winter cereals such as wheat, barley, oats, and triticale (forage and roots) at various forage yields (72% moisture) and protein levels (0% moisture basis).

	Forage protein (%)		
Forage yield	**8**	**10**	**12**
ton/acre	Crop N (lb N/acre)		
20	177	213	249
25	221	266	311
30	265	319	373

Assumptions: 1) Forage yield on a 72% moisture basis, 2) Forage protein on a 0% moisture basis, 3) Forage N = forage protein/6.25, 4) Root yield = 0.2 x total above-ground yield (Rajala and Peltonen-Sainio, 2001), and 5) Root N = 1.5% (Hicks, 1928).

Nitrogen in Soil and Water

The source of N in small grain crops is not only fertilizer, but also from residual soil N and N contained in irrigation water. In a study conducted at the Maricopa Agricultural Center with durum, about half of the N taken up by the crop was from fertilizer and the remainder was from soil and water (Ottman and Pope, 2000). The amount of N in the irrigation water (lb/acre) can be calculated by multiplying the ppm of nitrate-N in the water by 0.226 and by the number of acre-inches/acre of water to be applied. The amount of N in the soil (lb/acre) potentially available to the crop can be estimated by multiplying ppm of nitrate-N in each foot of soil by 4. Estimating the total amount of N the soil contributes to the crop is difficult, because of the dynamic nature of soil N such that availability varies depending on intrinsic soil properties, weather, and crop management.

Optimum N Fertilizer Rate

The actual amount of fertilizer N required for optimum yield and quality could vary from none (if soil residual N is high) to 400 lb N/acre (if fertilizer N is subject to high losses). N fertilizer requirement can be affected not only by yield potential and grain protein content but also by crop residues, soil type, irrigation practices, the efficiency of fertilizer applications, and the N contained in the soil and water. Insufficient N application reduces grain yield and results in unacceptable grain protein content. Excessive N application increases fertilizer cost, reduces yield, and increases lodging.

Fertilizer Types

A variety of N fertilizer types can be utilized by wheat and barley, although UAN-32 is the most common form used in practice. Ammonium forms of N result in better utilization of the fertilizer by the plant than urea or nitrate early in the season (Knowles et at., 1991) since ammonium will not leach past the limited root system of the young plant. Nitrate forms are more subject to leaching, ammonium forms are more subject to volatilization in high pH irrigation water and soil, and urea is also subject to volatilization. Aqua or anhydrous ammonia can injure the plants due to ammonia toxicity, particularly on sandy soils. Finally, the efficiency of N applied in the irrigation water is only as good as the distribution uniformity of the irrigation water.

N Application Methods

N fertilizer is usually applied in the irrigation water as liquid UAN-32, but there are other methods of application. At planting, N can be applied in a band near the seed typically with phosphorus fertilizer. Rates of banded N above 30 lb N/acre increase the risk of injury to germinating seedlings. Placement of urea (46-0-0) or diammonium phosphate (18-46-0) with or near the seed is not recommended due to the risk of seedling damage from ammonia toxicity. N fertilizer granules can be broadcast. All types of dry N fertilizer should be incorporated into the soil or watered in as soon as possible to avoid the risk of loss from volatilization, especially in the case of urea. Foliar N application can be as effective as other application methods (Ottman et al., 2016), but there is a limit to how much foliar N can be applied per application (usually 10 to 20 lb N/acre) depending on the fluid fertilizer formulation due to leaf burning.

N Fertilizer Application Timing

The common commercial practice in Arizona is to apply N fertilizer to small grains with each flood irrigation except the last one or two. Most crop N uptake occurs between the 5-leaf stage until heading, when crop N uptake is most rapid, and it is important that adequate N be available during that time. N applied up to the heading stage has the potential to influence yield, while applications after heading will have a minimal effect on yield but increase protein content of the grain. An example N fertilizer application schedule is contained in Table 3. Excessive N applications before planting should be avoided since N fertilizer efficiency is about 20% less when applied pre-plant compared to during the growing season due to leaching past the developing root system (Ottman and Pope, 2000). However, enough N fertilizer should be applied pre-plant to supply the crop with N until the next planned N application date.

Boosting Grain Protein Content

Durum grain protein content needs to be 13% or greater to meet end-use requirements. Grain protein content of wheat can be increased by N fertilizer applications after heading. An application of 30 lb N/acre applied at flowering will increase grain protein by about 1 percentage point depending on the N status of the plant and timing of the application (Ottman et al., 2000). If the crop is N-deficient at the time of this late season N application, the increase in protein will be greater, and if the N status of the plant is excessive, the increase in grain protein will be less. Also, N applications 4 weeks after flowering (end of soft dough stage) are about half as effective in increasing grain protein as applications at flowering and 2 weeks after flowering (milk stage). Varieties that tend to have

Table 3. Example of a nitrogen fertilizer schedule for barley (full season) and durum at Maricopa. Fertilizer applications after heading are intended to boost durum grain protein content and are not required for barley.

		Fertilizer rate	
Date	Stage	Barley	Durum
		--------------- lb N/acre ---------------	
Dec 10	Planting	75	75
Feb 04	5 leaf	40	40
Feb 27	2 nodes	40	40
Mar 16	Pre-boot	40	40
Mar 30	Heading-Flowering	0	30
Apr 11	Milk	0	30
TOTAL		195	255

protein levels below 13% are most likely to benefit from late season N application. Application of N fertilizer after heading to increase grain protein content is economical if this practice prevents dockage for grain protein below 13%.

Nitrogen Fertilizer Scheduling Methods

Pre-determined recipe – N fertilizer can be applied to small grains using a pre-determined recipe. A certain amount of fertilizer could be applied in each irrigation, 10 to 20 gal UAN-32/acre, for example regardless of growing season conditions.

Visual appearance of the crop – N fertilizer could be applied based on the visual appearance of the crop. Small grain crops show N deficiency by reduced growth, decreased plant height, and yellowing of the leaves, in particular. A crop with excessive N will have leaves that are very floppy and be difficult to walk through without tearing leaves. Crop lodging usually is an indication of excessive N availability. If the crop is lodged, late season application of N fertilizer to increase grain protein is usually not needed.

Nitrogen balance - This approach involves fertilizing at a rate that replaces N removed by the crop (Tables 1 and 2) using a particular yield and grain protein goal and reducing or increasing N rate depending on certain factors. A credit (less fertilizer) of 50 lb N/acre can be applied if the previous crop was alfalfa or a highly fertilized vegetable crop. A debit (more fertilizer) of 50 lb N/acre can be applied with a high residue previous crop such as grain sorghum, on a sandy soil prone to leaching, or with inefficient irrigation practices.

Soil and plant testing – N fertilizer can be applied based on a feedback approach provided by soil and plant testing. These methods are recommended since they are more likely to coincide with actual crop needs compared to other methods and will typically result in higher N use efficiencies.

Chlorophyll meters – Leaf chlorophyll content can be estimated using various commercially available meters that clamp onto a leaf. The readings provided by these meters are not well correlated with the nitrogen status of the plant and should be used with caution.

Optical sensors - The N status of the crop can be determined by optical sensors that measure reflectance of radiation from the crop and calculate various types of spectral indices. The spectral index that has shown the most promise in research conducted in Arizona is the green chlorophyll index (Green CI). The Green CI is calculated using the following formula and radiation wavelengths: (810 nm/550 nm)-1. Research in Arizona has shown that a wheat crop deficient, adequate, and excessive in N will have a Green CI of <89%, 93%, or 98%, respectively, of an excessively-fertilized N control strip that receives about 50% more N fertilizer than adequate. Excessively-fertilized N control strips can be useful in N management (Wang, 2012).

Chemical tests - Both soil and plant tissue can be tested for N status chemically. The nutrient chemically analyzed is usually nitrate in the soil before planting and nitrate in the lower stem during the growing season. Guidelines for nitrogen fertilizer application based on these tests are available for the soil (Table 4) or lower

Table 4. Suggested pre-plant N fertilizer rates based on nitrate-N content of the surface 6 inches of soil.

Pre-plant soil nitrate-N	Description	Recommended pre-plant N rate*
ppm		lb N/acre
< 5	Low	50 to 75
5 to 10	Medium	0 to 50
> 10	High	0

* Add 15 lb N/acre per ton of non-legume residue recently incorporated, up to an additional 50 lb N/acre.

Table 5. Recommended N fertilizer rates based on nitrate-N in dried lower stem tissue of barley and wheat.

Stage Sampled	Stem Nitrate-N	Description	N rate*	Stage to apply fertilizer
	ppm		lb N/acre	
3 to 4 leaf	> 5000 2000-5000 < 2000	Excess Adequate Deficient	0** 0-50 50-100	3-4 leaf to Jointing
Jointing to boot	> 3000*** 1000-3000 < 1000	Excess Adequate Deficient	0 0-50 50-75	Jointing to Heading
Heading****	> 3000 1000-3000 < 1000	Excess Adequate Deficient	0-30 30-60 60-90	Heading to Milk

* Decrease N rates by 20% for barley or if expected wheat yields are less than 5400 lb/acre.
** Apply 30 lb N/acre regardless of stem nitrate-N content at the 3-4 leaf stage if the pre-plant soil test for nitrate-N was below 10 ppm.
*** For malting barley, 2000 ppm is considered excessive between jointing and boot.
**** N applications after heading are intended for wheat only, to increase grain protein content.
***** To generate guidelines based on stem sap, divide the stem nitrate figures by 6.32.

stem (Table 5). Pre-plant N application is based on nitrate content of the surface 6 inches of soil. In-season N applications are based on nitrate content of the portion of the stem between the seed and soil surface before jointing and, after jointing, on the 2 inches of the stem just above the soil surface. The stems should be collected 7-10 days before a scheduled N fertilizer application so that the stem nitrate results will be available to guide N rate decisions. About 25 to 50 stems are necessary to provide a representative sample. N fertilizer recommendations are based on the nitrate-N content of an oven-dry stem sample. The variables that affect optimum N fertilizer rate, such as soil type, residue, crop growth, etc., are reflected in the nitrate content of the lower stem. A disadvantage of the lower stem nitrate test in that once in the deficient region, lower stem nitrate may not increase significantly with additional fertilizer application. Nevertheless, soil and plant tissue testing are valuable tools for N fertilizer management.

Phosphorus

Phosphorus (P) is the only fertilizer element other than N usually needed by wheat or barley in Arizona. Phosphorus fertilizer is not always required for optimum yields since some soils contain high levels of phosphorus. Soil phosphorus levels greater than 13 ppm sodium bicarbonate extractable P indicate that phosphorus fertilizer is not needed (Table 6). Phosphorus can be applied as a band near the seed, broadcast, or applied in the irrigation water at planting. Phosphorus rates can be decreased by half if phosphorus is applied in a band rather than broadcast. Monoammonium phosphate (11-52-0) is recommended when banding since ammonia toxicity can result from fertilizers such as diammonium phosphate (18-46-0) and ammonium phosphate sulfate (16-20-0). In any case, phosphorus fertilizer that also contains N should never be banded at a rate that results in an application of more than 30 lb N/acre.

Phosphorus deficiency in small grains is usually expressed as stunted growth and may not be readily apparent. Purpling may occur in extreme cases of

Table 6. Suggested pre-plant phosphorus fertilizer rates based on sodium bicarbonate extractable (Olsen extraction technique) phosphorus of the surface 6 inches of soil.

Pre-plant soil phosphorus	Description	Recommended pre-plant P rate
ppm		lb P_2O_5/acre
< 7	Low	50 to 100
7 to 13	Medium	0 to 50
> 13	High	0

Table 7. Grain yield increase from various phosphorus fertilizer rates for barley and wheat in studies conducted at the Maricopa Ag Center on a sandy loam soil with a preplant P level of 2.8 ppm (Ottman, 2010a, 2010b, 2012).

	Grain yield increase	
P rate	**Barley**	**Durum**
lb P_2O_5/acre	lb/acre	lb/acre
25	282	477
50	327	552
75	330	558
100	330	558

deficiency. Tillering is reduced and maturity is delayed. Phosphorus deficiency is most likely in cold soils due to decreased growth of roots to intercept the phosphorus and decreased diffusion of phosphorus to the roots.

Phosphorus fertilizer application to a soil low in P (2.8 ppm) has been shown to increase durum yield by 558 lb/acre and barley yield by 330 lb/acre in a test conducted at the Maricopa Agricultural Center (Ottman, 2010a, 2010b, 2012) (Table 7). This yield increase was obtained at a P fertilizer rate of 75 lb P_2O_5/acre. However, 99% of this increase was obtained at 50 lb P_2O_5/acre, and 85% of this increase was obtained at 25 lb P_2O_5/acre. Therefore, under the conditions of this study, if we assume 1) 11-52-0 costs $500/ton, then increasing P rate from 25 to 50 lb P_2O_5/acre costs $12/acre, 2) the increase yield for barley is 45 lbs/acre and that for durum is 75 lb/acre, and 3) to pay for the fertilizer cost the barley must be worth $27/cwt and the durum $16/cwt, then a P rate of 25 lb P_2O_5/acre is economically optimum under most scenarios.

Other Nutrients

Deficiencies of nutrients other than N or P have not been documented in Arizona, and presumably, application of these nutrients is rarely economically justified. Nevertheless, some of these elements are applied to small grains in the state.

Potassium and the secondary nutrients consisting of sulfur, calcium, and magnesium are plentiful in Arizona soils. **Potassium** strengthens the straw in cereals and prevents lodging. Potassium deficiency symptoms appear similar to drought stress. The plants are short, the stems are weak and spindly, and the older leaves dry out starting at the tips and progressing to the margins. Potassium deficiency is most likely on sandy soils low in organic matter. Sulfur deficiency consists of leaf yellowing similar to N, but is more striking. Leaves of sulfur deficient plants are light green and the older leaves may be bright yellow. Plants are stunted and have few tillers. **Sulfur** deficiency can occur on sandy, acidic, cold, or low organic matter soils. However, sulfur deficiency is not expected in Arizona due to the high sulfate content of most irrigation water in the state. **Calcium** deficiency is characterized by reduced or distorted growth of young tissue, withered leaf tips, brown roots, and weak stems. Calcium deficiency usually occurs on acid soils, but can occur on soils with high pH or high sodium content. Magnesium deficiency has not been reported in North America. Deficiency symptoms include yellowing between leaf veins and a yellow mottling of the leaf, purpling of the older leaf edges, weakened stems, and stunted growth. **Magnesium** deficiency is most likely on soils that are acidic, sandy, low in organic matter, or high in calcium.

The plant requirement for micronutrients is many times less than that of other nutrients. Arizona soils generally contain sufficient amounts of most micronutrients. Micronutrients include iron, zinc, copper, manganese, boron, molybdenum, and chlorine. A deficiency of **iron** is characterized by a sharp yellowing between veins of new leaves and stunted growth. Plants deficient in zinc develop yellowing, graying, or bronzing between veins on older leaves in contrast to development of symptoms on younger leaves with iron, manganese, and copper deficiency. **Copper** deficiency is expressed as stunting, leaf yellowing, wilting, dying of leaf tips, and a graying of leaves. Interveinal yellowing occurs in **manganese** deficiency, but not as sharply as with iron deficiency. **Boron** deficiency is characterized by stunted growth. **Molybdenum** deficiency is exhibited by pale, thick, brittle, withered leaves and a stunted plant. Deficiencies of iron, zinc, manganese, copper, and boron are associated with high pH soils coarse in texture and low in organic matter. Molybdenum deficiency is favored by low soil pH.

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