Fertilizing hard red spring wheat, durum, winter wheat and

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Spring wheat and durum are particularly adapted to the relatively cool and dry North Dakota climate. The short grov and durum allows the crops to mature with little chance of frost damage which may sometimes occur as early as Au

More acres are seeded to wheat in North Dakota than any other crop. The primary wheat grown in the state is hard red spring higher proportion of acres in the northern half of North Dakota, with a smaller portion in the rest of the state. Winter wheat is g primarily in the southwest. Rye is a relatively minor crop in North Dakota (Table 1). In 1995, North Dakota was ranked as the r (Table 2). Spring wheat and durum are particularly adapted to the relatively cool and dry North Dakota climate. The short gro durum allows the crops to mature with little chance of frost damage which may sometimes occur as early as August. Produce other crops such as barley, field peas, sunflower, sugarbeet, canola and dry bean. Growing other rotational crops reduces di planting and harvest seasons.

Table 1. Harvested acreage of major crops in North Dakota, 1995.

Crop	Acreage
Wheat, all	11,114,000
Hard red spring	8,200,000
Durum	2,880,000
Winter	34,000
Barley	2,250,000
Corn	510,000
Oat	450,000
Sunflower	1,210,000
Canola	211,000
Dry bean	540,000
Sugarbeet	204,200
Potato	121,000
Soybean	640,000
Flax	115,000
Alfalfa	1,400,000
Grass hay	1,300,000

Table 2. Wheat production, United States, top 5 states, 1995.

State	Ranking
North Dakota	1
Kansas	2
Montana	3
Washington	4
Oklahoma	5

Nutrients required for wheat production

Nitrogen

Nitrogen is the nutrient most often limiting to wheat production. Adequate nitrogen fertility is necessary to produce high yields to increase quality (protein content) of grain. High levels of protein are important for superior wheat flour milling and baking characteristics. Nitrogen (N) availability plays a key role in determining tiller number, kernel number and kernel size in the wh plant. Properly fertilized hard red spring wheat will normally have a protein content greater than 14 percent. Pasta processors prefer that durum wheat should have less than 20 percent starch, or "yellow bean" kernels. Winter wheat should have at leas percent protein content. Protein content consistently lower, or starch content higher than these values is an indication that a v producer needs to use more N fertilizer or better manage the N being applied (Figure 1).

Figure 1. Relative yield of Len hard red spring wheat as related to grain protein content. Goos, 1981-1982.

Soil testing and N recommendations

Studies have shown that fertilizing to the point of maximum economic yield and a good grain protein content takes about 2.5 l N)/bushel. This value is not an absolute, but is an average taken from years of research (Table 3).

Table 3. Soil plus fertilizer N needs for spring wheat, 1981-1982. Goos, North Dakota Farm Res., 41(1):27-33, 1983.

Site	Maximum yield, bu/acre	Minimum soil + fertilizer N needed for maximum yield	lb N/bu
1981			
Battleview	35	106	3.0
Dickinson	13	93	3.5
Fortuna	18	51	2.8
Minot	37	23	0.6
Minot	35	42	1.2
New Town	26	93	3.5
Stanley	43	104	2.4
Williston	33	75	2.2
Williston	32	75	2.4
1982			
Bowbells	17	43	2.5
Fortuna	35	69	2.0
Minot	34	98	2.9
Rawson	35	48	1.4
Stanley	31	95	3.1
Williston	18	54	3.0

Average and 95% confidence interval 2.5 � 0.5

Soil samples are taken to a depth of 0-2 ft. for wheat. Following analysis, recommendations are based on soil test results and formula:

N recommendation = (2.5 X YG) - STN - PCC - SDA

Where YG = yield in bu/A
STN = soil test nitrate-N in lb/A 2 ft.
PCC = Previous crop credits (Table 4)
SDA = Sampling date adjustment used if samples are collected in the fall before September 15. N needs are decreased by 0.5 lb/A per day the samples were taken prior to September 15.

Recommendations at selected yield goals are listed in Table 5. N recommendations at other yield goals can be calculated usi yield goal for a given year is nearly impossible because of the many factors which influence yield, particularly rainfall patterns cautiously optimistic, with the producer using the long-term average yield for the land as a starting point and highest yields a goal. Modifying factors include soil moisture levels at the beginning of the season and perhaps long-range weather forecasts.

Table 4. Previous crop credits for small grains.

First Year N Credits	
Previous crop	
Soybean	0.5 lb N/bu
Edible bean	10 lb N/acre
Pea and lentil	1.25 lb N/bu
Sweet clover that was harvested	10 lb N/acre
Alfalfa that was harvested and unharvested sweet clover	
>5 plants/sq ft	75 lb N/acre
3-4 plants/sq ft	50 lb N/acre
1-2 plants/sq ft	25 lb N/acre
<1 plants/sq ft	0 lb N/acre
Red clover that was harvested	35 lb N/acre
Sugarbeet	
Yellow leaves	0 lb N/acre
Yellow-green	15-20 lb N/acre
Dark green leaves	60-70 lb N/acre

Second Year N Credits

half of credit given for the first year for red clover, sweet clover and alfalfa, but none for other categories. Soil test nitrate-N levels from the second year usually would be expected to reflect second year contributions from annual legumes.

Table 5. Nutrient recommendations for wheat and rye.

			Soil Test Phosphorus, ppm				
Yield goal	Soil N plus fertilizer N required		VL	L	M	H	VH
		Bray-1	0-5	6-10	11-15	16-20	21+
		Olsen	0-3	4-7	8-11	12-15	16+
bu/A	lb/A 2 ft.		lb P_2O_5/acre				
20	50		20	15	10	0	0
40	100		40	30	15	10	0
60	150		60	40	25	10	0
80	200		80	55	35	10	0

			Soil Test Potassium, ppm				
Yield goal	Soil N plus fertilizer N required		VL	L	M	H	VH
		Bray-1	0-40	41-80	81-120	121-160	160+
		Olsen					
bu/A	lb/A 2 ft.		lb K_2O/acre				
20	50		50	35	20	0	0
40	100		95	70	40	15	0
60	150		140	100	60	20	0
80	200		190	135	80	25	0

Nitrogen recommendations = 2.5 YG - STN - SDA - PCC
Bray-1 P recommendations = (1.071-0.54 STP)YG
Olsen P recommendations = (1.071-0.067 STP)YG
Potassium recommendations = (2.710-0.017 STK)YG

The abbreviations used in the equations are as follows:
YG = yield goal
STN = soil test nitrate-N
STP = soil test phosphorus
STK = soil test potassium
SDA = sampling date adjustment
PCC = previous crop credit

Use of fallow

Historically, N fertility has been the sum of release from the degradation of organic matter following the break up of prairie soi
Fallow was once a very common production practice throughout North Dakota which allowed a portion of land to idle for a sea
producing more yield the second year. Fallow land was typically tilled several times during the idle period to kill weeds. Tillag
allowing aerobic microorganisms to break down organic matter into carbon dioxide and mineral components. Producers were
organic matter breakdown during fallow, since for every 10 pounds of carbon released into the atmosphere, about 1 pound of
soil.

In recent years, the practice of fallow has diminished. Research has shown that continuous cropping often returns more incor
organic matter levels have plummeted to less than half original prairie levels. Organic matter levels have been depleted to the
one-third of fallowed fields require supplemental N fertilizer. Losing organic matter also has a detrimental effect on soil physic
crusting, poor aggregation, limited water holding capacity and higher bulk density. By continuous cropping, producers are mo
steady. Adding N fertilizers into the cropping program and reducing tillage has been observed to slowly increase organic matt

Use of manures

Supplemental N can be added as manures, green manures and commercial fertilizers. To use manures properly, the applicat
Applications should be made as evenly to the soil as possible and incorporated within 24 to 48 hours. Composting manure cr
manure pile to kill weed seeds. Composting, however, reduces the nitrogen content of the manure through ammonia volatiliza
estimated through the use of an appropriate chart (Table 6) and a sample of the manure taken on the day of application and
analysis. Additional N can then be added before seeding.

Manure application is limited by the practical distance manure can be hauled by livestock producers. Consideration should be
the manure and its long-term value to improved soil health.

Table 6. Average nutrient analysis of liquid and solid manure. From Livestock Waste Facilities handbook, Midwest Plan Service, March, 1985.*

Form	Condition	Dry Matter	Total N	P2O5	K2O
		(%)	-- lb/1000 gal. --		
Liquid -					
Beef	anaerobic pit	11	40	27	34
Dairy	anaerobic pit	8	24	18	29
Swine	anaerobic pit	4	36	27	22
			----- lb/ton -----		
Solid -					
Beef	no bedding -				
	dirt	15	11	7	10
	concrete	52	21	14	23
	with bedding	50	21	18	26
Dairy	no bedding	18	9	4	10

	with bedding	21	9	4	10
Swine	no bedding	18	10	9	8
	with bedding	18	8	7	7
Turkey	no bedding	22	27	20	17
	with bedding	29	20	16	13

* Nutrient values may vary due to animal diet, time of manure sampling, method of manure sampling and age of the manure.

Use of green manures

Green manures are crops grown to be plowed under. After the residues are incorporated into the soil, microbes decompose tl nitrogen they contained. Green manure crops should have a low carbon/nitrogen (C/N) ratio for greatest benefit. C/N ratios le into the soil. C/N ratios greater than 30/1 result in N tie-up following decomposition. C/N ratios between the two values genera content of the soil. Legumes generally have low C/N ratios and produce their own N if properly inoculated with N-fixing bacter legume needs to be incorporated into the soil to attain the maximum benefit of legume N fixation. Harvesting the legume and nitrogen benefits of the green manure.

Green manure use in North Dakota is limited by reluctance to leave land idle, by fear that excessive water will be taken from t and decomposition, and because the timing of N release by the green manure is less predictable than N availability from an a

Commercial N fertilizers and use in hard red spring wheat, durum and rye

Anhydrous ammonia

Anhydrous ammonia is a gas at atmospheric pressure but is stored as a liquid under pressure. Anhydrous ammonia is a and there are specific safety precautions related to its use (see Extension Circular SF-962). One major problem associat is the escape of the vapor from the soil during and after application. An occasional "puff" of ammonia vapor may be exp general, ammonia should be applied so that vapor losses are minimized. Vapor loss is reduced by applying ammonia in sealing behind the band, and by fitting the ammonia application equipment with covering tools that help to cover the ap deeper in the soil is often effective in sealing an ammonia band.

Fall application

Fall application of anhydrous ammonia is very popular for a number of practical reasons. The spring workload is decrea they are in the spring, and the cost of ammonia is often lower in the fall. Fall application of ammonia is recommended in October when early morning soil temperatures at 4 inch soil depth fall to 50� F or less.

Use of this guideline includes a degree of risk. The bacteria that convert ammonium-N to nitrate-N do not stop their activ below 50� F, but the process greatly slows. In most years, colder temperatures follow soon after application, so conver However, there may be years when soil temperatures remain warm for several weeks following application. In these unu nitrate may be produced.

If only a small amount of water, 2 inches or less, is contributed to the soil between late fall and spring, the nitrate forme the top foot of soil and crop response to fall applied fertilizer will be as good as a spring application. This is usually the and in most years in central and western North Dakota. However, if spring soil moisture levels are high, then significant textured soils. Leaching of nitrate out of the soil before a crop has a chance to take up the N is very uncommon in mediu these soils, nitrate may move downward enough that early wheat growth is poorer than had the N been spring applied. outgrow this condition, but yields may be somewhat reduced.

In general, wheat responds profitably to fall applied anhydrous ammonia in North Dakota when it is applied on the prop

Spring application

Spring application of anhydrous ammonia is an effective practice if two problems are avoided. The first problem is direct application. The second is reduced germination and seedling damage. Ammonia is toxic to seedlings. Using traditional t little seedling damage occurs if the ammonia is placed at a depth of 5-6 inches and the seed placed at 1-1.5 inches dee slightly different angle to seeding may also reduce damage.

Simultaneous seed and fertilizer placement is being used as a result of air-seeder technology. Minimum separation betw ammonia band should be 2 inches in medium or heavier soils and 3 inches in coarse textured soils. However, at higher seedbed conditions such as cloddiness, some seedling damage may occur. As this practice is still relatively new, produ adopting it until they have adequate first hand experience to know that seedling damage will not occur with their equipm potential problem with applying ammonia using air seeders is that sometimes the ammonia is applied too shallow for so loss as vapor.

More details regarding anhydrous ammonia application may be found in the North Dakota Fertilizer Handbook (EB-65).

Urea

Applying N in urea form is increasing in popularity despite a higher price per pound of N than anhydrous ammonia. Part convenience and flexibility of use and safety concerns with ammonia application. Urea is broken down into carbon dioxic enzyme called urease. Urease is more active when temperatures are warm, but somewhat active at temperatures as low be covered with soil to keep ammonia formed during urea breakdown from volatilizing off the soil surface. Coverage may by at least 1/4-1/2 inch of precipitation depending on residue and soil surface conditions and initial moisture content.

The time interval between urea application and soil coverage necessary to minimize ammonia volatilization depends on s dryness and the evaporation of water from the soil surface. Cool temperatures, dry soils and low wind speed allows mor surface. High temperatures, moist soils and windy conditions may require urea incorporation much sooner. In the spring soil surface for up to a week. If weather conditions are more favorable for ammonia volatilization, incorporation within two from occurring, as loss generally does not begin until three to four days after application. Recent research in a number impregnation of urea fertilizer with NBPT urease inhibitor may hold off urea volatilization for another week.

Applying urea with the seed is restricted because of some salt effect, but mostly because of the ammonia toxicity from u zone. With air-seeder seed spread devices, urea rates can be increased due to a dilution effect. However, seed and fert and confirmed to minimize seed injury and stand loss. Table 7 shows the amounts of urea-N allowed with different seed Rates are also modified by surface soil texture.

Table 7. Maximum urea-N fertilizer rates recommended with wheat seed at planting based on planter spacing, type and seed spread. Assumes a coarse soil texture for the lower end or each range and heavier texture for the upper end of each range of urea-N values. For more detail, see NDSU Ext. Cir. EB-62.

Planter Type	Seed Spread	Planter Spacing, inches 6	7.5	10	12
	(inches)	------ lb urea-N/acre -------			
Double disc	1	20-30	19-28	17-23	15-20
Hoe opener	2	32-44	27-38	23-31	20-27
	3	44-58	37-48	30-40	26-34
Air seeder	4	56-72	46-58	37-48	32-42
	5	68-86	56-68	44-57	38-49
	6	80-100	66-79	51-55	44-56
	7		76-90	58-74	50-64
	8			66-83	56-71
	9			73-92	62-78
	10			80-100	68-86
	11				74-93
	12				80-100

Urea-ammonium nitrate liquid fertilizers (UAN)

UAN is a liquid formulation of urea and ammonium nitrate. The analysis usually used is 28-0-0, but this may vary depen applications of UAN should be treated similarly to urea, although the ammonium nitrate fraction is not subject to the sar urea. UAN is sometimes applied in a surface band to reduce urea volatilization risks. UAN is also frequently used as a fo protein enhancement under certain conditions.

Winter wheat N fertility considerations

Although equivalent total rates of N are recommended for winter wheat as spring wheat, a minimum amount of N is desi Excessive N before planting may reduce winter hardiness. Most of the N needs are topdressed in early spring immediat broken. Nitrogen application is usually made with dry or liquid N fertilizer sources.

Topdressing for yield or protein increase

Although most nitrogen should be applied before or at planting, sometimes circumstances do not permit N application until af is called topdressing. Usually the fertilizer source is urea, especially if greater than 20 lb N/acre is needed. UAN solutions are may cause serious leaf burning if used at high rates or applied at midday. Topdressing for yield enhancement should be mac Data in Table 8 show that wheat yield response to topdressing is greatest through tillering.

Recent research has shown that although yield is not increased with a post-anthesis application of N, protein may be increas N/acre (about 10 gal of 28-0-0 liquid, diluted 50-50 with water) was effective in increasing protein about 1 percent. This resear at flowering is not as desirable, and that application is best made in the early morning or evening to avoid burning. Improper a and plant injury resulting in grain shriveling and lower test weights.

Table 8. Influence of rate and time of foliar application of nitrogen on grain yield, 1986, Swenson, Dahnke and Johnson.

Growth stage of wheat at time of application	Application Rate ---- lb N/acre ---- 0	20	40	60
2 leaf (Feekes 2)	26	28	38	33
Tillering (Feekes 2-3)	28	36	37	34
Boot (Feekes 10)	24	28	28	31
Flowering (Feekes 10.2)	25	26	30	25

Table 9. Percent protein with different foliar N rates applied post-anthesis to `Butte 86' hard red spring wheat, Carrington, ND, 1988-1991.

Year	lb N/acre 0	15	30	45
	---- percent protein ----			
1988	16.0	16.5	16.9	16.8
1989	11.6	12.1	12.8	13.0
1990	13.6	13.2	13.6	13.6
1991	13.4	13.6	15.3	14.1
Average	13.6	13.8	14.7	14.4

Phosphorus

It is important for wheat to have adequate P near the young root system early in its growth, as well as adequate P available in feed the plant through kernel fill. P nutrition should be approached using both short-term and long-term fertility.

Banding at planting with or near the seed is important since wheat roots initially are in cool soils relative to air temperature. Le plants that young roots may be unable to accomplish without some phosphate placed so that roots are able to intercept high Wheat plants make "decisions" concerning the number of tillers early in growth. Inadequate P will reduce tiller number and th Providing early, banded P is very important and is the "short-term" P strategy. Wheat will respond to starter phosphate regard

Banding P provides early P needed for adequate tiller initiation and development. Where soil test levels are medium or highe

demands of P for wheat kernel fill. When soil test levels are low or very low, P levels are not adequate to meet late season de
system in contact with high levels of P is very small when P is banded alone. To allow P uptake within the entire root system,
whole soil surface. Therefore, the long-term P fertilization strategy should be to apply enough P to build soil levels to at least
period and to maintain these levels by applying starter P with or near the seed. The P recommendations shown in Table 5 pro
from low and very low levels within a 10 year period or less. It takes about 40 lb/acre of P2O5 to build Olsen P soil test levels

Phosphate fertilizers may include 10-50-0/11-52-0 (MAP, monoammonium phosphate) or 18-46-0 (DAP, diammonium phosph
fertilizers include 10-34-0 (ammonium polyphosphate) or other liquid P grades. Phosphate fertilizer rates which can be applie
the nitrogen content of the application as shown in Table 7. Manure is also an excellent supplier of P to wheat (Table 6).

Potassium

Potassium (K) is required for wheat growth, but, most North Dakota soils contain adequate levels of K for maximum wheat gro
usually restricted to leachable sandy or gravelly soils. K recommendations are shown in Table 5.

Chloride

Wheat is sensitive to low chloride levels. Adequate chloride reduces disease incidence and severity. It is also necessary for pl
maintain turgor. Chloride is an anion and can move with soil water. It is not a nutrient whose level can effectively be built up in
chloride should be made with soil testing and an understanding of the probability of response based on test results. The prob
Dakota information is listed in Table 10. Based on the table, a soil test level of 60 lb/acre or higher in the top 2 feet is not resp
and 60 lb/acre responded about 31 percent of the time. The average response was only 2.6 bu/acre. Levels below 30 lb/acre
time with an average response of over 4 bu/acre. Therefore, chloride application is most justified when levels are under 30 lb/
even a modest application of 10 lb chloride/acre (20-25 lb 0-0-60/acre) can be very helpful.

Table 10. Probability of response of small grains to chloride based on soil test chloride levels. From S. Dakota data.

Soil Test Category	Soil Cl Content	Yield Response Frequency	Average response at: Responsive Sites Only	Average response at: Across All Sites
	lb/acre 2-ft.	%	bu/acre	
Low	0-30	69	5.0	4.0
Medium	31-60	31	6.3	2.6
High	60+	0	--	0.3

Sulfur

Wheat does not accumulate high levels of sulfur (S). However, S deficiencies are identified occasionally in North Dakota. Defi
with low organic matter soils or areas with higher topography which are sandy or gravelly and leachable. Sulfur deficiency is a
plentiful and yield levels are high. Wheat absorbs S as the sulfate anion. Fertilizer S needs to be applied so that adequate su
season to provide adequate full season nutrition. Elemental S needs to be broken down to sulfate by soil bacteria. In seasons
delayed. Ammonium sulfate (21-0-0-24S) is a fertilizer with immediately available sulfate-S. Ammonium thiosulfate (12-0-0-27S
source.

Nitrogen and S deficiency symptoms can easily be confused.

Sulfur needs are most often identified through soil testing. Levels below 16 lb/acre in the top 2 feet are generally low in S and
Plant tissue testing is also very helpful in diagnosing S deficiency. Addition of 10 lb/acre S at planting is usually adequate to c

Copper

Responses to copper are common in Canada in high organic matter soils. Copper is excessively chelated (bound by organic c
reducing its availability. Copper deficiency can be observed as browning of wheat leaf tips, higher incidence of ergot and false
copper has been observed in the Red River Valley. However, not enough is known in North Dakota to determine whether or n
increasing yields or plant health or under what conditions to expect a response.

Copper deficiency is treated with a preplant application of 3 lb/acre copper sulfate applied to the soil and incorporated. Coppe
symptoms are seen. Canadian recommendations call for supplemental copper when copper soil test levels fall below 0.6 ppm

Other nutrient and fertility problems

Zinc, boron and iron deficiencies in wheat are rare. Wheat is not very sensitive to low soil levels of these nutrients in North Da

Excessive salinity may lower wheat yields. Salts are not lowered by addition of soil amendments. Sometimes manure is applie
of temporary dilution and is not a long time benefit. Manure itself contains salts and may contribute to the problem long-term.
water table depth. The water table should be lowered through management of soil water through tillage, cropping and residu
Saline soil management and development is discussed in two extension bulletins, EB-57, Salinity and Sodicity in North Dakot
Saline Soils in North Dakota.

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