B-1725
July 1995

Plant Nutrition and Fertilizer Management for Winter Wheat Production in the Blackland Prairie

Texas Agricultural Experiment Station
Edward A. Hiler, Director
The Texas A&M University System
College Station, Texas

Plant Nutrition and Fertilizer Management for Winter Wheat Production in the Blackland Prairie

Tim C. Knowles, Billy W. Hipp, David S. Marshall, and Russell L. Sutton

Respectively: Research associate, professor, professor, and assistant research scientist. Texas Agricultural Experiment Station, Texas A&M University Research and Extension Center at Dallas.

Keywords: Nitrogen, phosphorus, soil, plant testing, timing, residue, no-till, grain

Contents

Introduction

Nitrogen (N), and to a lesser extent phosphorus (P), are the two fertilizer nutrients that are often required for maximum grain and forage yield of Blackland Prairie winter wheat crops. Occasional sulfur (S) and zinc (Zn) deficiencies in Blackland Prairie soils have also been identified by soil testing prior to planting winter wheat. Interrelationships between soil moisture availability, soil temperature variation, soil chemistry and nutrient cycling, wheat plant nutrient availability and uptake, and efficient fertilizer management are complex and dynamic. Excessive amounts, poor timing late in the wheat growing season, and ineffective techniques of fertilizer application can lower winter wheat yields, have the potential to create environmental problems such as pollution of ground and surface water with nitrate, and are expensive to growers since very little of the total applied fertilizer can be utilized by the wheat crop. Therefore, understanding dynamic processes occurring in the plant, soil, and climate, and their interrelationships between efficient fertilizer management practices, will enable wheat producers to make informed sound fertilization decisions that increase net profits and reduce the potential for environmental pollution.

The Blackland Prairie is one of the major agricultural regions of Texas. Approximately 12.6 million acres are included in the Texas Blackland Prairie which is a belt of land extending from the Red River to near San Antonio (Figure 1). About 5.6 million acres of the Blackland Prairie are in the Houston Black-Heiden-Austin soils association. Other major soil associations in the Blackland Prairie include the Wilson-Crockett-Burleson (Greylands) association, Burleson-Heiden-Crockett association and Austin-Stephen-Eddy association. Blackland soils are dark colored, high in montmorillonite clays (smectites), swell when wet, and shrink when dry. Cracks three feet deep and three inches wide during dry periods are common on Blackland soils classified as Vertisols. Primary Blackland crops include wheat, oats, grain sorghum, corn, cotton, forage sorghum, and legumes. About half of the region is rangeland with pasture crops consisting primarily of Coastal bermudagrass, clover, alfalfa, wheat, oats, and native grasses such as bluestem, Indiangrass, switchgrass, and sideoats grama. Erratic rainfall during the summer growing period can limit production of cotton, sorghum, and corn in some years. Winter wheat and oats are more adaptable to the fall and spring peak rainfall patterns that occur in the Texas Blackland.

Rainfall and Winter Wheat Water Use

Long-term average annual rainfall at Dallas is 35.08 inches with distinct peak rainy periods from April through May (4.5 inch/month) and September through October (3.5 inch/month). These periods of peak rainfall are extremely important for winter wheat production in the Blackland. Winter wheat water use (including evaporation) peaks twice at 4.8 inch/month during March, then at 5.6 inch/month during May (Figure 2). In a normal year, water requirements of winter wheat exceed available soil moisture supplies resulting in moderate moisture stress from February through June. During years that have less than normal rainfall, severe moisture stress can occur during this period, drastically reducing wheat grain yields. Topdress applications of mobile fertilizer nutrients such as nitrogen require adequate rainfall for incorporation into the soil and uptake by wheat plant roots. Thus, mobile fertilizer nutrients should be topdressed not only prior to periods of peak wheat demand for these nutrients, but also in time for rainfall to move these nutrients into the soil-plant root zone where they are available for uptake by wheat plant roots. Furthermore, under limited soil moisture, larger winter wheat plants that are developed due to excessive rates of fertilizer which stimulated early season growth may experience severe moisture stress, resulting in lower grain yield than wheat fertilized at sufficient levels.

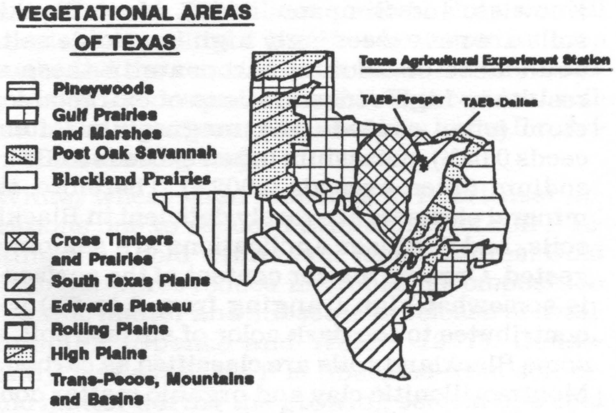


Figure 1. Location of Texas A&M Research and Extension Centers in the north Blackland region (Courtesy Dennis W. Walker, TAES-Dallas).

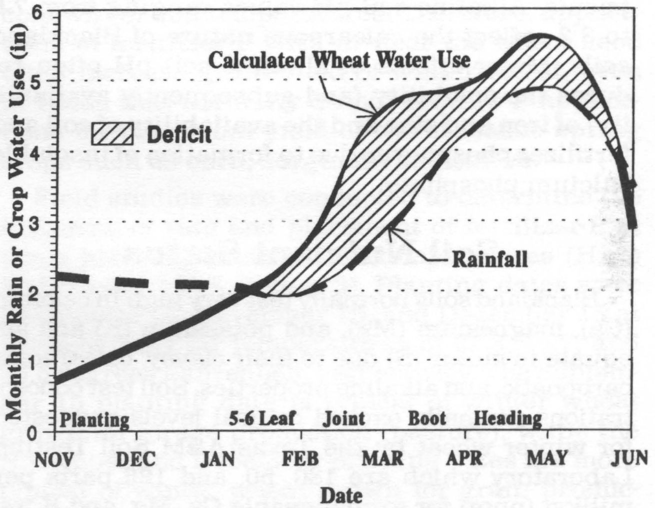


Figure 2. Normal monthly rainfall and calculated winter wheat crop water use recorded from 1947 to 1983 at TAES-Dallas.

Blackland Prairie Soils

Blackland soils are high in clay (45 to 60%), and productivity is generally regulated by available soil moisture (Welch et al., 1977). When soils are dry, initial water intake (infiltration) is relatively high. However, swelling of the shrink/swell montmorillonitic clay closes pores and cracks upon wetting, thereby substantially reducing further infiltration of water into the soil. This condition increases the potential for runoff on the soil surface from intense rainfall and soil losses by erosion. Erosion control measures that reduce runoff from soils and increase water infiltration are necessary for efficient agricultural production. This may be accomplished by maintaining a vegetative or crop residue cover on the soil surface through crop residue management (Hipp and Simpson, 1988). Terraces and diversions that reduce the length of slopes also can help reduce runoff and erosion.

The light colored chalk and interbedded marl subsoil from which most Blackland soils formed is primarily calcium carbonate (lime or calcite). The surface soils are high in calcium carbonate (generally ranging from 15 to 45%), consequently these soils are classified as calcareous (Hipp, Knowles, and Simpson, 1992). Most Blackland soils are not exceedingly high in soluble salt. An abundance of calcium carbonate in these soils results in high concentrations of extractable calcium (often exceeds 1%), magnesium (often exceeds 0.02%), potassium (often exceeds 0.03%), and sodium (often exceeds 0.002%). Therefore, these mineral elements are rarely deficient in Blackland soils, and fertilizer applications are seldom suggested. Organic matter content of the surface soil is somewhat high (ranging from 2 to 5%) which contributes to the dark color of surface soil, thus some Blackland soils are classified as carbonatic. Montmorillonitic clay and organic matter content contribute to high cation exchange capacities (CEC) of these soils (ranges from 25 to 50 meq/100 g). Soil pH, a measure of hydrogen ion activity in soil, greatly affects availability of plant nutrients. Alkaline soil pH values ranging from 7.6 to 8.3 reflect the calcareous nature of Blackland soils. Major effects of alkaline soil pH often reduces the solubility (and subsequently availability) of iron and zinc and the availability of soil and fertilizer phosphorus due to formation of insoluble calcium phosphate.

Soil Nutrient Status

Blackland soils normally test very high in calcium (Ca), magnesium (Mg), and potassium (K) and adequate in sulfur (S) due to their clayey, calcareous, carbonatic, and alkaline properties. Soil test concentrations normally exceed critical levels suggested for winter wheat by the Texas A&M Soil Testing Laboratory which are 180, 50, and 126 parts per million (ppm) for exchangeable Ca, Mg, and K, respectively, and 25 ppm for sulfate-S. Fertilizer additions are suggested when soil test values are below these critical levels. Therefore, fertilizer additions of Ca, Mg, K, and S are rarely profitable and seldom suggested in the Blackland. Calcium is abundant due to high levels of calcium carbonate in these soils. Large quantities of exchangeable K are fixed within clay minerals and are slowly available to plants. Magnesium levels also appear adequate for current production levels. Sulfur fertilizer applications are normally not suggested for winter wheat grown on Blackland soils since the S released from organic matter and that inadvertently supplied by nitrogen and phosphorus fertilizer applications provide adequate S to prevent widespread S shortages (Welch et al., 1977).

Soil micronutrients, including iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl), are required in trace amounts for optimum plant growth plus maximum grain yield, but can be toxic at even slightly excessive levels. Soil levels of these mineral elements have been adequate for current winter wheat production levels. Conditions do exist where iron and/or zinc fertilizer application can increase wheat grain yields, however, yield increases from these applications are rarely profitable. Zinc and iron deficiencies are sometimes associated with alkaline, calcareous soils that are inherently high in soil phosphorus (P). Excessive fertilizer-P applications on Zn deficient Blackland soils can result in severe Zn deficiencies that appear to retard development and maturation of wheat grain heads (Hipp and Hooks, 1978). A preplant soil test should be used to confirm micronutrient deficiency or adequacy. Currently, soil-test critical levels defined by the Texas A&M University Soil Testing Laboratory for winter wheat are 4.2 and 0.28 ppm for Fe and Zn, respectively.

Nitrogen (N), and to a lesser extent phosphorus (P), are the two essential nutrient elements which most often limit the production of wheat in the Texas Blackland. Cold soils in late winter can decrease P uptake by young rapidly growing winter wheat plant roots and can reduce the availability of soil-P reserves. Thus, a cool-season crop such as winter wheat often responds to fertilizer P applications when N is applied in adequate amounts. Phosphorus fertilizers are normally broadcast and worked into the surface 4 to 6 inches of soil prior to planting, or banded below the seed with the grain drill at planting due to the immobility of P in soils. Following 35 years of non-fertilized continuous wheat, Blackland soils had the nutrient-supplying capacity to yield about 20 to 30 bushels of grain per acre (Hipp and Simpson, 1988). When fertilized with sufficient N and P, Blackland soils can yield 40 to 70 bushels of wheat per acre, or up to 100 bushels of oats per acre when rainfall is adequate to meet seasonal crop moisture requirements. Split applications of N fertilizer are not required for maximum grain yield of winter wheat that is not grazed or planted in dense or no-till crop residues. These soils will mineralize (make N available to wheat from organic matter) from 40 to 120 pounds N/acre/year, depending on soil moisture, temperature, crop residue management, and soil organic N levels. Wheat in no-till and non-fallow rotations (such as wheat immediately following sorghum, corn, or cotton) requires higher N application rates than if a fallow period has occurred between crops (for example, wheat after wheat, or sorghum-fallow-wheat). Again, a preplant soil test will confirm N and P deficiencies. Currently, soil test critical levels defined by the Texas A&M University Soil Testing Laboratory for winter wheat at typical Blackland yield potentials are 40 and 26 ppm for nitrate-N and TAEX-phosphorus, respectively.

Phosphorus Fertilization

A soil sample taken up to one month prior to planting winter wheat, and analyzed for available P content should be used to predict if additional P fertilization may increase winter wheat grain yields. Ideally, this soil test characterizes the quantity of soil-P reserves that is readily available to, and that can readily be assimilated by a winter wheat crop. The accuracy of a preplant soil test in predicting P fertilizer requirements at planting can be affected by stratification of available P in the soil profile and the laboratory chemical solution (the extractant) used to extract available soil P. When stratification of soil-P occurs, available P concentrations in the surface 2 inches of soil can be two to four times the concentration of available P at soil depths ranging from 2 to 8 inches. Sampling this 2 inch band of concentrated soil P can result in erroneously high concentrations of available P resulting in insufficient recommendations for fertilizer-P application in the soil test report. Consequently, soil should be sampled from a 2 to 6 (or preferably 8) inch soil depth for available P soil tests.

Two chemical solutions are currently used to extract available P from alkaline, calcareous Blackland soils. The Texas A&M University Soil Testing Lab utilizes an ammonium acetate-EDTA extractant for available P soil analyses (TAEX-P). Some soil testing laboratories use a sodium bicarbonate solution to extract available P from soil (Olsen-P). For routine determinations of available soil-P in regions where a wide range of acid, neutral, and alkaline soils are found such as in the state of Texas, the acidic TAEX extractant is preferred if a laboratory is limited to the use of only one extractant. However, in alkaline, calcareous soils of the Blackland, the weak acid in the TAEX extractant is rapidly neutralized by soil carbonate rather than utilized in extraction of calcium phosphates. Additionally, the EDTA component of the extracting solution can dissolve calcium carbonate in calcareous soils and the associated soil calcium-P that may be unavailable to wheat plants, resulting in overestimation of available P in Blackland soil. When calcareous Blackland soil is extracted with the alkaline Olsen's sodium bicarbonate solution, the calcium concentration in the extraction solution is decreased by precipitation as calcium carbonate, and as a result, the concentration of P from calcium phosphate in the extracting solution increases. Often, the Olsen soil test gives a better index of plant available or soluble soil-P for alkaline, calcareous soils such as those found in the Texas Blackland.

Various factors affect the availability of fertilizer phosphorus (P) to winter wheat, including fertilizer rate, placement of P (Hipp and Hooks, 1978), soil test level P, soil temperature or planting date (Hipp, 1987a), and available soil moisture. Phosphorus is immobile, in that it does not move very much in the soil profile. Therefore, fertilizer P must be either incorporated into surface soil or banded with seed at planting in order to be positionally available to wheat plant roots. Phosphorus fertilizer formulations consist primarily of two chemical forms, orthophosphate (ordinary superphosphate, triple superphosphate, ammonium phosphate, and potassium phosphate fertilizers) and polyphosphate (urea ammonium phosphate, ammonium polyphosphate, and potassium polyphosphate fertilizers). Plant roots take up the orthophosphate form, and polyphosphates are readily converted to orthophosphate in the soil. Thus, both fertilizer forms give essentially equal results as P fertilizer sources. Only a small percentage of applied P fertilizer is utilized for crop growth, and the remaining fertilizer-P will eventually enrich various pools of soil P. This residual soil-P can make significant contributions to the P nutrition of succeeding crops.

Winter wheat often responds to P fertilizer applications due to reduced availability of soil-P resulting from cold winter soil temperatures. Cold soil temperatures reduce microbial decomposition of organic matter and subsequent release of available soil-P (Spence and Welch, 1977). Consequently, less available P is liberated from soil organic matter during the growing season of a cool season crop (winter or fall) than during growth of a warm season crop (spring or summer). Furthermore, the absorption and utilization of soil P reserves by winter wheat plants are decreased by cold winter soil temperatures. Therefore, applications of fertilizer P with or near the wheat seed often increase grain yield of winter wheat, even in fields that normally do not require P applications for maximum yield of warm-season spring crops such as corn, sorghum, and cotton.

Field studies were conducted to determine the influence of rate and placement of fertilizer-P at three planting dates or soil temperatures (Hipp and Hooks, 1978, Figure 3). Planting dates were September 15, November 15, and December 15 at average daily air temperatures of 67.8, 46.7, and 36.5 degrees Fahrenheit, respectively. The September 15 planting date is typical of winter wheat grown for forage production (pasture), while the November and December planting dates are more typical of winter wheat grown for grain production. Wheat forage and grain yields were not increased by P fertilizer applied to wheat planted at the relatively warm September 15 planting date, but P application increased forage and grain yields of wheat planted later at colder soil temperatures occurring in November and December (Figure 3a, 3b). Furthermore, incorporation of fertilizer P into surface soil was necessary for optimum positional availability to plant roots and maximum winter wheat forage and grain yields at the November and December planting dates (Figure 3c). Broadcast fertilizer P without soil incorporation did not result in higher wheat forage and grain yields compared to unfertilized wheat. Field studies over a 4-year period indicated an interaction between soil-P level required for winter wheat production and planting date or temperature (Hipp, 1987a). Early planting (September-October) resulted in warm temperatures during the five-week period of early growth that is critical for uptake of soil P by winter wheat. Later plantings (November-December) resulted in much colder air temperatures during this critical five-week period. Therefore, grain and forage yield increases with P fertilization at later planting dates indicated a need for higher amounts of available soil- or fertilizer-P for early growth of winter wheat on cold soils that have marginally adequate reserves of soil P. Regardless of planting date, P fertilizer applications were not required for maximum winter wheat forage and grain yields when preplant Olsen available P soil levels exceeded the critical level of 19 ppm.

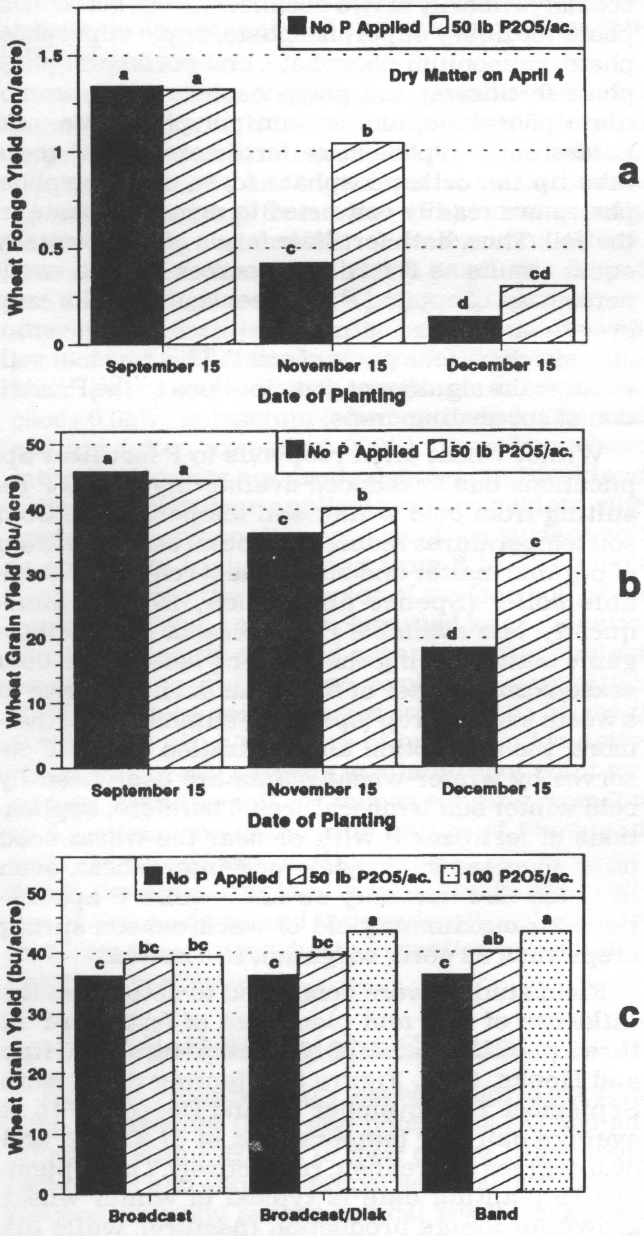


Figure 3. Influence of phosphorus (P) rate, date of planting, and P application method on Sturdy winter wheat grain and forage yield.

Frequently, wheat forage yield increases due to P fertilization are 100 to 200% higher than unfertilized wheat, while grain yield increases may be only 10 to 50% higher than unfertilized wheat. Four hard red winter wheat varieties (TAM 201, 2180, Siouxland 89, and TAM 300) and two soft red winter wheat varieties (Pioneer 2548 and Coker 9543) were grown with and without P fertilizer at Prosper (Figure 4). Phosphorus, as triple superphosphate (0-46-0), banded with the seed during planting at a rate of 50 lb P_2O_5 increased grain yields of all six varieties by 10 to 12% compared to unfertilized plots (Figure 4b). At the same fertilizer-P rates, all six varieties had similar grain yields, but Siouxland 89 hard red winter wheat had the highest forage yield compared to the other five varieties (data not shown). Nonetheless, P fertilizer applications to winter wheat did not result in higher net income from wheat grain selling for $2.60/bushel at harvest in 1993 (Figure 4c). Typically, Blackland winter wheat grown for pasture will be grazed out beyond the normal animal removal date of February 15 (jointing) sacrificing grain production for livestock production when grain prices are this low. Therefore, when winter wheat grain prices are low, P fertilization may not be profitable for grain production, but can be profitable due to increased forage yields of pasture wheat that may be planted late on cold, P-deficient soils.

When available P is deficient in Blackland soils, applications of 40 to 60 lb P_2O_5/acre are customarily suggested. When P is band-applied utilizing a grain drill at planting, 40 lb P_2O_5/acre should be adequate for winter wheat grown on P deficient soils. This is the least expensive application method for P fertilization. However, when P is broadcast preplant and incorporated into the surface 4 to 6 inches of soil, the 50 to 60 lb P_2O_5/acre P application rate is necessary. Depending upon the rate, application method and formulation of P fertilizer, 1994 cost per acre of P fertilization ranged from $12 to $15/acre. Grain yield increases due to P fertilization of 3.4 to 6 bushel/acre higher than unfertilized wheat are the break-even points for the cost of P fertilization when wheat grain is sold for between $2.50 and $3.50/bushel. Many Blackland wheat producers band 100 lb 18-46-0/acre with the grain drill at planting to supply 18 lb N and 46 lb P_2O_5 per acre. This application is advisable for P deficient soils and results in a suffi-

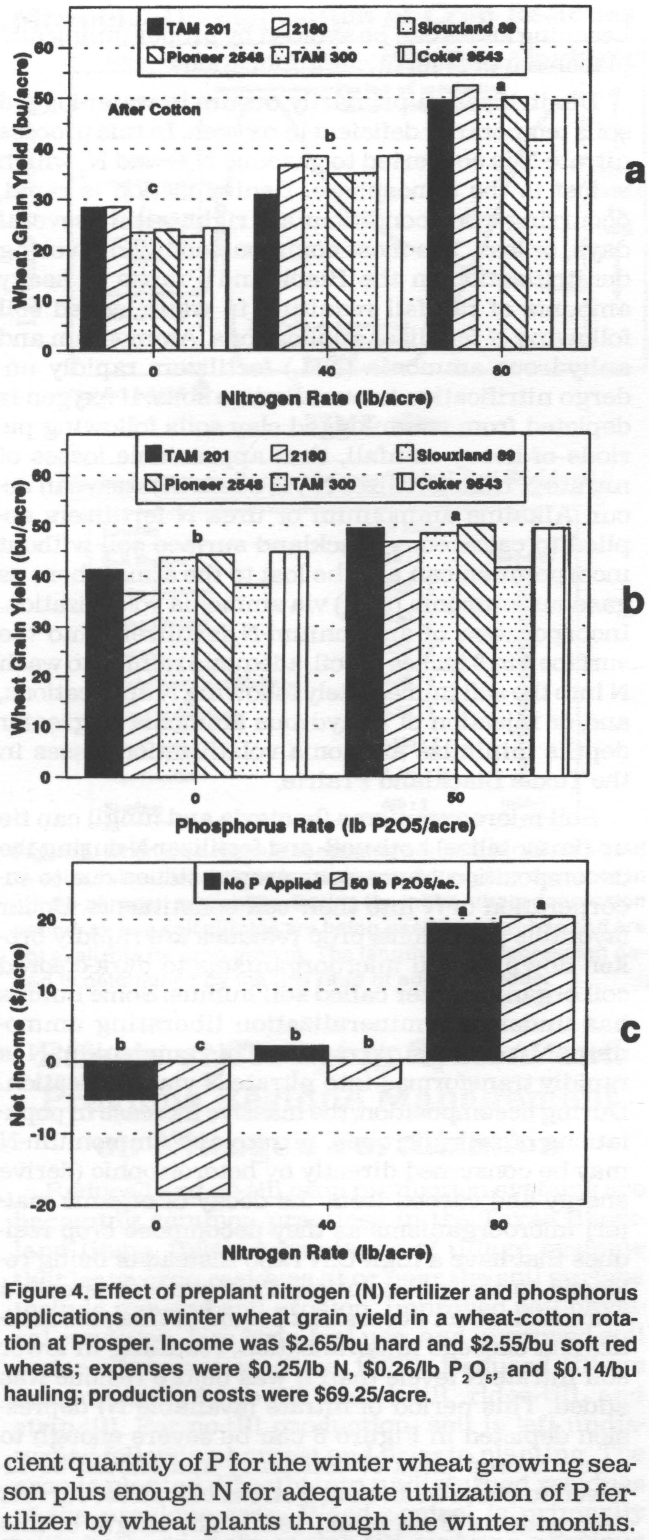


Figure 4. Effect of preplant nitrogen (N) fertilizer and phosphorus applications on winter wheat grain yield in a wheat-cotton rotation at Prosper. Income was $2.65/bu hard and $2.55/bu soft red wheats; expenses were $0.25/lb N, $0.26/lb P_2O_5, and $0.14/bu hauling; production costs were $69.25/acre.

cient quantity of P for the winter wheat growing season plus enough N for adequate utilization of P fertilizer by wheat plants through the winter months. Excessive rates of P fertilization can result in severe winter wheat zinc deficiencies on already zinc deficient Blackland soils. Occasional zinc deficiencies occur in Blackland soils when soil P and/or P fertilization is excessive; however, at an application cost of $6 to $12/acre for 4 to 6 lb zinc/acre, growers in the Texas Blackland Prairie would seldom break-even on the cost of zinc fertilization since grain yield increases of less than 5 to 10 bushel/acre can normally be expected. Therefore, Blackland wheat producers should determine the sufficiency of soil-P and zinc from a preplant soil test to ascertain whether P or zinc fertilization at planting would result in profitable grain yield increases.

The Nitrogen Cycle

Nitrogen (N) is the key fertilizer nutrient for profitable winter wheat crop production in the Texas Blackland. More than any other plant nutrient, N in the soil is subject to a complex system of gains, losses, and interrelated reactions (Donahue, Miller, and Shickluna, 1983). Intelligent crop management demands a working knowledge of these relationships depicted in Figure 5. Soil-N gains and transformations include fertilizer or manure applications, fixation of atmospheric N_2 by legumes (clover, alfalfa, and soybean crops), decomposition of crop residues, mineralization of ammonium (NH_4^+) from organic matter, and nitrification transforming ammonium to more readily available nitrate (NO_3). Available N losses from the system consist of leaching of soil N as NO_3, gaseous losses of N by denitrification in water-logged soils and ammonia volatilization of surface applied ammonium or urea fertilizers on calcareous soils. Immobilization of applied N fertilizer by decomposing crop residues and changes in availability such as fixation of ammonium by clay minerals can result in a temporary loss of N from the system. Large quantities of soil N exist in the organic form in soil organic matter and N_2 gas in the soil atmosphere, but these forms of N cannot be utilized directly by crop plants. Leguminous crops such as alfalfa, clover, and soybean can utilize atmospheric-N, however most non-leguminous crop plants take up soil-N primarily in the nitrate (NO_3) form, and to a lesser extent, the ammonium (NH_4^+) form. Only a small part of soil N pool exists in these forms. Nitrate-N is easily leached from soil and both nitrate- and ammonium-N can be lost to the atmosphere as N_2O and NH_3 gases, respectively.

The primary source of indigenous soil-N in Blackland soils is derived from mineralization of organic N from soil organic matter. Mineralization is the conversion of organic N from soil organic matter to ammonium-N mediated by soil

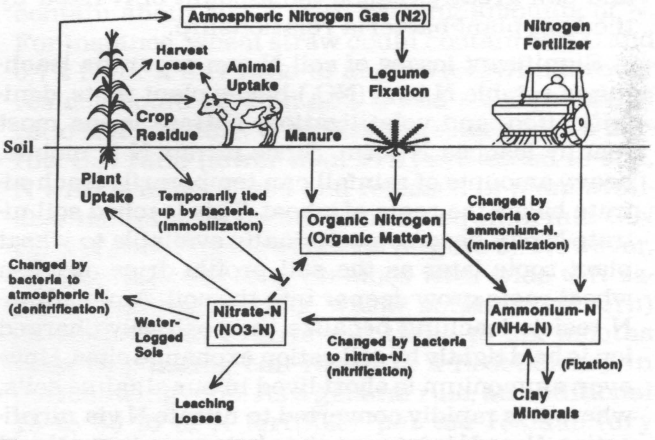


Figure 5. The nitrogen (N) cycle showing N additions, transformations, and losses.

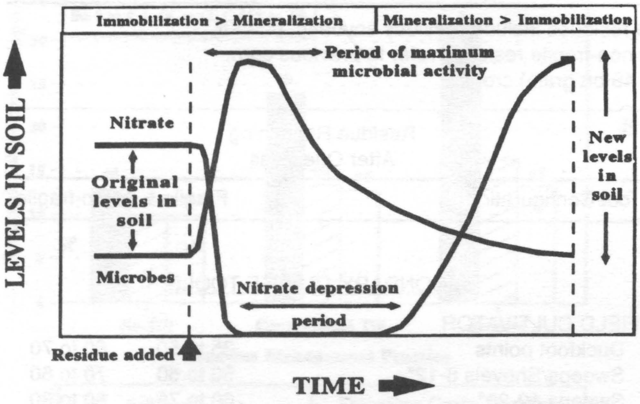
bacteria. Principal sources of soil organic matter include decomposing crop, plant and animal residues, and animal manure. Soil ammonium-N ions are short lived in alkaline, calcareous soils. Ammonium-N can become unavailable by temporary fixation within the structure of clay minerals, can be absorbed directly by plant roots or microbes, and/or predominately is oxidized by soil bacteria to nitrite (NO_2), and then to nitrate-N. Nitrite-N is toxic to plants, but rarely accumulates in large quantities in soil. The oxidation of ammonium-N to nitrate-N by soil bacteria is called "nitrification". This process is rapid, normally occurring within hours to 1 or 2 days, and is an important step in soil acidification. Mineralization of N from soil organic matter occurs at a higher rate in noncropped, fallow soils than it does in soils currently under crop production. Mineralized nitrate-N can accumulate in fallow soils since no crop is present to remove it. Therefore, preplant soil nitrate-N levels are normally much higher for winter wheat following a 6 to 12 month fallow period than preplant soil nitrate-N levels immediately following spring crops such as sorghum and cotton.

Another significant source of soil-N comes from nitrogen fixation. Bacteria of the genera Rhizobium and Bradyrhizobium (and a few others) induce formation of nodules on roots of legume plants and have the ability to convert atmospheric N_2 into a form of N usable by the host legume plant. Leguminous crop plants commonly grown in the Blackland Prairie include clovers, vetch, soybean, peanut, cowpea, edible beans, and garden peas. The amount of N supplied by symbiotic fixation varies from 30 to 80% of the total N requirement of leguminous crops. Low numbers of Rhizobia generally occur in soils not previously cropped to legumes, resulting in poor nodulation of roots. Thus legume seed is often inoculated with the proper bacteria just prior to planting. Active nodules containing Rhizobia normally form on roots of legumes three to four weeks after planting and leave a red-colored stain when crushed. Applications of fertilizer N to leguminous crops will reduce the number of nodules formed by Rhizobia on roots and can greatly reduce the amount of N fixed by the host plant-bacteria relationship.

Significant losses of soil N can occur via leaching of soluble N ions (NO_3) below plant roots, denitrification, and volatilization. Nitrate is the most readily leached N form. Since nitrate-N is mobile, heavy amounts of rainfall can temporarily leach nitrate below the roots of wheat. This leached soil nitrate-N can become positionally available to wheat plant roots later as the soil profile dries or when wheat roots grow deeper into the soil. Ammonium-N resists leaching because the positively charged ion is held tightly by soil cation exchange sites. However, ammonium is short lived in our alkaline soils, where it is rapidly converted to nitrate-N via nitrification. Urea-N is intermediate between nitrate-N and ammonium-N in its leachability from surface soil. Leaching losses can be avoided by proper timing and placement of N fertilizer applications.

Denitrification primarily occurs in water-logged soils temporarily deficient in oxygen. In this process nitrate-N is converted to gaseous N_2O and N_2 which is lost to the atmosphere. Denitrification is rapid, occurring when conditions are right, within several days, or less. The most common condition favoring denitrification in the Blackland Prairie is heavy amounts of rainfall resulting in water-logged soil following N fertilizer applications. Ammonium and anhydrous ammonia (NH_3) fertilizers rapidly undergo nitrification in our alkaline soils. If oxygen is depleted from water-logged clay soils following periods of heavy rainfall, then appreciable losses of nitrate-N from fertilizer-N via denitrification can occur. Alkaline ammonium or urea N fertilizers applied to calcareous Blackland surface soil without incorporation can also be lost to the atmosphere as gaseous ammonia (NH_3) via ammonia volatilization. Incorporation of ammonium-N fertilizers into the surface 4 to 6 inches of soil, adequate rainfall to wash N into the soil immediately following N applications, and/or injection of anhydrous ammonia at greater depths minimize ammonia volatilization losses in the Texas Blackland Prairie.

Soil microorganisms (bacteria and fungi) can tie up (immobilize) both soil- and fertilizer-N during the decomposition of previous crop residues due to incorporation of N into their cell constituents. Under favorable conditions, crop residues are rapidly broken down by soil microorganisms to dark-colored soil organic matter called soil humus. Some humus has undergone mineralization liberating ammonium-N from organic matter. This ammonium-N is rapidly transformed into nitrate-N via nitrification. During decomposition, the massive increase in populations of soil microbes, nitrate and ammonium-N may be consumed directly by heterotrophic (derive energy and carbon from the decay of organic matter) microorganisms as they decompose crop residues that have a high C:N ratio instead of being released to the soil solution. This process is called immobilization. For a short period of time, immobilization exceeds mineralization, resulting in lower soil nitrate-N levels than it was before residue was added. This period of nitrate (available N) depression depicted in Figure 6 can be severe enough to cause a crop plant N deficiency and should be allowed to occur before such stress can affect current crop growth (Foth et al., 1982). The length of this available N depression period and the final concentration of nitrate-N in the soil solution is determined by the carbon to nitrogen (C:N) ratio of the previous crop residue. The narrower the C:N ratio of the residue the shorter the depression period for available N, and the higher the new N concentration in the soil solution (Figure 6). For example, residues of a previous alfalfa crop incorporated into soil would return more nitrogen to the soil in a shorter period of time than incorporating the same amount of wheat straw.


Microbial Decomposition of Crop Residues

Carbon-Nitrogen Ratios of Some Typical Soil Residues

Residue	C:N Ratio	
Soil Humus	10 : 1	(narrow)
Young Legumes	12-20 : 1	↑
Young Grasses	20-40 : 1	
Manure	20-50 : 1	
Sorghum or Corn Stalks	40-60 : 1	
Wheat or Oat Straw	60-80 : 1	
Tree Leaves	60-100 : 1	
Pine Needles	200-250 : 1	
Sawdust	400 : 1	(wide)

Figure 6. When crop residue containing a wide C:N ratio is added to soils, microbial activity increases resulting in a decrease in nitrate-nitrogen availability. During the initial nitrate depression period, all free soil nitrates are being used by microbes and are not available for crop growth. The length of the depression period is determined by the C:N ratio of added residue.

Effects of Cropping System and Previous Residue Management on Nitrogen Fertilization

Reduced and no-till crop production systems are becoming common practices in the Texas Blackland (Pigg, 1994). Advantages of tillage systems that leave crop residues at or near the soil surface include reduced soil erosion, improved soil physical condition, less farm fuel use, and improved soil water conservation (Box, 1973). Reduced tillage systems include no-till, mulch-till, ridge-till, and strip-till. For no-till production, soil is left undisturbed following harvest and prior to planting. The crop is planted directly into undisturbed residues of the previous crop. Weed control is primarily with herbicides. In mulch-till systems previous crop residues are tilled leaving sufficient residue (30 to 60% remaining) on the soil surface to reduce erosion prior to planting. Only a small portion of the previous crop residue is incorporated into the top few inches of soil using tools such as chisels, field cultivators, disks, sweeps, or blades. Weed control is with herbicide and/or cultivation. Ridge-till and strip-till systems are predominately used for row-crops. They involve normal tillage of a narrow band in the seed row prior to planting, leaving previous crop residues between seed row strips and on the soil surface.

Residue management begins at harvest since the sequence and number of tillage and planting operations affect the amount of previous crop residue remaining on the soil surface. The type of point or blade used with tillage implements has a great impact on the amount of residue remaining on the soil surface (Table 1). A shallow chisel plow with sweeps can leave up to 85% of the existing crop residue on the soil surface after one pass while a deep disk chiseling with 4-inch twisted points could leave as little as 30% of the previous crop residue on the surface (John Deere, 1991). V-shaped blades that are 30 or more inches wide undercut and disturb very little of the existing crop residue on the soil surface. These blades can leave up to 85 to 95% of the wheat residue that existed before one tillage pass. Straight chisel points turn and mix the soil less than twisted chisel points. Thus, in wheat residue, straight points can leave 60 to 80% of the residue that existed before a pass, while twisted points leave 50 to 70% of the existing wheat residue. Sweeps with low crowns fracture and loosen the soil, but incorporate less crop residue than medium crown sweeps. In wheat residue, a chisel plow with 12 inch small crown sweeps can leave 70 to 85% of the residue that existed before the pass. Soybean, cotton, peanut, and low-yielding wheat (under 45 bu/acre) are fragile crop residues in that considerably less residue remains on the soil surface after tillage, compared to non-fragile corn, sorghum and 45 bu/acre or higher yielding wheat crop residues. Pictorial guides and beaded string-line kits are available from offices of the USDA Natural Resource Conservation Service (former Soil Conservation Service) to help growers estimate crop residue levels on the soil surface in fields under conservation plans (Soil Conservation Service, 1992).

When crop residues are added to the soil, microorganisms use the carbon (C) for energy and nitrogen (N) for building body tissues. Soil organisms assimilate about 30% of the C in crop residues, with the balance given off and lost from the soil as carbon dioxide (CO_2). Most crop residues contain about 50% C with varying amounts of N. For instance, wheat straw could contain 50% C and 0.7% N for a C:N ratio of about 70:1, while clover residue could contain 50% C and 4% N for a C:N ratio of about 13:1. When crop residues with a narrow C:N ratio (lower than 17:1) are added to soil, N will be mineralized and released in plant available inorganic N forms until an equilibrium C:N ratio of about 10:1 is obtained (Figure 6). However, incorporation of crop residues with wide C:N ratios exceeding 17:1 (e.g. wheat, sorghum, or corn) into Blackland Prairie soil three to six months prior to planting can result in a N deficiency in the following crop. As a general rule, an additional 15 to 30 lb of N fertilizer per ton residue (dry weight basis) will be adequate to offset any tem-

Table 1. Effect of tillage tools on crop residue levels remaining on the soil surface after one pass as a percentage of existing residue.

For percentage of existing residue remaining, fragile residues include previous soybean, peanut, cotton, and wheat (under 45 bu grain) crops, while non-fragile residues refer to previous corn, sorghum, and wheat (over 45 bu grain) crops.

Tool/Configuration	Residue Remaining After One Pass Fragile	 Non-fragile
	%	%
PRIMARY TILLAGE TOOLS		
MOLDBOARD PLOW	0 to 5	0 to 10
DISK PLOW	5 to 15	10 to 20
V-RIPPER/SUBSOILER	60 to 80	70 to 90
SUBSOILER + CHISEL	40 to 50	50 to 70
DISK + SUBSOILER	10 to 20	30 to 50
CHISEL PLOW		
Sweeps	50 to 60	70 to 85
Straight points	40 to 60	60 to 80
Twisted points	30 to 40	50 to 70
COMBINATION CHISEL PLOW		
Coulter + sweeps	40 to 50	60 to 80
Coulter + straight chisel points	30 to 40	50 to 70
Coulter + twisted chisel points	20 to 30	40 to 60
Disk + sweeps	30 to 50	60 to 70
Disk + straight chisel points	30 to 40	50 to 60
Disk + twisted chisel points	20 to 30	30 to 50
OFFSET/TANDEM DISK HARROWS		
Plowing >10" spacing	10 to 25	25 to 50
Primary >9" spacing	20 to 40	30 to 60
Finishing 7-9" spacing	25 to 40	40 to 70
One way w/12-16" blades	20 to 40	40 to 50

Tool/Configuration	Residue Remaining After One Pass Fragile	 Non-fragile
	%	%
SECONDARY TILLAGE TOOLS		
FIELD CULTIVATOR		
Duckfoot points	35 to 50	60 to 70
Sweeps/Shovels 6-12"	50 to 60	70 to 80
Sweeps 12-20"	60 to 75	80 to 90
COMBINATION FINISHING TOOLS		
Disks, shanks, leveler	30 to 50	50 to 70
Rollers and spring teeth	50 to 70	70 to 90
Spring tooth harrow	50 to 70	60 to 80
Spike tooth harrow	60 to 80	70 to 90
Flex-tine tooth	70 to 85	75 to 90
CULTIPACKER ROLLER	50 to 70	60 to 80
PACKER ROLLER	90 to 95	90 to 95
ROTARY TILLER		
3" deep	20 to 40	40 to 60
6" deep	5 to 15	15 to 35
STUBBLE-MULCH PLOWS		
V-blades	70 to 80	85 to 95
Sweeps	65 to 75	80 to 90
ROTARY RODWEEDER	50 to 60	80 to 90
PLANTERS/DRILLS	90 to 95	90 to 95

Overwinter/seasonal soil surface residue losses from weathering, wind, etc. can range from 10 to 30%.
Generally, shallower depths and lower operating speeds leave more residue on the soil surface.
Source: John Deere, 1991.

porary immobilization of soil-N by the decomposition processes (Box, 1973). It is estimated that about 2 tons of residue/acre are required per year for most Blackland Prairie soils to maintain the status quo of soil organic matter (Box, 1973). Typical Blackland Prairie wheat and sorghum crops yield from 2 to four tons of dry straw (residue)/acre. If this straw contains 0.7% N, 2 to 4 tons/acre of residue would supply 28 to 56 lb N/acre to soil microorganisms. About 30 lb soil- and fertilizer-N per ton of residue is necessary for optimum residue decomposition in Blackland soils, therefore an additional 32 to 64 lb fertilizer-N/acre would be required to offset losses of soil-N immobilized by microbes during decomposition of crop residue when a short fallow period occurs between crops.

Nitrogen requirements of Blackland winter wheat in conventional and no-till grain sorghum (maize) and winter wheat residues were determined on 4 different sites at Dallas (Knowles et al., 1993). Winter wheat was grown in conventional till (shred, disk, plow), no-till (standing), and removed (burned or baled) grain sorghum and winter wheat residues. Preplant soil testing by the Texas A&M University Soil Testing Laboratory indicated that fertilizer-N applications were required for optimum winter wheat production following sorghum and wheat in no-till and conventional tillage systems (Figure 7). Grain sorghum residues reduced soil-N levels in the top 6-inch of soil to a greater extent than winter wheat residues. At low rates of broadcast N fertilizer (40 lb N/acre), winter wheat was; (1) more N deficient in no-till residue management systems compared to conventional tillage systems; (2) more N deficient under conventional tillage systems than when sorghum and wheat residues were removed; and (3) more N deficient when winter wheat followed grain sorghum compared to continuous wheat (Figure 8). At the highest N fertilizer application rate (120 lb N/acre) grain yields of winter wheat did not differ between either no-till and conventional tillage systems, nor previous sorghum and wheat rotations.

The N deficiency of winter wheat growing in no-till systems and sorghum-wheat rotations was attributed primarily to a reduced mineralization rate of soil-N in sorghum-wheat rotations, and immobilization of fertilizer-N by decomposing no-till crop residues. Although sorghum straw has a narrower C:N ratio (ranges 20:1 to 30:1) compared to wheat (ranges 50:1 to 60:1), winter wheat grain yields following sorghum were less at low N rates compared to continuous wheat. Sorghum was chemically terminated with herbicide applications

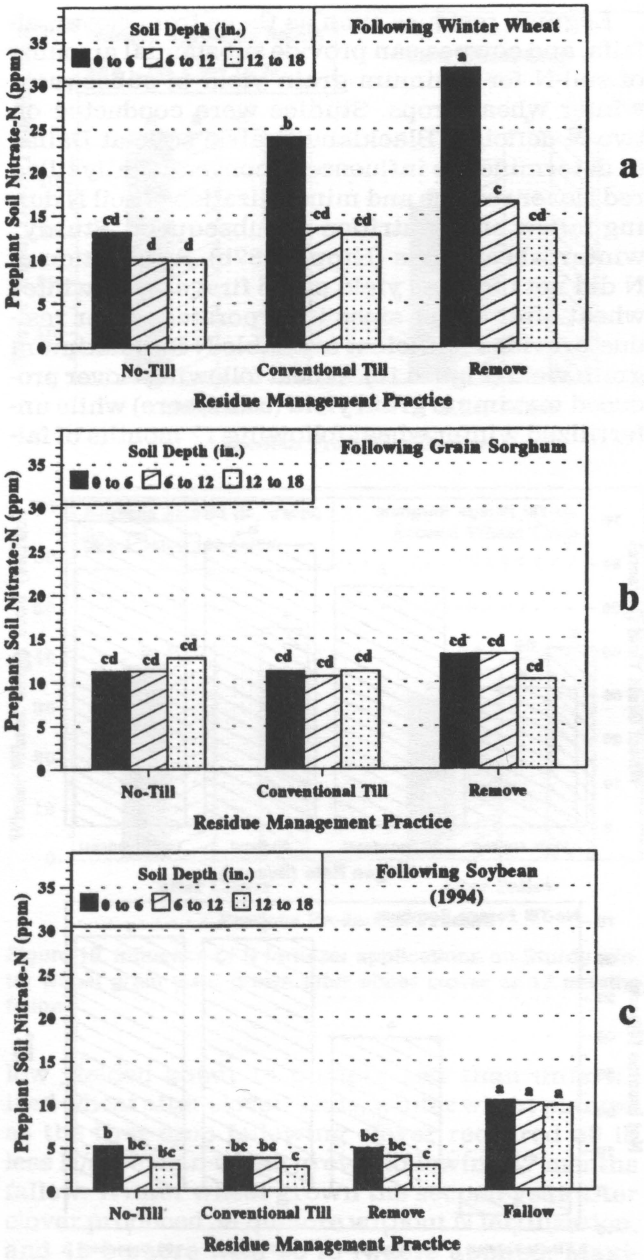


Figure 7. Effect of previous crop residue management practices on preplant soil nitrate-N (NO_3-N) for winter wheat following wheat (a) and sorghum (b) in 1990, and following soybean (c) in 1994 at TAES-Dallas.

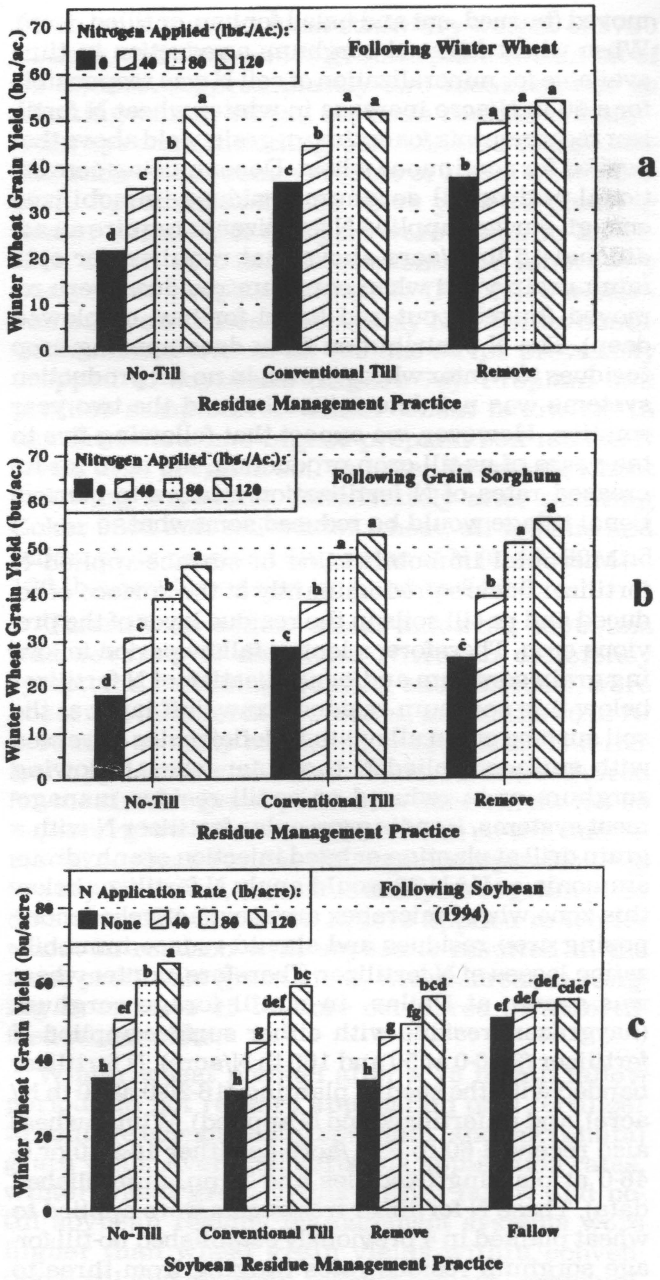


Figure 8. Effect of previous crop residue management practices and preplant nitrogen (N) fertilizer application rate on winter wheat grain yields following wheat (a) and sorghum (b) from 1988 to 1991, and following soybean (c) in 1994 at TAES-Dallas.

following grain harvest in August or September, which was about three months later than senescence (death) of winter wheat harvested for grain in May or June. Thus, sorghum was removing N from the soil while fallow soil previously under wheat was mineralizing soil-N from residue additions and soil organic matter. Previous wheat residue soils were fallow about five months allowing time for initial immobilization of and final mineralization of soil-N from crop residue and soil organic matter while sorghum was terminated only two months prior to planting winter wheat. Therefore, sorghum residues from sorghum-wheat rotations removed soil-N during the summer months which decreased the amount of time available for mineralization of previous crop residue and soil organic matter prior to planting winter wheat. In contrast, decomposing no-till wheat residues and, to a lesser extent, decomposing sorghum residues immobilized surface applied N fertilizer.

Greater quantities of surface-applied N fertilizer were required for optimum grain yield of winter wheat grown two consecutive seasons in decomposing wheat residue and immediately following grain sorghum compared to residue removal. Decomposing wheat residues under conventional tillage and no-till management systems required an additional 25 and 50 lb N/acre, respectively, above that required for optimum grain yield when wheat residue was removed (burned, cut and baled for hay, or tilled deep). When wheat followed sorghum, a reduction in time available for mineralization of soil-N was responsible for a 50 lb N/acre increase in winter wheat N fertilizer requirements for optimum grain yield above that needed for continuous wheat. Decomposing conventional and no-till sorghum residues immobilized enough surface-applied N fertilizer to require an additional 15 lb N/acre above that required for optimum grain yield when sorghum residues were removed (burned, cut and baled for hay, or plowed deep). The N contribution from decomposing crop residues to winter wheat grown in no-till production systems was not determined beyond the two year rotation. However, we expect that following five to ten years of no-till crop production, the need for increased rates of N fertilization relative to conventional tillage would be reduced somewhat.

Microbial immobilization of surface-applied N fertilizer occurs predominantly at the surface of reduced and no-till soils in the residue layer of the previous crop. Therefore, a longer fallow period following grain sorghum and/or application of N fertilizer below this sorghum residue straw-duff layer at the soil surface could alleviate N deficiencies observed with surface-applied N to winter wheat following sorghum or in reduced or no-till residue management systems. Banding granular fertilizer-N with a grain drill at planting or band injection of anhydrous ammonia or UAN-32 would apply N fertilizer below this zone where microbes are most actively decomposing crop residues and should reduce immobilization losses of N fertilizer. Therefore, winter wheat was grown at Dallas in no-till forage sorghum (haygrazer) residue with either surface-applied N fertilizer (34-0-0 at 50 and 100 lb N/acre), N fertilizer banded with the seed at planting (16-20-0 at 50 lb N/acre), and unfertilized (no N applied). Winter wheat also received 60 lb P_2O_5/acre as either 16-20-0 or 0-46-0 at planting (Knowles and Hipp, unpublished data). These N fertilizer treatments were applied to wheat planted in 4 previously established no-till forage sorghum residue rates ranging from three to six tons dry straw/acre remaining on the soil surface. The tonnage of forage sorghum residue remaining on the soil surface had no effect on N fertilizer requirements for optimum winter wheat grain yield. However, economically optimum winter wheat grain yields resulted from either 100 lb N broadcast as 34-0-0 to surface soil or 50 lb N/acre from 16-20-0 banded with a grain drill at planting (Figure 9). Consequently, band application of N fertilizer below no-till forage sorghum residue at planting reduced N fertilizer requirements for optimum winter wheat grain yield about 50 lb N/acre and had a higher N fertilizer use efficiency compared to surface-applied 34-0-0. Split N fertilization, application of 1/3 to 1/2 of the total N required at planting, then one or two additional applications prior to spring to meet the total N requirement, could also benefit winter wheat grown in no-till residue and/or for grazing plus grain production.

Legume residues such as those from clover, alfalfa, and cowpea can provide substantial amounts of soil-N for optimum grain yield of subsequent winter wheat crops. Studies were conducted on two N deficient Blackland Prairie soils at Dallas to determine the influence of conventionally tilled red clover residue and mineralization of soil N during fallow on N nutrition of subsequent "Sturdy" winter wheat crops (Hipp, 1987b). Application of N did not increase yield of the first crop of winter wheat after clover since incorporated clover residue provided sufficient available N for maximum grain yield (Figure 10). Wheat following clover produced maximum grain yield (51 bu/acre) while unfertilized winter wheat following 17 months of fal-

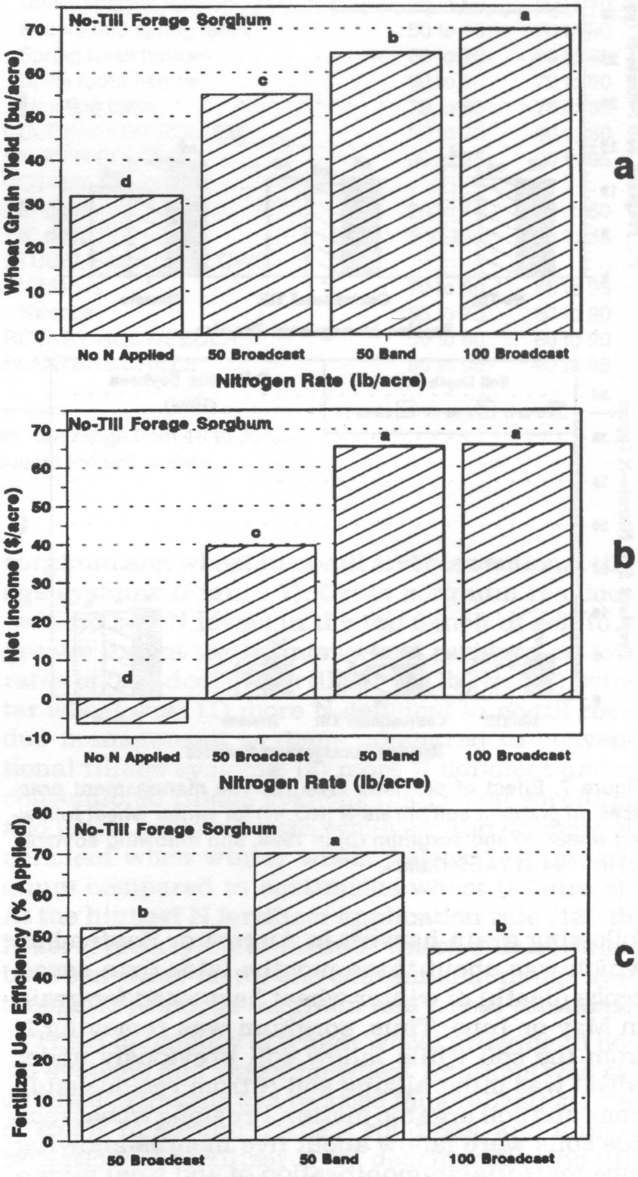


Figure 9. Effect of no-till forage sorghum residue and nitrogen (N) fertilizer applications on Coker 9803 winter wheat grain yield and N fertilizer use efficiency at Dallas. Income was $2.60/bu and expenses were $0.25/ lb N, $0.14/bu hauling, with production costs of $76.05/acre.

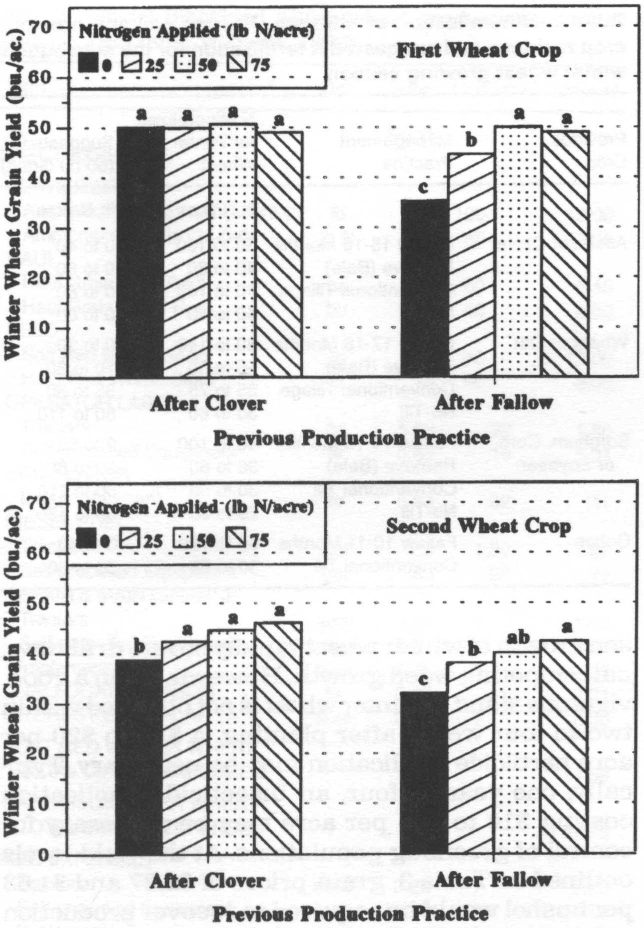


Figure 10. Influence of N fertilizer applications on Sturdy winter wheat grain yield grown after either clover or 17 months fallow.

low yielded about 14 bu/acre less than unfertilized wheat after clover. Thus, winter wheat planted as the first crop following clover required 50 lb less N/acre than wheat grown following 17 months fallow. Winter wheat grown the second year after clover produced 38 bu/acre without N fertilization, and 45 bu/acre with 50 lb N/acre applied. Maximum grain yield was obtained with 25 lb N/acre less for the second winter wheat crop after clover compared with winter wheat following fallow. Therefore, decomposed clover residue provided sufficient residual available N to supply 50 lb N/acre to the first subsequent winter wheat crop, then 25 lb N/acre to the second winter wheat crop. Benefits from increased residual soil-N levels resulting from decomposed clover residue would probably be minimal for the third subsequent winter wheat crop.

Other field studies on two different sites at Prosper examined the effects of decomposing conventional and no-till soybean residue on winter wheat N fertilizer requirements (Knowles and Hipp, unpublished data). Winter wheat was grown in a two-year rotation with soybeans. Northrup King S-4884 soybean residue strips and unplanted fallow strips were established one year prior to planting winter wheat. The soybean crop had a bean yield of 25 bu/acre, post-harvest straw dry weight of 5700 lb/acre, and total above ground plant N content of 46 lb/acre. Approximately two months prior to planting winter wheat, soybean residue management systems including conventional tillage, no-till, and residue removal (bale or burn) were initiated. Approximately one week prior to planting winter wheat, soil samples were taken to an 18-inch depth in 6-inch increments for laboratory analysis of preplant nitrate-N (NO_3-N). Preplant soil analysis indicated severely N deficient conditions existed within all residue strips previously cropped to soybeans (Figure 7c). Preplant soil profiles sampled for winter wheat following 15 months fallow had higher preplant soil nitrate-N levels than preplant soil samples for winter wheat following soybeans. Immediately after planting Coker 9803 soft red winter wheat, all residue and fallow plots received four rates of N (0, 40, 80, and 120 lb/acre) broadcast by hand as 34-0-0.

Unfertilized winter wheat following soybeans was severely N deficient. Nitrogen deficiency symptoms, including stunting and chlorosis, were observed in unfertilized wheat, and at the 40 lb N/acre rate as early as March 1. Broadcast N fertilizer applications of 120 lb N/acre were required for maximum grain yield of winter wheat (55-65 bu/acre) grown in conventional-till, no-till, and removed soybean residue management systems (Figure 8c). However, economic analysis of grain yield data revealed that 80 lb N/acre applied to winter wheat in rotation with soybeans resulted in the most profitable grain yield, with increases ranging from 11 to 25 bu/acre compared to unfertilized wheat plots.

Winter wheat planted after a 15 month fallow period did not require application of N fertilizer to achieve economically optimum (and maximum) grain yield. Averaged across N application rates, winter wheat grain yields within fallow and no-till soybean residue management systems were higher than wheat grain yields within conventional till and soybean residue removal systems.

Soybean residue-derived N was not mineralized in a timely manner to become a readily available N source for a succeeding winter wheat crop. Approximately 80 lb N/acre supplemental fertilizer N was required for optimum grain yield when winter wheat followed soybeans compared to fallowed land. This was due in part to the short fallow period of two to three months between soybean harvest and winter wheat planting that reduced the amount of time available for decomposition of soybean crop residues and mineralization of soybean derived residue-N and organic matter derived soil-N. Higher grain yield in no-till systems compared to conventional tillage systems was attributed primarily to increased plant available water throughout the soil profile at planting due to a reduction in soil disturbance resulting from reduced tillage.

However, in a previous study, clover crop residue-derrived N was mineralized in a timely manner to be a readily available source of N for a succeeding winter wheat crop. Other research at Texas Agricultural Experiment Station at Corpus Christi showed that a four year cotton-soybean rotation was necessary before soybeans contributed enough available soil-N so that cotton required minimal N fertilizer inputs for maximum lint yield (Matocha, 1995). Although both soybean and clover are legume crops, clover provided N to a succeeding winter wheat crop in a more timely fashion than did soybeans. We expect a longer fallow period between clover and winter wheat compared to wheat after soybeans contributed to increased N availability in the clover-winter wheat rotation compared to the soybean-winter wheat rotation. Furthermore, clover produced five to seven times more tonnage of crop residue compared to soybean residue. Thus, we suspect that more residue-derrived N was available from the immense volume of clover residue incorporated into the soil compared to the relatively small amount of soybean residue incorporated into soil prior to planting winter wheat.

The contribution of soil N from decomposition of previous crop residues and fallow periods to N requirements of the first subsequent winter wheat crop is described in Table 2. If winter wheat grown in the Blackland Prairie normally requires 1.5 lb N/bushel for grain production only, or 2.0 lb N/bushel for livestock grazing plus grain production, and typical Blackland Prairie winter wheat grain yields range from 40 to 60 bu/acre, then wheat would have soil- plus fertilizer-N requirements ranging from 60 to 90 lb N/acre for grain production only, or 80 to 120 lb N/acre for grazing plus grain production. Suggested fertilizer N application rates for an optimum grain yield of 60 bu/acre ungrazed winter wheat following soybean, clover, wheat, oat, sorghum (grain or forage), corn, or cotton crops are also listed in Table 2. Extra fertilizer N requirements of winter wheat due to losses via immobilization of soil- and fertilizer-N by decomposing previous crop residues are included in these suggested estimates of N application rate. Moreover, these rates of N fertilization could be reduced by 30% for a subsequent winter oat grain crop, or up to 50% if the preplant N application is either banded (granular-N) or injected (fluid-N) below the soil surface beneath decomposing crop residues, or N is foliar applied just after winter recovery and prior to vigorous spring growth.

Table 2. Mineralization of nitrogen (N) from soil and previous crop residues and suggested N fertilization for the subsequent winter wheat growing season.

Previous Crop	Management Practice	N Mineralized for Winter Wheat	Suggested N (60 bu Grain)
		lb N/acre	lb N/acre
Alfalfa or Clover	Fallow 15-16 Months	50 to 100	0 to 40
	Remove (Bale)	40 to 80	0 to 80
	Conventional Tillage	40 to 100	0 to 80
	No-Till	40 to 80	0 to 60
Wheat or Oat	Fallow 17-18 Months	60 to 140	0 to 30
	Remove (Bale)	60 to 80	10 to 30
	Conventional Tillage	55 to 75	35 to 60
	No-Till	30 to 60	80 to 110
Sorghum, Corn, or Soybean	Fallow 14-15 Months	40 to 100	0 to 50
	Remove (Bale)	30 to 60	30 to 60
	Conventional Till	30 to 55	60 to 110
	No-Till	25 to 30	80 to 130
Cotton	Fallow 10-11 Months	60 to 120	0 to 40
	Conventional Till	30 to 60	30 to 80

Winter Wheat Production Costs in the Texas Blackland Prairie

Production costs for winter wheat grown in the Texas Blackland Prairie include seed, fertilizer, operator labor, fuel, machinery repair, harvesting, and hauling grain to the mill (Table 3). Most years, herbicide applications are not required since early season growth of winter wheat rapidly covers drill rows, outcompeting weed growth. However, when a good, vigorous stand of winter wheat is not obtained within two to four weeks after planting, a $10 to $20 per acre herbicide application may be necessary. Typically, one year in four, an insecticide application costing $10 to $15 per acre may be necessary for control of greenbug populations. At the yield levels outlined in Table 3, grain prices of $2.27 and $1.63 per bushel would be required to recover production costs of hard and soft red winter wheats, respectively. Currently, commercial soft red winter wheat varieties are more tolerant of wheat diseases common in the Blackland Prairie. Therefore, soft red winter wheat normally outyields hard red winter wheat, and is more profitable to Blackland producers. Of all the expenses summarized in Table 3, fertilizer costs would probably be the most flexible expense that is under the control of a winter wheat producer by simply reducing fertilizer rates for optimum efficiency. A preplant soil test to determine optimum but not excessive fertilizer requirements, more efficient application methods, and fertilization at optimum stages of growth can all reduce fertilizer application rates required for optimum grain yield of winter wheat.

Fertilizer Economics

The true cost of fertilization is based on the actual cost of the fertilizer material, the nutrient composition (analysis) of the fertilizer, and the cost of the most reasonable application methods for the fertilizer. Fertilizer labels show the minimum percentages by weight of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) which is the fertilizer guarantee or grade (%N-%P_2O_5-%K_2O). Although fertilizer materials may cost the same, the actual cost of a particular nutrient may be different. For instance, assuming equal effectiveness, if urea (46-0-0) and ammonium nitrate (34-0-0) both are the

Table 3. Typical Blackland winter wheat production costs at Dallas in 1994 (after Williams, 1992).

Item	Unit	Price	Quantity	Amount
		$/unit		$/acre
DIRECT EXPENSES				
FERTILIZER				
Ammonium Phosphate (18-46-0)	lb	.13	100	13.00
Ammonium Nitrate (34-0-0)	lb N	.25	80	20.00
HAUL				
Haul Grain (Soft Red)	bu	.14	60	8.40
Haul Grain (Hard Red)	bu	.14	40	5.60
SEED				
Soft Red Wheat Seed	lb	.15	80	12.00
Hard Red Wheat Seed	lb	.10	80	8.00
OPERATOR LABOR				
Tractors	hr	5.63	.32	1.80
Self-propelled Equipment	hr	5.63	.18	1.01
HAND LABOR				
Labor (Flagman)	hr	5.63	.02	.11
DIESEL FUEL				
Tractors	gal	.83	1.89	1.57
Self-propelled Equipment	gal	.83	.86	.72
REPAIR & MAINTENANCE				
Tractors	acre	1.01	1	1.01
Self-propelled Equipment	acre	7.81	1	7.81
Implements	acre	2.55	1	2.55
UNALLOCATED LABOR	hr	5.63	.41	2.31
INTEREST ON OP CAP	acre	2.30	1	2.30
SOFT RED WINTER WHEAT				
TOTAL DIRECT EXPENSES				74.59
HARD RED WINTER WHEAT				
TOTAL DIRECT EXPENSES				67.79
FIXED EXPENSES				
Tractors	acre	3.28	1	3.28
Self-propelled Equipment	acre	14.19	1	14.19
Implements	acre	5.44	1	5.44
TOTAL FIXED EXPENSES				22.91
SOFT RED WINTER WHEAT				
TOTAL SPECIFIED EXPENSES				97.50
HARD RED WINTER WHEAT				
TOTAL SPECIFIED EXPENSES				90.70
INCOME				
Soft Red Wheat Grain	bu	3.00	60	180.00
Hard Red Wheat Grain	bu	3.50	40	140.00
SOFT RED WINTER WHEAT				
RETURNS ABOVE DIRECT EXPENSES	acre			105.41
RETURNS ABOVE SPECIFIED EXPENSES	acre			82.50
HARD RED WINTER WHEAT				
RETURNS ABOVE DIRECT EXPENSES	acre			72.21
RETURNS ABOVE SPECIFIED EXPENSES	acre			49.30

same price per ton, urea is the better buy since it contains 920 lb N/ton compared with 670 lb N/ton of ammonium nitrate. If a producer was to apply 80 lb N/acre, only 174 lb urea per acre is required to equal the N applied in 235 lb ammonium nitrate per acre. Phosphorus and N granular fertilizers banded with the seed using a grain drill at planting is cheaper and more efficient requiring lower application rates than broadcast/incorporate application since nutrients are applied below the soil surface directly to plant roots. Additionally, broadcast applications often require higher N and P fertilizer rates compared to band applications. Often, foliar fertilization is an inexpensive application method if fluid fertilizers are tank mixed with compatible pesticides.

Figure 11 shows break-even winter wheat grain yield increases required to recover the cost of N fertilization at 3 N rates depending on the market value of wheat grain. Three values for fertilizer N expense are represented; $0.20/lb N which is typical for urea and aqua ammonia (Figure 11a), $0.25/lb N which is typical for ammonium nitrate and UAN 32 (Figure 11b), and $0.30/lb N which is typical for ammonium sulfate and calcium nitrate (Figure 11c). The value of the extra wheat grain yield

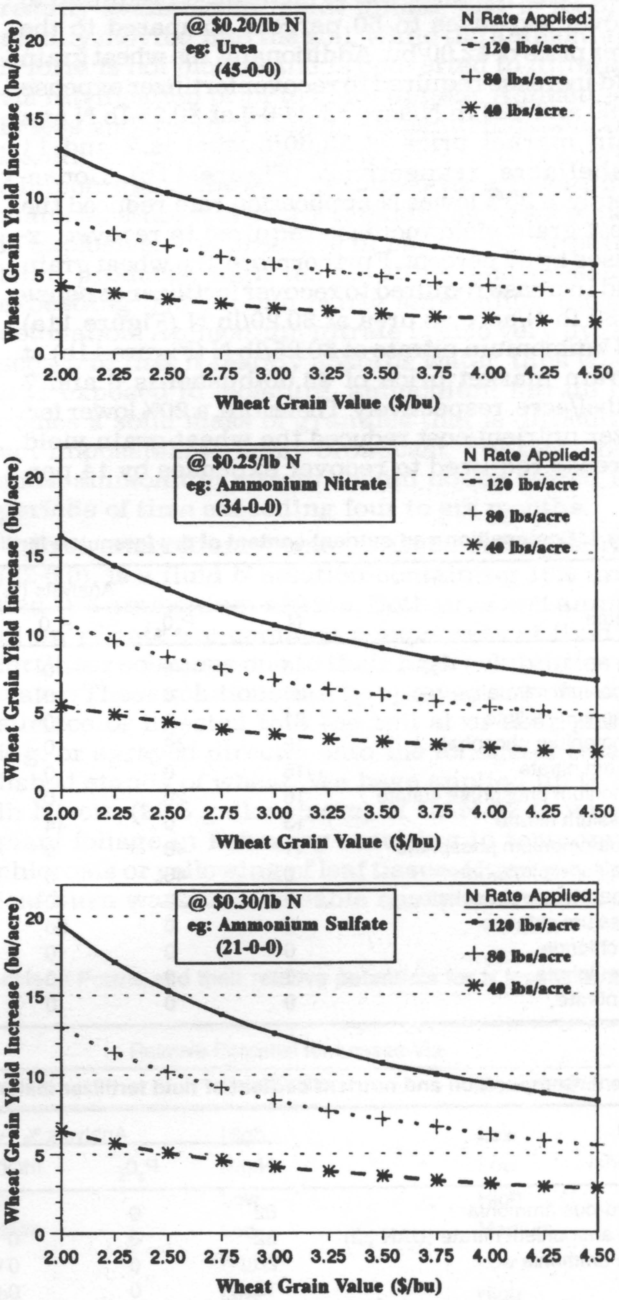


Figure 11. Winter wheat grain yield increases required to recover the expense of nitrogen (N) fertilizer applications (includes $0.15/bu grain hauling).

obtained due to fertilization determines the profitability of fertilizer applications. This profitability is sensitive to the market value of wheat grain, and affected by the cost of the fertilizer material and application rate. When winter wheat grain is priced at $2.00/bushel, grain yield increases due to the application of 34-0-0 ($0.25/lb N) of 6 and 12 bushel/acre are required to recover expenses at fertilizer rates of 40 and 80 lb N/acre, respectively (Figure 11b). However, when the market price for wheat grain hits $3.50/bushel, lower grain yield increases due to 34-0-0 application of 3 and 6 bushel/acre are required to recover fertilizer expenses at rates of 40 and 80 lb N/acre, respectively. Thus, 75% higher grain prices reduced the wheat grain yield increase due to fertilization required to recover expenses to 50 percent compared to the lower price of $2.00/bu. Additionally, the wheat grain yield increase required to recover fertilizer expense for 80 and 120 lb N/acre as 34-0-0 at $0.25/lb N at a grain market price of $3.00/bushel is 7 and 11 bushel/acre, respectively (Figure 11b). Consequently, a 33% lower N application rate reduced the wheat grain yield increase required to recover expenses by 36 percent. Furthermore, the wheat grain yield increase required to recover fertilizer expense for 80 lb N/acre as urea at $0.20/lb N (Figure 11a) and ammonium nitrate at $0.25/lb N (Figure 11b) at a grain market price of $3.00/bushel is 6 and 7 bushel/acre, respectively. Therefore, a 20% lower fertilizer nutrient cost reduced the wheat grain yield increase required to recover expenses by 14 percent. Generally, at reasonable rates of application and grain incomes, grain yield increases due to fertilization ranging from 3 to 8 bushels per acre were required to recover fertilizer expenses.

Fertilizer Materials for Winter Wheat Production

The nutrient contents of commonly used dry and fluid fertilizer materials are listed in Tables 4 and 5, respectively. Fertilizers that are injected into soil or banded with the seed at planting, or foliar applied to foliage, should have a low salt index. This index is used to compare solubilities of chemical compounds. Most nitrogen (N) and potassium (K) compounds are very soluble with a high salt index (range from 50 to 120) , while phosphorus (P) compounds have a low salt index (range from 10 to 30). When applied too close to the seed or on foliage, the fertilizer materials with a high salt index will burn the leaves and can kill young emerging wheat plants. Ammonium phosphates and P fertilizers have a relatively low salt index, so they are best suited to band or injection fertilizer applications for winter wheat at planting. Nevertheless, band and injection fertilizer applications of these materials should seldom exceed 100 lb/acre, and should not be in direct contact with the seed.

Anhydrous ammonia, NH_3 (82-0-0), is the N fertilizer formulation used most, with over 90% of all N fertilizers consisting of or derived from ammo-

Table 4. Composition and nutrient content of dry (granular) fertilizer materials commonly used in the Texas Blackland Prairie.

Dry	Analysis (%)					lbs/ton			
Material	N	P_2O_5	K_2O	S	Zn	N	P_2O_5	S	Zn
Urea	46	0	0	0	0	920	0	0	0
Ammonium nitrate	34	0	0	0	0	670	0	0	0
Ammonium sulfate	21	0	0	24	0	420	0	480	0
Diammonium phosphate	18	46	0	2	0	360	920	40	0
Calcium nitrate	16	0	0	0	0	320	0	0	0
Ammonium phosphate sulfate	16	20	0	12	0	320	400	240	0
Potassium nitrate	13	0	44	0	0	260	0	0	0
Monoammonium phosphate	11	48	0	0	0	220	960	0	0
Triple superphosphate	0	46	0	2	0	0	920	220	0
Ordinary superphosphate	0	20	0	12	0	0	400	30	0
Potassium chloride	0	0	60	0	0	0	0	0	0
Zinc chloride	0	0	0	0	48	0	0	0	960
Zinc sulphate	0	0	0	18	36	0	0	360	720
Zinc nitrate	9	0	0	0	22	240	0	0	440

Table 5. Composition and nutrient content of fluid fertilizer materials commonly used in the Texas Blackland Prairie.

Fluid	Analysis %				lbs/gal			
Material	N	P_2O_5	K_2O	S	N	P_2O_5	S	Density
Anhydrous ammonia	82	0	0	0	4.21	0	0	5.13
Urea ammonium nitrate (UAN 32)	32	0	0	0	3.54	0	0	11.06
Aqua ammonia	20	0	0	0	1.52	0	0	7.60
Urea	15	0	0	0	1.50	0	0	10.00
Ammonium nitrate	20	0	0	0	2.10	0	0	10.50
Ammonium polysulfide	20	0	0	40	1.94	0	3.88	9.70
Ammonium polyphosphate	10	34	0	0	1.10	3.74	0	11.00

nia compounds. Ammonia is a colorless gas that can be hazardous since it is normally stored at high pressure in tanks. It can cause severe irritation of the eyes, nose, throat and lungs, and even suffocation, and can burn skin on contact. Because anhydrous ammonia can be dangerous to handle, water solutions of ammonia and other soluble N formulations are more widely used. Anhydrous ammonia dissolved in water forms aqua ammonia (20-0-0). Aqua ammonia is a low-pressure liquid that is safer to handle, but has a lower N analysis than ammonia. Ammonia containing fertilizers must be injected below the soil surface in order to minimize losses of N via ammonia volatilization (Table 6). Aqua ammonia also needs to be injected below the soil surface, only not as deeply as anhydrous ammonia. Furthermore, improper application of ammonia when injector shanks leave open trenches that expose fertilizer to the atmosphere can cause significant losses on N via ammonia volatilization. Blackland Prairie soils that are high in montmorillonitic clays swell when wet and shrink when dry often resulting in soil cracking. Volatilization losses of ammonia from N fertilization can occur when subsequent soil cracks develop above the anhydrous ammonia band injected below the soil surface.

Urea, $CO(NH_2)_2$ (46-0-0), is a widely used N fertilizer that is also used as a protein source in livestock feeds. Urea contains the highest N percentage of commonly used solid fertilizers. Thus, it is cheaper per pound of N than other solid N fertilizer materials. It is very soluble (6.5 lb material/gallon), less leachable through the soil profile than nitrate (NO_3^-) fertilizers, but is more leachable than ammonium (NH_4^+) N fertilizers (Table 6). Biuret, a manufacturing contaminant of urea fertilizer, is one hazard of urea fertilization because biuret is toxic to sensitive plants in concentrations of more than 1 percent. Urea is a popular material for fluid N fertilizer solutions since it is high in N and quite soluble in water. However, due to the threat of biuret contamination, urea of high purity, and low biuret (LB urea) content must be used in foliar N solutions containing urea. When urea fertilizer (especially urea solutions) is topdressed to residue or alkaline soils, it should be incorporated into the soil immediately to avoid large N losses via volatilization. Research by the Texas Agricultural Experiment Station at El Paso has shown that the addition of 6 to 12% calcium (Ca) as calcium chloride ($CaCl_2$) to urea fertilizer solutions markedly reduces volatilization losses of N, and increased plant uptake of foliar applied urea (Fenn, 1986).

Ammonium nitrate, NH_4NO_3 (34-0-0), is an extensively used, and relatively inexpensive solid N fertilizer that is readily soluble in water (about 37 lb material/gallon). Half of the N is in the ammonium form and the other half is in the nitrate form. Following application, the nitrate-N portion is readily available for plant uptake and is mobile, readily moving into the soil, while the ammonium-N form is not mobile and is converted to nitrate-N via nitrification prior to plant uptake. Ammonium is less subject to N losses via denitrification and leaching compared to the nitrate-N form (Table 6). Ammonium nitrate is classified as a hazardous material since it is a strong oxidizing agent which is explosive. The presence of carbon (C) or petroleum products, high temperature, and pressure exceeding 500 psi can cause ammonium nitrate detonation. Ammonium nitrate is also very hygroscopic in that it readily absorbs water, thus when it is exposed to moisture, ammonium nitrate becomes a solid mass of granules that is difficult if not impossible to apply broadcast. For these reasons, ammonium nitrate should not be stored for periods of time exceeding four to six months.

Urea ammonium nitrate, UAN 32 or Solution 32 (32-0-0), is a fluid N solution containing 16% urea and 16% ammonium nitrate. Both urea and ammonium nitrate are common components of fluid N fertilizer solutions due to their high solubilities in water. These solutions can be sprayed onto the soil surface or injected into the soil at or near planting, or sprayed directly onto the foliage of established stands of wheat. We have applied up to 80 lb N/acre (22.6 gallons/acre) of UAN 32 to wheat plant foliage in February resulting in temporary chlorosis or yellowing of leaf tissue. However, this leaf burn was not noticeable one to two weeks af-

Table 6. Common nitrogen (N) fertilizer formulations used in the Blackland Prairie and their relative potentials for N losses to the environment.

		Relative Potential for Losses Via		
Nitrogen Fertilizer	Nitrogen Form(s)	Leaching	Volatilization	Denitrification
Ammonia	NH_3	Low[1]	High	Low
Urea	NH_2	Medium	High	Low
Ammonium Nitrate	NH_4,NO_3	High	Low	High
Urea Ammonium Nitrate	NH_2,NH_4,NO_3	Medium	Low	Medium
Ammonium Sulfate	NH_4	Low	High	Low
Calcium Nitrate	NO_3	High	Low	High
Ammonium Phosphate	NH_4	Low	Medium	Low

[1] After conversion to nitrate (NO_3), leaching potential is high for all fertilizer sources.

ter application. Thus damage was only cosmetic since subsequent grain yield was unaffected. Care should be exercised that these solutions are not exposed to temperatures below 32 degrees F which can cause salting-out. Salting-out occurs at below freezing temperatures when crystals begin to form in the N solution due to the decrease in solubility of the dissolved N components with declining temperature. Furthermore, nitrogen solutions are very corrosive, rapidly destroying copper, brass, zinc, galvanized steel, and concrete materials, and are moderately corrosive to carbon steel and cast iron. Therefore, N solutions should be stored in stainless steel, aluminum alloy, or polyethylene plastic tanks, and should not remain stored in sprayer tanks and booms for extended lengths of time. Also, stainless steel nozzles are suggested for applications of fluid N solutions.

Nitrogen fertilizer sources including urea (46-0-0), ammonium nitrate (34-0-0) and urea ammonium nitrate (UAN 32, 32-0-0) have been examined for winter wheat and oat production at Dallas and Prosper . In 1994, one soft red winter wheat variety (Coker 9803), one hard red winter wheat variety (TAM 300), and one winter oat variety (H-833) were subjected to 80 lb N/acre broadcast applications of urea, ammonium nitrate, or UAN 32 at planting or at jointing in mid February (Knowles and Hipp, unpublished data).

The application of 80 lb N/acre increased grain yields of Coker 9803, TAM 300, and H-833 oat varieties by 15.1, 7.2, and 10.0 bu/acre, respectively, compared to unfertilized plots (Figure 12a). Grain yield of the H-833 oat was approximately 7 bu/acre higher than Coker 9803 which had grain yield approximately 11 bu/acre higher than TAM 300. Broadcast N fertilizer applications at planting (10 November) and jointing (15 February) were equally as effective to correct N deficiencies of the small grain crops examined in this study. Different broadcast applications of 80 lb N/acre as either 34-0-0, 46-0-0, or 32-0-0 fertilizer formulations were equally as effective to obtain the highest grain yields in this study (57.6, 46.3, and 67.4 bu/acre for Coker 9803, TAM 300, and H-833 oat, respectively). Furthermore, N fertilizer application of 80 lb N/acre increased grain protein concentration of TAM 300 and H-833 oat by 2.0 and 1.7 percent, respectively, compared to unfertilized plots (Figure 12b). Grain protein concentration of Coker 9803 was unaffected by fertilization, and was approximately 1 percent less than TAM 300 and H-833 oat. The three N fertilizer formulations were equally as effective for producing the highest grain protein levels observed in this study (14.2, 15.7, and 16.0% for Coker 9803, TAM 300, and H-833, respectively).These results are consistent with other field experiments conducted at Dallas that showed 34-0-0, 46-0-0, and 32-0-0 were equally effective N fertilizer sources for correcting N deficiencies of small grain crops when broadcast at an adequate rate sometime between planting and the jointing stage of growth.

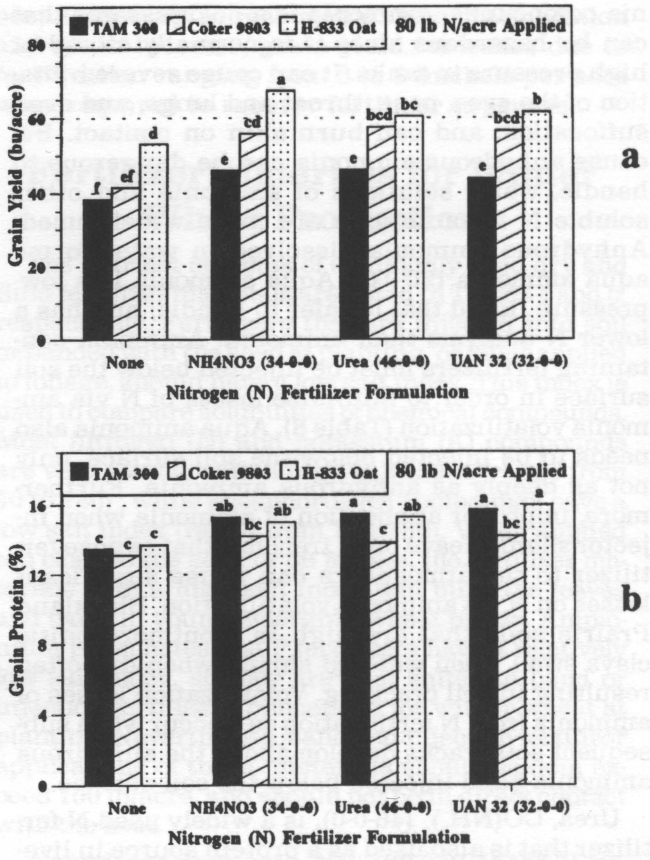


Figure 12. Effect of urea, ammonium nitrate, and UAN 32 nitrogen (N) fertilizer formulations on grain yield and protein concentration of TAM 300 hard red winter wheat, Coker 9803 soft red winter wheat, and H-833 winter oat at Prosper.

Ammonium sulfate, $(NH_4)_2SO_4$ (21-0-0), and calcium nitrate, $Ca(NO_3)_2$ (16-0-0), are two less commonly used solid N fertilizer materials due to their relatively low N content which makes them expensive N fertilizer sources on a per pound of N basis. Ammonium sulfate, however, is a good sulfur (S) source for S deficient soils since this material contains 24% sulfur. Ammonium sulfate applications can promote soil acidification lowering pH of non-calcareous soils, while calcium nitrate applications impart an alkaline residue to the soil that can slightly raise soil pH. Calcium nitrate is very soluble in water, and ammonium sulfate is somewhat souluble in water. However their low N content and high salt indexes make them poor components of fluid N solutions.

Common ammonium phosphate fertilizer sources include granular (dry) monoammonium phosphate, MAP (11-48-0), diammonium phosphate, DAP (18-46-0), and fluid ammonium polyphosphate, APP (10-34-0). High application rates (in excess of 100 lb material/acre) of DAP (18-46-0) in direct seed contact can burn germinating wheat plants resulting in death of the young plant and thin wheat plant stands. Both DAP and MAP are somewhat soluble in water, however DAP has a higher solubility (4 lb material/gallon) than MAP (3 lb/gallon). The MAP and DAP formulations are commonly used in the manufacture of other dry bulk blends and fluid fertilizer solutions. Research in Oklahoma on calcareous clay soils has shown that banded MAP can provide more phosphorus to wheat plants than DAP banded at an identical application rate due to the lower dissolution pH for MAP (Follett, Murphy, and Donahue, 1981). Granular ammonium phosphate sulfate is derived from a mixture of dry ammonium sulfate and dry monoammonium phosphate (MAP) and has a fertilizer analysis of 16-20-0. This material is a good source of sulfur (12% S) on S deficient soils and can be banded with a grain drill at planting at rates up to 300 lb material/acre. Blackland Prairie wheat producers commonly band 100 lb 18-46-0 with the seed using a grain drill at planting, then topdress the remainder of the required N as 34-0-0 sometime prior to February 15.

Calcium phosphates, $Ca(H_2PO_4)_2$, include granular (dry) ordinary or normal superphosphate (0-20-0) and triple superphosphate (0-46-0) fertilizers, are also common P fertilizer materials. Although ordinary superphosphate has a low concentration of P relative to other P fertilizers, it is a good source of sulfur. Ordinary superphosphate and triple superphosphate are only sparingly soluble in water (0.15 lb material/gallon). Triple superphosphate contains only trace amounts of sulfur from contaminating sulfuric acid in phosphoric acid used to manufacture triple superphosphate. It is widely used in the manufacture of other fertilizer grades in dry bulk blends or for direct application. Agronomically, there is little difference in the availability of P from either ordinary or triple superphosphate (Follet, Murphy, and Donahue, 1981).

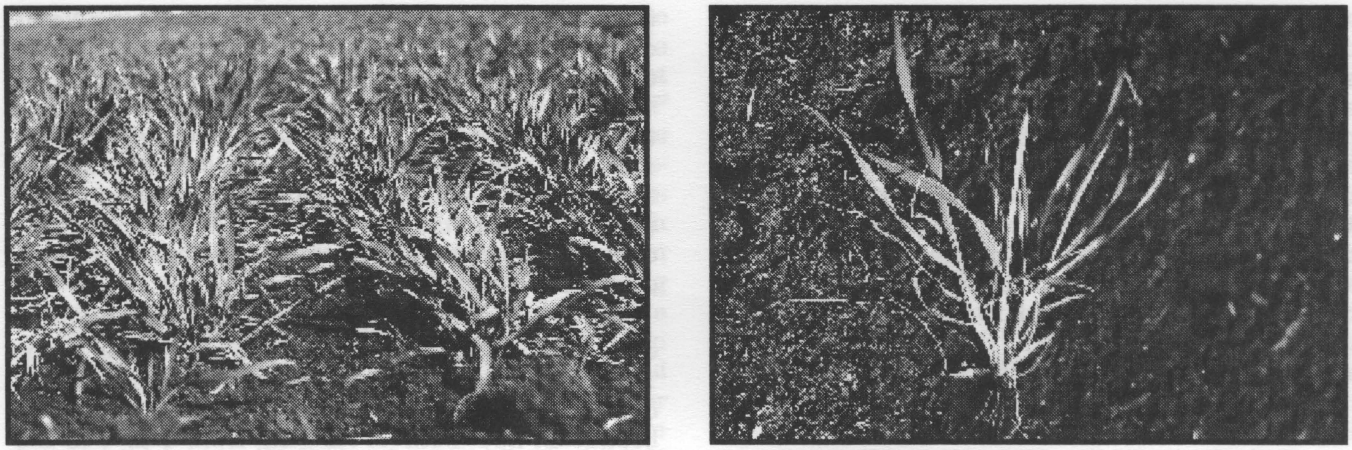
Potassium nitrate, KNO_3 (13-0-44), and potassium chloride, KCl (0-0-60) are two common dry K or potash fertilizer formulations. Potassium fertilizer applications are rarely suggested since applications are not profitable for optimum grain yield of winter wheat grown in the Texas Blackland Prairie. Potassium nitrate is highly soluble in water (2 lb material/gallon) and has a relatively low salt index (74), thus it is commonly used to manufacture other grades of foliar-applied fluid fertilizer solutions for high-value vegetable and cotton crops. Potassium chloride, or muriate of potash, is lower in cost due to its relatively high K content, and is more soluble (2.3 lb material/gallon) than other K carriers, but has a relatively high salt index (115). This relatively high salt index limits its usefulness in the manufacture of foliar applied fluid fertilizer solutions. It is an excellent source of chloride (Cl) containing about 47% Cl by weight. Recently, research by Dr. Travis Miller in Hill and Bosque Counties (Texas) has indicated that spring applications of chloride can increase winter wheat grain yields by about 5 bushel/acre compared to unfertilized wheat by suppressing common fungal diseases (Taylor, 1993). Spring topdress application of potassium chloride at 40 lb Cl per acre seemed to reduce leaf rust severity by up to 75% for winter wheat varieties susceptible to this fungal disease, and subsequently may have increased grain yield by 5 to 10 bushel/acre. Consequently, response to chloride is greater for leaf rust susceptible wheat varieties, and seems to be related to chloride levels in the soil. Moreover, foliar applications of chloride in fluid fertilizer solutions should be avoided since chloride materials have a very high salt index, thus they can act as a desiccant drying out plant leaves possibly defoliating wheat plants under hot, dry conditions.

Applications of zinc (Zn) fertilizer are seldom required for profitable winter wheat production in the Texas Blackland Prairie. On rare occasions, Zn deficient soils are encountered that require preplant broadcast applications ranging from 1 to 4 lb Zn/acre based on a preplant soil test report. Excessive P fertilization and/or preplant available P levels in alkaline, calcareous soils can intensify soil Zn deficiencies. Commonly available dry inorganic zinc fertilizer sources include zinc chloride, $ZnCl_2$ (48% Zn), zinc sulphate, $ZnSO_4$ (36% Zn), and zinc nitrate, $Zn(NO_3)_2$ (22% Zn). These Zn fertilizers are highly soluble in water and can be either broadcast and incorporated or banded dry at or near planting. They may also be foliar applied later in the season as a fluid fertilizer solution that could be tank mixed with pesticides. Water solubility of zinc sulfate, zinc nitrate, and zinc chloride is 7.4, 27, and 36 lb material per gallon water, respectively. Organic Zn chelates are also available that can be soil or foliar applied, however these formulations are very expensive and wheat grain yield increases due to their application are not profitable for Blackland Prairie winter wheat grain production.

Winter Wheat Developmental Growth Stages

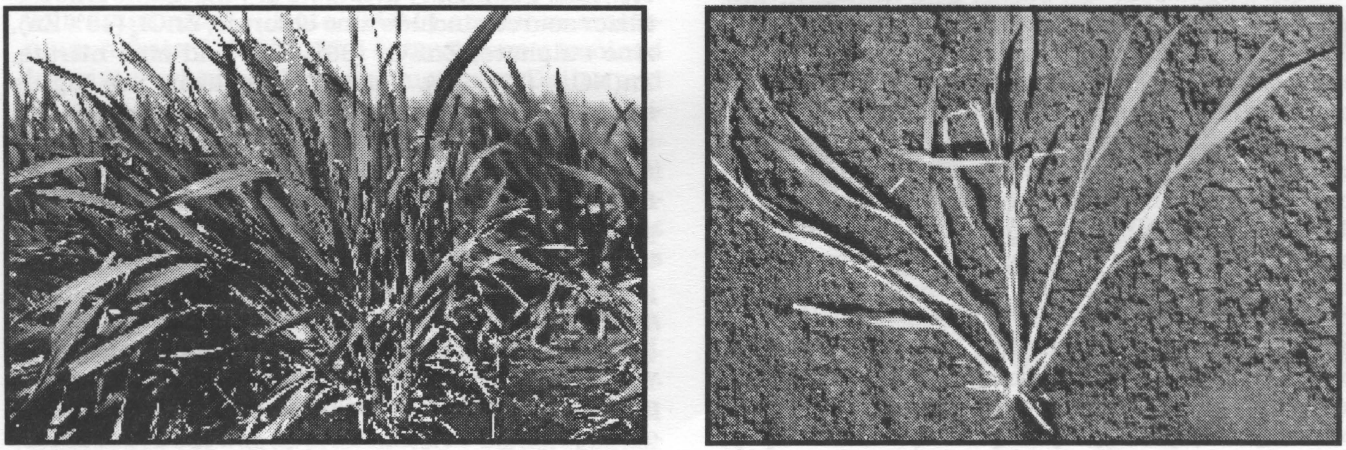
Recognition and proper identification of the stage of growth of winter wheat at any point during the growing season is necessary for intelligent crop management decisions. Producers need to have a basic understanding of growth stages of winter wheat since many herbicides and fungicides are most effective when applied within a narrow range of the wheat plants development. Water availability and timing of fertilizer application to coincide with specific growth stages can improve the efficiency and profitability of both. For instance, winter wheat nitrogen (N) uptake is most rapid from tillering through the booting developmental growth stages with 80% of the total N uptake occurring before grain filling. We have found that optimum window of time for N fertilization resulting in maximum N uptake efficiency by winter wheat coincides with the developmental growth stages from tillering through jointing.

Several growth stage scales including the Feekes Scale have been developed to designate specific stages of development of wheat as they progress from emergence through tillering and jointing, then to boot, heading, and grain ripening (Baur, Smika,



A) 4-5 leaf growth stage (February).

B) Tillering growth stage.



C) Jointing growth stage.

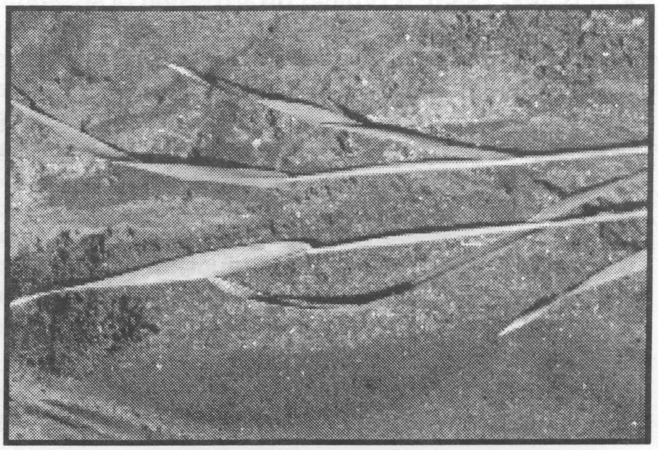
D) Swollen first node on stems at jointing

E) Pre-booting growth stage. Note 2nd joint is visible on stems.

F) Booting growth stage. Note extended (curled) flag leaves (March).

Inset 1a. Winter wheat developmental growth stages ranging from four to five leaf through booting.

G) Boot swollen. Pre-heading growth stage.

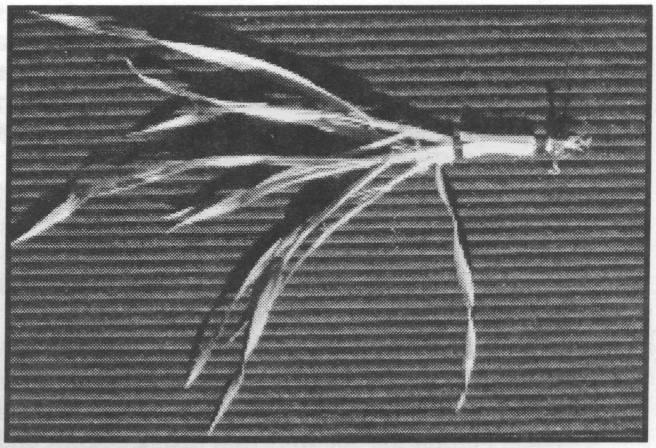


H) Close-up of booting growth stage just prior to heading.

I) Heading growth stage (April).

J) Flowering or anthesis growth stage (May).

K) Milky ripe growth stage.



L) Basal stem tissue sampled for nitrate-N analysis.

Inset 1b. Winter wheat developmental growth stages ranging from booting through milky ripe, and basal stem tissue sampled at four to five leaf for nitrate-N analysis.

and Black, 1983). A typical progression of seasonal developmental growth stages of winter wheat grown for grain production in the Texas Blackland Prairie is illustrated in photographs located in Inset 1 of this bulletin. Winter wheat for grazing is normally planted from August through September and the progression of early developmental growth stages depends on grazing intensity and duration. The developmental growth stages of winter wheat grown for grain production were based on the following events (calendar dates are approximate and may vary two to four weeks either side of those given):

A. Planting (October 15-November 15): Seed is sown into moist soil or prior to rainfall (Feekes Stage 0).

B. Emergence (November 25): It is first possible to see emerged plants (Feekes Stage 1).

C. 3-4 Leaf (December 15): Three fully-expanded leaves visible on the main stem and a fourth immature leaf is also developing on the main stem (Feekes Stages 2-4).

D. 5-6 Leaf (January 15): Five fully-expanded leaves are visible on the main stem and the sixth immature leaf is also developing on the main stem (Feekes Stages 5-6).

E. Tillering (January 15): Occurs at or near the 5-6 leaf stage when leaf tillers develop above leaf sheath bases (in the axil of leaves) on the main stem (Feekes Stages 2-5).

F. Jointing (February 15): The stage of first internode elongation when the first swollen node is visible on the main or largest stem just above the soil surface. This swollen node is visible only after stripping lower leaves from the main stem, and usually occurs just before expansion of the fifth or sixth leaf on the main stem (Feekes Stages 6-9).

G. Booting (March 15): About nine fully-expanded leaves are visible on the main stem (the lower 2 leaves may be shed at this stage). The uppermost (flag) leaf is fully extended just above its swollen leaf sheath containing the wheat head (spike, ear) in its axil (Feekes Stage 10).

H. Heading (April 15): The green head (inflorescence) is fully emerged from the base of the flag leaf. Awns (fine bristles growing from kernels of awned varieties) are fully extended about the wheat head (Feekes Stage 10.1).

I. Anthesis, Flowering, and Soft Dough (May 1): The head or inflorescence is still green and anthers emerge from kernels on the central part of the head. Pollination occurs, grain filling begins, and lower leaves begin to turn yellow as wheat begins senescence (Feekes Stage 10.5).

J. Milky Ripe (May 15): Kernels from the central part of the head are still easily deformed when pressed between the fingers and a milky liquid exudes under such pressure (Feekes Stages 11-11.2).

K. Hard Dough or Ripe (June 1): Kernels on the head lose their green color. It is no longer possible to deform the kernel by pressure between the fingers, but the kernel can still be cut by pressure from the fingernail. Upon breaking the kernel open, the interior displays a white, floury appearance (Feekes Stages 11.3-11.4).

L. Maturity or Harvest (June 15): Kernels are completely ripe and the wheat straw has died (senescent).

More precise growth scales exist, however, the preceding developmental stages of growth are adequate to define optimum windows for winter wheat crop management decisions in the Texas Blackland Prairie. These developmental growth stages are more reliable than calendar dates since they accurately define precise one to two week periods of plant development during the winter wheat growing season. Calendar dates approximate developmental growth stages within two to four weeks at best since growth stages are highly influenced by seasonal variations in climate (weather) and timing of production practices (e.g. planting date).

Timing and Methods of Fertilization for Blackland Prairie Winter Wheat Production

High rates of fertilizer N at planting can cause excessive vegetative growth that can increase the susceptibility of winter wheat to early season winterkill and fungal diseases. Under limited moisture, excessive fall vegetative growth of wheat can also deplete available soil moisture and cause plants to suffer from moisture stress. A suggestion for grain production is to, apply 15 to 30 lb N/acre at planting, then topdress the remainder prior to jointing. For grazing and grain, an application of 40 to 50 lb N/acre at planting is suggested to obtain adequate vegetative growth for fall and winter grazing, depending on available soil moisture. For intensive grazing from early fall seedings, suggested topdressing of one half the total N required should be applied in late fall and one half applied in late winter, especially when grain harvest is not planned (Gray, Welch, and Hodges, 1976). Grazing should be deferred to at least one week after rainfall has incorporated topdressed N fertilizer into the soil. Phosphorus should be applied and incorporated or banded into the soil before or at seeding so it will be in the root zone of young seedlings to increase early season growth and vigor and to help develop winter hardiness. Fertilizer-P can be broadcast on the soil surface then incorporated into the soil preplant or drilled in a band within the seed row at planting. An increase in broadcast P rates by 15 to 20 lb P_2O_5/acre over drilled P rates determined from a soil test is suggested. If grazing is planned, P should be band-applied in the seed row rather than broadcasted and incorporated. Drill-applied N fertilizer that does not contain P (has a high salt index) should be separated from the seed by at least 1 to 2 inches, and should not be applied at rates greater than 15 lb N/acre for wheat or 30 lb N/acre for oats (Gray, Welch, and Hodges, 1976).

Nitrogen fertilizer use efficiency by winter wheat is highest when N applications are timed to correspond to periods when crop use of N is high. Winter wheat N uptake is most rapid from tillering through booting growth stages with 80% of the total N accumulation occurring before grain filling (Doerge, Roth, and Gardner, 1991). Much of the N fertilizer applied to Blackland Prairie winter wheat is topdressed as ammonium nitrate (34-0-0) in late winter or early spring. Growers often delay N application to evaluate winter survival and potential productivity of their wheat crop before investing in N fertilizer. However, wet field conditions following prolonged rainy periods can delay N fertilizer applications to winter wheat until late spring.

Eight years of data from field experiments conducted at Dallas and Prosper were examined to determine optimum timing of N fertilizer applications for efficient use of applied N by plants throughout the winter wheat growing season (Knowles et al., 1994). Ammonium nitrate (34-0-0) was topdressed at three rates (0, 40, and 80 lb N/acre) at or near planting, and at the tillering, jointing, booting, and heading growth stages, plus split applications at these dates. Conventional tillage was used for seedbed preparation, and winter wheat followed wheat, oats, cotton, or fallow, depending on the year of the study. Optimum grain yield resulted from single N topdressings of 40 lb N/acre at jointing, 80 lb N/acre applied at planting through jointing, or split applications of 40 lb N/acre at planting and at jointing (Figure 13a). Fertilizer N topdressed following booting resulted in grain yields that were 15 to 20% lower than obtained with N topdressed prior to booting. This was attributed to low amounts of rainfall following booting which reduced movement of N fertilizer into the soil in time for uptake by winter wheat plant roots (Figure 2). Sufficient split N applications were equally as effective as sufficient single N applications for optimum winter wheat grain yield, however split applications of N fertilizer are more expensive because of extra fertilizer applicator trips over the field.

Nitrogen uptake by winter wheat proceeds very slowly until tillering begins, then peaks at a maximum of about 1.9 lb N/acre/day during the jointing growth stage (Figure 13b). Adequate soil-N reserves (or N fertilizer) should be made available to wheat plants so that N deficiencies do not occur during this period of peak vegetative growth and N uptake. Lower N rates were required for optimum winter wheat grain yield when fertilizer-N was topdressed during the period between tillering and jointing wheat growth stages. Therefore, the most efficient time to topdress N fertilizer for optimum winter wheat grain yield was between the tillering and jointing growth stages (January 15 through February 15) . Nitrogen applied during this time period was incorporated into the soil by rainfall such that N was available to wheat plant roots in time for rapid spring vegetative growth following jointing. Fertilizer-N applied at or near planting was more subject to N losses via immobilization by decomposing crop residues, leaching, and denitrification, while N applied after booting would have the greatest potential for carry-over of fertilizer-N into the next cropping season which should cause environmental concerns.

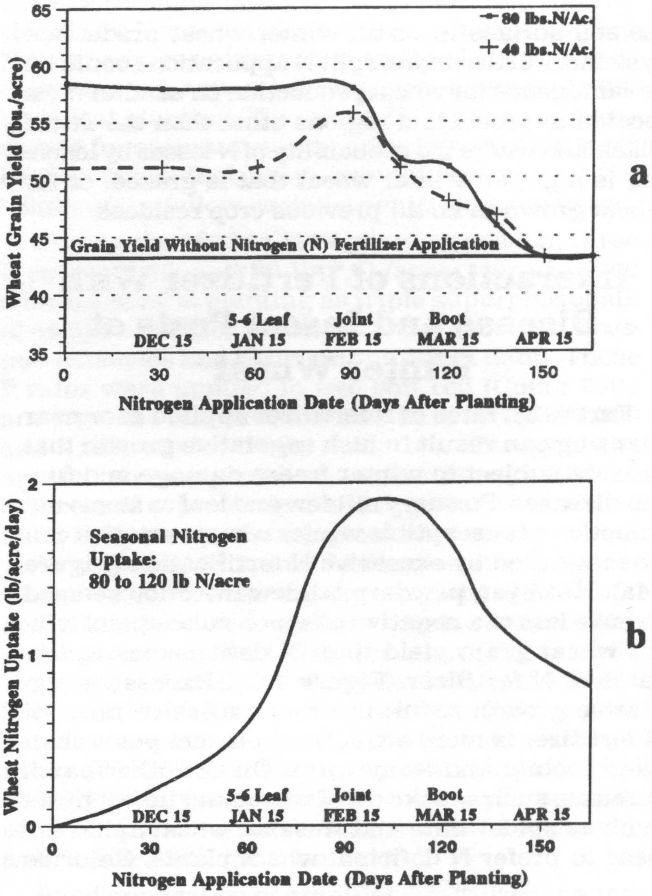


Figure 13. Effect of timing of two nitrogen (N) fertilizer rates on winter wheat grain yields measured from 1985 to 1992, and daily N uptake (flux) typical of winter wheat grown at TAES-Dallas.

Several factors can affect optimum timing of N fertilizer applications for winter wheat. Late spring foliar-N applications can be beneficial resulting in foliar N uptake by wheat plant leaves when lack of rainfall prevents movement of dry N fertilizer into the root zone of plants. Preplant urea applied to the soil surface can be less effective for optimum winter wheat grain yield due to N losses via volatilization and leaching compared to ammonium nitrate applied preplant. Urea applied preplant can also be less effective than urea ammonium nitrate, or foliar N applied in early spring because of early season N losses. Lower rates of N fertilizer are required when N is banded below the soil surface in no-till winter wheat production systems. Furthermore, split N applications could be advantageous for wheat production on sandier soils located in production regions other than the Texas Blackland where the probability of N losses by leaching is high, for winter wheat that is grazed, or for wheat grown in no-till previous crop residues.

Interactions of Fertilizer With Disease and Insect Pests of Winter Wheat

Excessive rates of N fertilizer applied at or near planting can result in lush vegetative growth that is more subject to winter freeze damage and fungal diseases. Powdery mildew and leaf or stem rust infection of susceptible winter wheat varieties can be magnified by excessive N fertilization (Figure 14a). However, powdery mildew infection seemed to have less of a negative effect on subsequent winter wheat grain yield than N deficiencies at low rates of N fertilizer (Figure 14b). Excessive vegetative growth resulting from excessive rates of N fertilizer is more attractive to insect pests such as greenbug and armyworm. On the other hand, diseases such as take-all of wheat and insect pests such as spider mite and Russian wheat aphid appear to prefer N deficient wheat plants. Chloride (Cl) fertilization as either potassium chloride or ammonium chloride topdressed at 40 lb Cl/acre in spring seemed to decrease leaf rust infection of susceptible winter wheat varieties. Interactions of fertilizer nutrients with insect and disease pests of wheat have not been studied extensively since this is a relatively new field of study with many opportunities for future research.

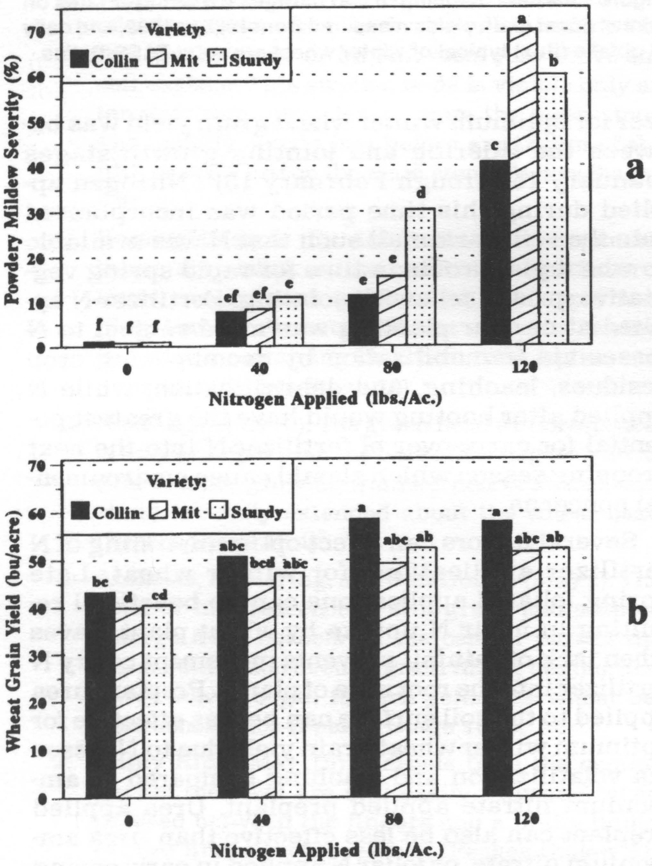


Figure 14. Effect of nitrogen fertilizer applications on powdery mildew severity (a) and winter wheat grain yield (b) at TAES-Dallas.

Interactions of Fertilizer With Winter Wheat Varieties

Occasionally, during years with high yield potential, winter wheat varieties will respond differently to N fertilizer application rates. During the 1991 to 1992 growing season, four N rates (0, 40, 80, and 120 lb N/acre) were topdressed as ammonium nitrate (34-0-0) at planting to 5 winter wheat varieties grown at Prosper (Knowles and Hipp, unpublished data). These N rates were applied to one soft red (Pioneer 2548) and four hard red (TAM 201, 2180, Siouxland 89, and Collin) winter wheat varieties. Averaged across varieties, the N application rate of 80 lb N/acre resulted in maximum winter wheat forage and grain yield (Figure 15a, 15b). Averaged across N rates, Pioneer 2548 had the highest grain yield followed by TAM 201, 2180, Siouxland 89, and Collin. Siouxland 89 had the highest straw yield followed by Collin, 2180, TAM 201, and Pioneer 2548. The N by variety interaction was significant ($P < 0.05$), with maximum winter wheat grain yield resulting from application of 40 lb N/acre to Pioneer 2548, TAM 201, and Siouxland 89; or 80 lb N/acre applied to 2180 and Collin winter wheat. An economic analysis of the data to determine optimum grain yield showed 40 lb N/acre applied to Pioneer 2548 and 80 lb N/acre applied to 2180 resulted in profitable grain yield increases while grain yield increases due to N fertilizer application to TAM 201, Siouxland 89, and Collin did not recover the expense of N fertilization (Figure 15c). Overall, Pioneer 2548 and 2180 required higher rates of N fertilizer for optimum grain and forage yield compared with TAM 201, Siouxland 89, and Collin.

During the 1992 to 1993 growing season, three N rates (0, 40, and 80 lb N/acre) were topdressed as 34-0-0 at planting to 6 winter wheat varieties grown at Prosper (Knowles and Hipp, unpublished data). Phosphorus was banded with the seed at planting as triple superphosphate (0-46-0) at two rates (0 and 50 lb P_2O_5/acre). These fertilizer treatments were applied to two soft red (Pioneer 2548 and Coker 9543) and four hard red (TAM 201, 2180, TAM 300, and Siouxland 89) winter wheat varieties. Averaged across varieties, fertilizer applications of 80 lb N/acre plus 50 lb P_2O_5/acre resulted in maximum winter wheat grain yield (Figure 4a, 4b). Grain yields were not significantly different between the six varieties, and the fertilizer by variety interaction was not significant. Economic analysis of grain yield showed fertilizer applica-

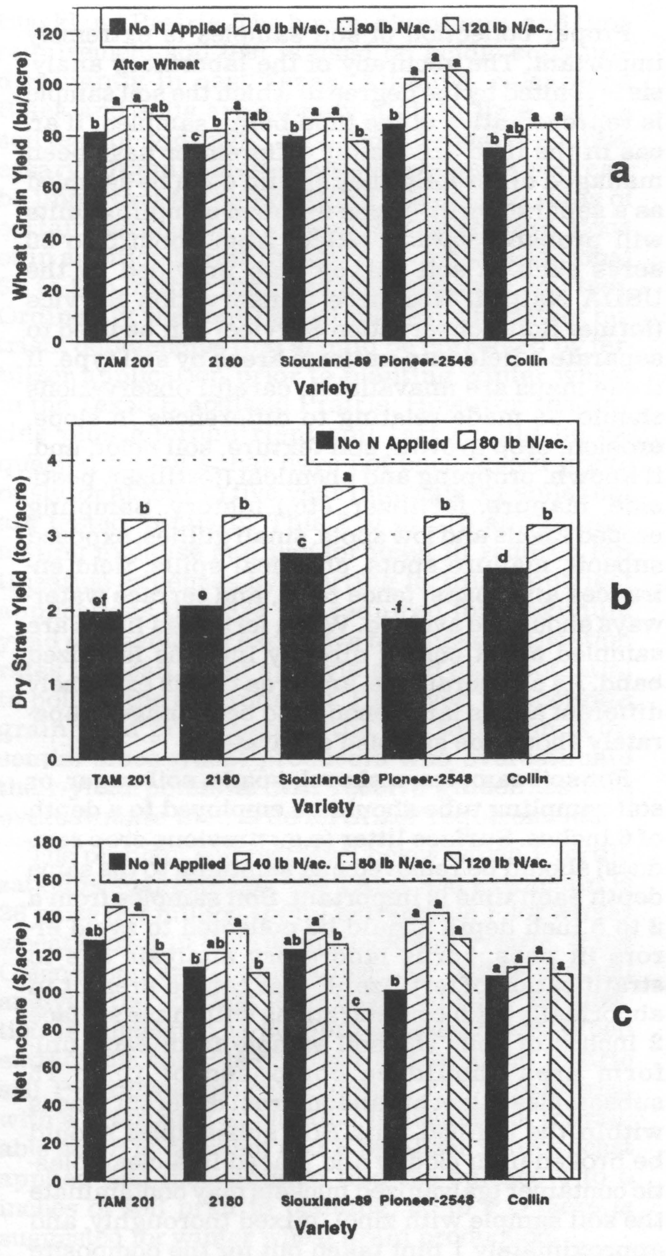


Figure 15. Effect of nitrogen (N) fertilizer applications on winter wheat yield in a wheat-wheat rotation at Prosper. Income was $3.50/bu hard and $3.00/bu soft red wheats; expenses were $0.25/lb N and production costs were $117/acre.

tions of 80 lb N/acre resulted in profitable grain yield increases for all six varieties (Figure 4c). However, the higher grain yields obtained with phosphorus fertilizer applications were not profitable since yield increases did not recover the expense of P fertilization.

Although rainfall was not limiting and leaf rust was minimal in 1992-93, winter wheat grain yield was lower compared with 1991-92. In 1991-92, winter wheat followed winter wheat with a prior one-year fallow period. This fallow period resulted in higher residual preplant soil-N for winter wheat due to higher mineralization rates of organic soil-N into more available inorganic soil-N (nitrate-N). In 1992-93, winter wheat followed cotton after a one month fallow period prior to planting, thus residual soil-N was very low. The response to applied N fertilizer was greater due to the short period of time between cotton harvest/plow-down and winter wheat planting. Therefore, N fertilizer rates required for optimum winter wheat grain yield were highly dependent upon previous crop and the length of the fallow period prior to planting wheat.

During the 1993 to 1994 growing season, three P rates (0, 40, and 80 lb P_2O_5/acre) were banded with the seed at planting as triple superphosphate (0-46-0) to 4 winter wheat varieties grown at Prosper (Knowles and Hipp, unpublished data). These P rates were applied to two soft red (Coker 9803 and AgriPro Mallard) and two hard red (TAM 300 and 2163) winter wheat varieties. Nitrogen was applied to every plot at 80 lb N/acre as 34-0-0 topdressed at planting. Band application of 40 and 80 lb P_2O_5/acre at planting did not increase grain yield of Coker 9803 and Mallard soft red winter wheat , nor did it increase grain yield of TAM 300 and 2163 hard red winter wheat, compared to unfertilized plots at this location (Figure 16). Preplant soil analysis of available P by the TAEX Soil and Plant Tissue Testing Laboratory indicated that a response to P fertilization was unlikely (TAEX-P was 160 ppm). Grain yield of TAM 300 (39.9 bu/acre) was lower than grain yields of 2163 (53.9 bu/acre), Mallard (52.1 bu/acre), and Coker 9803 (54.0 bu/acre).

Band application of granular P fertilizer at a rate of 40 lb P_2O_5/acre at planting has increased winter wheat grain yields by 5 to 10 bu/acre compared to unfertilized wheat plots at Prosper (Figure 4b). Fertilizer P applications have been most important for obtaining maximum forage yield of small grain pasture. Grain yield response to P fertilization is highest when cold soil conditions caused by inclement weather limit the availability and wheat plant uptake of native soil-P. When P fertilizer is broadcast applied, normally an additional 10 to 20 lb P_2O_5/acre is required compared to banded P applications. This broadcast P also needs

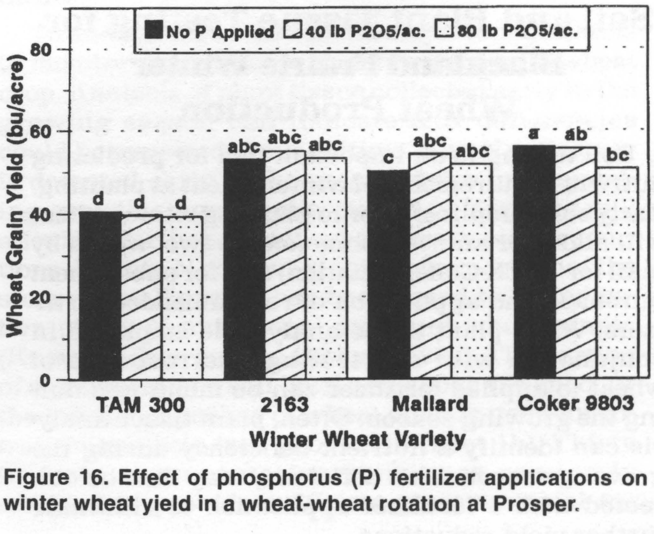


Figure 16. Effect of phosphorus (P) fertilizer applications on winter wheat yield in a wheat-wheat rotation at Prosper.

to be incorporated into the surface 4 to 6 inches of soil so that immobile P fertilizer is positionally available to winter wheat plant roots early in the season.

Generally, in years of average to above average rainfall, the soft red winter wheats that have been bred for superior disease resistance (e.g.: leaf rust) had higher yields and net income than did hard red winter wheat varieties grown in North Texas. However, in a dry year, at equivalent N and P fertilizer rates, hard red winter wheats will normally outyield soft red winter wheats.Variety by N and/or P fertilizer interactions are not normally seen in Texas Blackland Prairie wheat production; however, this interaction has been observed when seasonal rainfall is abnormally high and winter wheat has an unusually high grain yield potential. Most years, when winter wheat N fertilizer requirements are determined based on preplant soil nitrate and actual grain yield potential, all wheat varieties can be managed the same with 40 to 80 lb N/acre applied at or near planting (118 to 235 lb 34-0-0/acre, or 100 lb 18-46-0 at planting plus 100 to 217 lb 34-0-0 topdressed between the tillering and jointing wheat growth stages) resulting in optimum winter wheat grain yield. No-till grain production, short crop rotations, and/or early season grazing (with livestock removed prior to jointing for grain harvest) can increase this N requirement by an additional 30 to 40 lb N/acre. Nitrogen fertilizer should be banded below no-till decomposing crop residues for optimum efficiency. Other research has shown that topdress N fertilizer applications delayed as late as the jointing growth stage (around Feb. 15) and can still result in maximum grain yield of winter wheat grown with conventional tillage practices. Split N fertilizer applications have not been superior to sufficient single N fertilizer topdress applications when the single application occurs sometime between planting and jointing for optimum grain production. The actual quantity of N and P fertilizer applied should be determined from a preplant soil test to avoid costly excessive fertilizer application rates.

Soil and Plant Tissue Testing for Blackland Prairie Winter Wheat Production

Soil testing is an important tool for predicting nutrient requirements of winter wheat at planting. Early soil sampling prior to planting winter wheat will allow for analysis time (one to two weeks by mail for TAEX-College Station) and for subsequent purchase and application of recommended fertilizers. When plant tissue analysis is employed in conjunction with soil testing, the response of wheat to applied fertilizer can be monitored during the growing season. Often, plant tissue analysis can identify a nutrient deficiency during the growing season. This deficiency may then be corrected with a fertilizer application to eliminate further yield reductions.

Proper collection of soil samples is extremely important. The accuracy of the laboratory analysis is limited by the degree to which the soil sample is representative of the field being sampled. If areas in the field are visibly different or have been managed differently, they should each be sampled as a separate unit. These uniform sampling units will probably vary in extent from about 5 to 20 acres each. A soil survey map provided by the USDA Natural Resource Conservation Service (former Soil Conservation Service) can be used to separate a field into uniform areas by soil type. If these maps are unavailable, careful observations should be made relating to differences in slope, erosion, crop growth, soil texture, soil color, and, if known, cropping and chemical (fertilizer, pesticide, manure, fertilizer, etc.) history. Sampling eroded knolls and low spots, small gullies, exposed subsoil, manure spots, chemical spills, field entrances and roads, fence rows, and terrace waterways should be avoided. When fertilized fields are sampled avoid coring directly into the fertilized band. As a general rule, any area that is extremely different and is large enough to be managed separately should be sampled separately.

For soil samples, a shovel, spade, soil auger, or soil sampling tube should be employed to a depth of 6 inches. Surface litter (e.g.: previous crop residues) should be removed and sampling to the same depth each time is important. Soil samples from a 2 to 6 inch depth should be collected to avoid errors in phosphorus laboratory analysis due to stratification of fertilizer-P that can be present in abnormally high concentrations within the surface 2 inches of soil. The soil sample from each uniform area should be composed of 10 to 15 subsamples taken at random from different places within the defined unit. Soil subsamples should be broken-up if cloddy and placed in a clean plastic container (galvanized buckets may contaminate the soil sample with zinc), mixed thoroughly, and approximately 1 pint taken out for the composite soil sample representative of the field or sampling unit. Soil samples should not be dried with heat.

Soil samples can be mailed to the testing laboratory in soil sample bags provided by the laboratory or in sealable "zip-lock" plastic sandwich bags carefully packed in a cardboard box. Five different soil test options are currently available from the Texas A&M University soil testing laboratory. These options include a \$10 routine analysis (pH, NO_3-N, P, K, Ca, Mg, Na, S, and total salts), a \$15 routine plus micronutrients (Zn, Fe, Cu, Mn) analysis, a \$25 routine plus micronutrients plus boron, aluminum, and lime requirement analysis, a \$30 Routine plus micronutrients plus boron, aluminum, and lime requirement, plus organic matter analysis, and a \$25 routine plus detailed salinity analysis. The detailed salinity analysis is primarily used for irrigated crop production on saline-sodic west and south Texas soils, and is normally not necessary for wheat production in the Texas

Blackland Prairie. The boron, aluminum, and lime requirement soil test is used on acidic soils predominantly in east Texas. Alkaline, calcareous Blackland soils are already high in lime, thus a soil test for additional lime requirement is not necessary. Organic matter concentration in soil can be important for determining application rates of certain herbicides. This soil test can be run alone or in addition to routine soil tests for an additional \$5 to \$10, rather than the \$30 complete soil test. Ordinarily, the routine \$10 soil test will detect nutrient deficiencies that should be corrected by fertilizer application prior to planting winter wheat in the Texas Blackland Prairie. However, the routine plus micronutrient soil test should be requested for soils that have not been tested previously, or at four to five year intervals for soils that are tested annually. This \$10 to \$15 annual soil testing expense can pay for itself in reduced fertilization expenses by averting fertilizer nutrient applications that are not required for maximum yield and avoiding excessive fertilizer application rates that can lower crop yield and have potential to pollute the environment. However, an accurate grain yield prediction on the soil test form is essential since wheat producers who overestimate their yield potential will receive guidelines that overestimate their true fertilizer requirements.

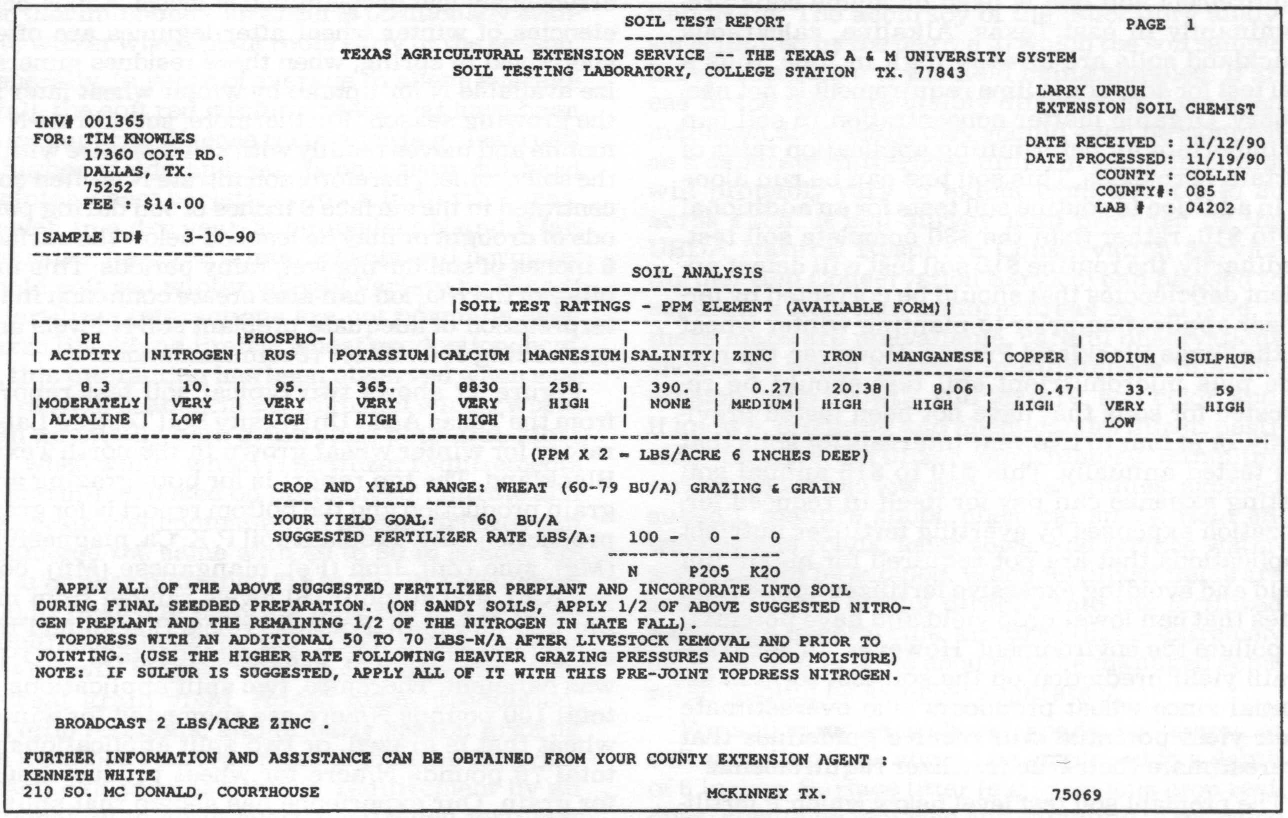
The preplant soil test level below which P fertilization is suggested for the TAEX soil extractant is 26 parts per million (ppm) extractable P for winter wheat grown in the Texas Blackland Prairie. If the Olsen-P soil extractant is used for laboratory soil analysis the soil test level below which P fertilization is suggested is 20 ppm extractable P. When extractable soil-P is deficient in Blackland Prairie soil, P fertilizer application of 40 lb P_2O_5/acre banded with a grain drill at planting is suggested. If available soil-P is deficient and P fertilizer is broadcast applied and incorporated into the surface 4 to 6 inches of soil prior to planting, 60 lb P_2O_5/acre is suggested for winter wheat grain production.

After the available N level in soil is obtained from the laboratory, Table 6 can be used to determine the base requirement for N fertilizer. Microbial decomposition of previous crop residues such as wheat, corn, cotton, or sorghum can immobilize enough soil- and fertilizer-N to require an additional 20 to 40 lb N/acre. Generally, this additional N requirement will be reflected in lower preplant soil nitrate-N (NO_3-N) levels (see Table 2). Winter wheat used for grazing will have a 20 to 40 lb N/acre higher N requirement than wheat for grain production only. Since soil test values are determined from laboratory analysis of the NO_3 ion, soil-N levels from recent anhydrous ammonia, urea, or other ammonium (NH_4) fertilizer applications may not be reflected in the soil test report. If these ammonium-based fertilizer materials have not had time to undergo nitrification, soil test N levels may be erroneously low. Additionally, previous legume residues (eg: clover) that have not had time to undergo mineralization and make soil-N available as NO_3-N may result in erroneously low preplant soil-N levels. Soil-N deficiencies of winter wheat after legumes are often short-lived in spring, when these residues mineralize available N for uptake by winter wheat later in the growing season. Furthermore, soil nitrate-N is mobile and moves readily with soil moisture within the soil profile. Therefore, soil nitrate-N is often concentrated in the surface 6 inches of soil during periods of drought or may be leached below the surface 6 inches of soil during wet, rainy periods. This mobility of the NO_3^- ion can also create confusion in interpretation of adequate preplant soil-N levels and misleading N fertilizer recommendations.

Figure 17 shows two typical soil test reports from the Texas A&M University Soil Testing Laboratory for winter wheat grown in the north Texas Blackland. The top report is for both grazing and grain production and the bottom report is for grain production only. Preplant soil P, K, Ca, magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and sulphur (S) levels ranged from medium to very high. For this typical Blackland Prairie soil sample, only preplant nitrate-N (NO_3-N) was deficient. Therefore, two split applications to total 100 pounds N/acre are suggested for winter wheat that is grazed, or two split applications to total 70 pounds N/acre for wheat produced only for grain. Our experience has shown that split N applications are unnecessary for grain production only, consequently one application of 70 pounds N/acre sometime between preplant and jointing would probably be adequate for optimum grain yield in the Texas Blackland Prairie. Additionally, since soil P concentrations are very high, application of 2 lb Zn/acre is suggested at planting. However, since Zn was not actually deficient in this soil test report (0.27 ppm, medium), and previous research at this site indicated no response to Zn, winter wheat probably would not benefit from the application of Zn. The cost of Zn application most likely would not be recovered from a possible insignificant grain yield increase obtained with Zn fertilization, thus we would not suggest the expenditure.

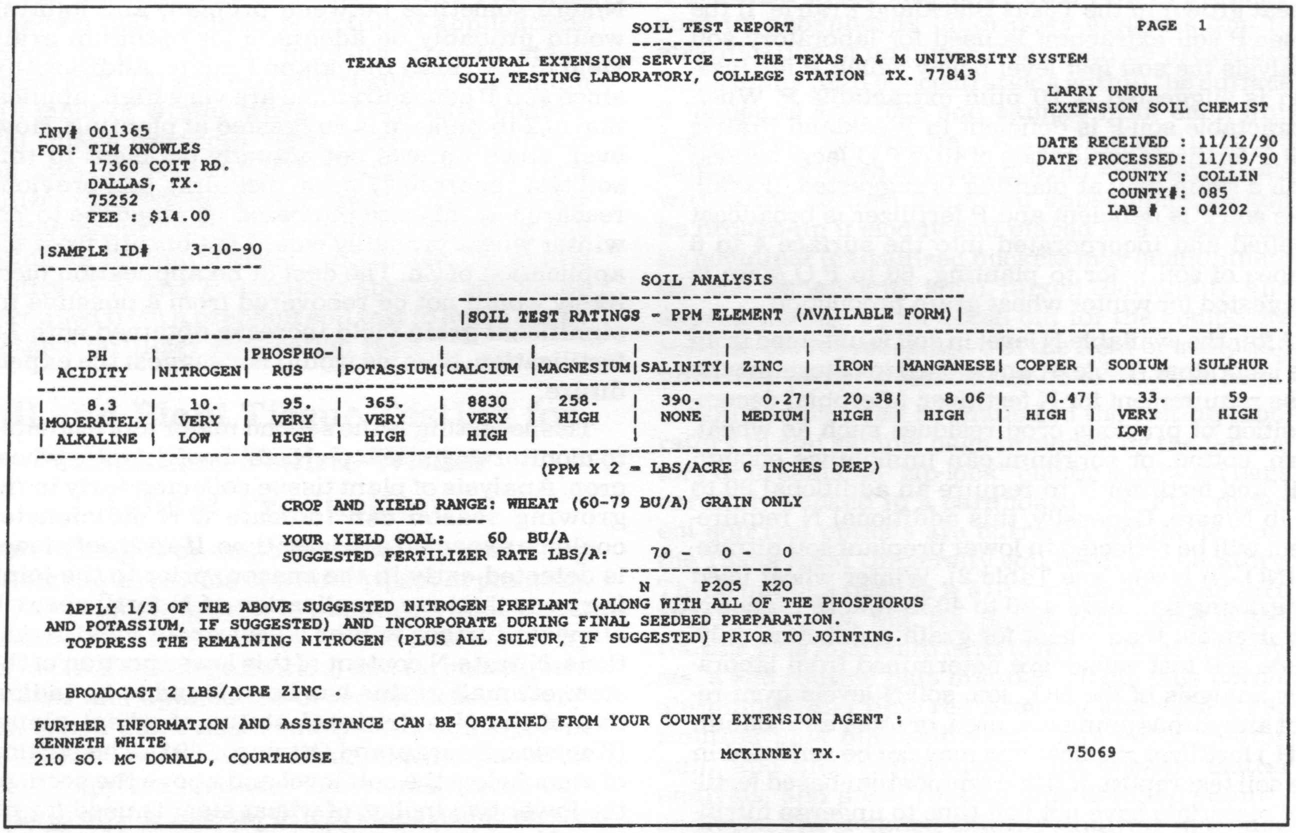
Tissue testing is the second major tool available to monitor the in-season N status of a winter wheat crop. Analysis of plant tissue collected early in the growing season can indicate if N deficiencies could be expected at a later time. If an N deficiency is detected early in the season, prior to the jointing growth stage, application of N fertilizer will alleviate further winter wheat grain yield reductions. Nitrate-N content of this lower portion of the stem of small grains has been found to be indicative of the N nutritional status of wheat plants (Knowles, Doerge, and Ottman, 1991). The portion of stem below the soil level and above the seed, or the lower two inches of wheat stem is used for nitrate-N analysis (see photo L in Inset 1b). Thirty to forty representative stems are randomly sampled to provide sufficient plant material for

Both Grazing and Grain Production



```
                                        SOIL TEST REPORT                                    PAGE  1
                                        ----------------
                    TEXAS AGRICULTURAL EXTENSION SERVICE -- THE TEXAS A & M UNIVERSITY SYSTEM
                              SOIL TESTING LABORATORY, COLLEGE STATION  TX. 77843
                                                                                  LARRY UNRUH
                                                                                  EXTENSION SOIL CHEMIST
INV# 001365
FOR: TIM KNOWLES                                                                  DATE RECEIVED : 11/12/90
     17360 COIT RD.                                                               DATE PROCESSED: 11/19/90
     DALLAS, TX.                                                                       COUNTY : COLLIN
     75252                                                                             COUNTY#: 085
     FEE : $14.00                                                                      LAB #  : 04202

|SAMPLE ID#     3-10-90
-----------------------
                                          SOIL ANALYSIS
                              ------------------------------------------------
                              |SOIL TEST RATINGS - PPM ELEMENT (AVAILABLE FORM)|
-------------------------------------------------------------------------------------------------------------------
|    PH      |          |PHOSPHO-|          |         |          |         |         |         |         |         |          |
| ACIDITY    |NITROGEN| RUS    |POTASSIUM|CALCIUM  |MAGNESIUM|SALINITY|  ZINC   |  IRON   |MANGANESE| COPPER  | SODIUM   |SULPHUR
-------------------------------------------------------------------------------------------------------------------
|   8.3      |   10.   |   95.  |   365.  |  8830   |  258.   |  390.  |   0.27| 20.38|   8.06  |   0.47|    33.   |   59
|MODERATELY|  VERY   |  VERY  |  VERY   |  VERY   |  HIGH   |  NONE  | MEDIUM|  HIGH   |  HIGH   |  HIGH   |  VERY    |  HIGH
| ALKALINE |  LOW    |  HIGH  |  HIGH   |  HIGH   |         |        |         |         |         |         |  LOW     |
-------------------------------------------------------------------------------------------------------------------
                                    (PPM X 2 - LBS/ACRE 6 INCHES DEEP)

                    CROP AND YIELD RANGE: WHEAT (60-79 BU/A) GRAZING & GRAIN
                    ---- --- ----- -----
                    YOUR YIELD GOAL:     60  BU/A
                    SUGGESTED FERTILIZER RATE LBS/A:    100 -   0 -   0
                                                      ------------------
                                                        N     P2O5  K2O
   APPLY ALL OF THE ABOVE SUGGESTED FERTILIZER PREPLANT AND INCORPORATE INTO SOIL
 DURING FINAL SEEDBED PREPARATION. (ON SANDY SOILS, APPLY 1/2 OF ABOVE SUGGESTED NITRO-
 GEN PREPLANT AND THE REMAINING 1/2 OF THE NITROGEN IN LATE FALL).
   TOPDRESS WITH AN ADDITIONAL 50 TO 70 LBS-N/A AFTER LIVESTOCK REMOVAL AND PRIOR TO
 JOINTING. (USE THE HIGHER RATE FOLLOWING HEAVIER GRAZING PRESSURES AND GOOD MOISTURE)
 NOTE:  IF SULFUR IS SUGGESTED, APPLY ALL OF IT WITH THIS PRE-JOINT TOPDRESS NITROGEN.


   BROADCAST 2 LBS/ACRE ZINC .

FURTHER INFORMATION AND ASSISTANCE CAN BE OBTAINED FROM YOUR COUNTY EXTENSION AGENT :
KENNETH WHITE
210 SO. MC DONALD, COURTHOUSE                             MCKINNEY TX.                    75069
```

Grain Production Only



```
                                        SOIL TEST REPORT                                    PAGE  1
                                        ----------------
                    TEXAS AGRICULTURAL EXTENSION SERVICE -- THE TEXAS A & M UNIVERSITY SYSTEM
                              SOIL TESTING LABORATORY, COLLEGE STATION  TX. 77843
                                                                                  LARRY UNRUH
                                                                                  EXTENSION SOIL CHEMIST
INV# 001365
FOR: TIM KNOWLES                                                                  DATE RECEIVED : 11/12/90
     17360 COIT RD.                                                               DATE PROCESSED: 11/19/90
     DALLAS, TX.                                                                       COUNTY : COLLIN
     75252                                                                             COUNTY#: 085
     FEE : $14.00                                                                      LAB #  : 04202

|SAMPLE ID#     3-10-90
-----------------------
                                          SOIL ANALYSIS
                              ------------------------------------------------
                              |SOIL TEST RATINGS - PPM ELEMENT (AVAILABLE FORM)|
-------------------------------------------------------------------------------------------------------------------
|    PH      |          |PHOSPHO-|          |         |          |         |         |         |         |         |          |
| ACIDITY    |NITROGEN| RUS    |POTASSIUM|CALCIUM  |MAGNESIUM|SALINITY|  ZINC   |  IRON   |MANGANESE| COPPER  | SODIUM   |SULPHUR
-------------------------------------------------------------------------------------------------------------------
|   8.3      |   10.   |   95.  |   365.  |  8830   |  258.   |  390.  |   0.27| 20.38|   8.06  |   0.47|    33.   |   59
|MODERATELY|  VERY   |  VERY  |  VERY   |  VERY   |  HIGH   |  NONE  | MEDIUM|  HIGH   |  HIGH   |  HIGH   |  VERY    |  HIGH
| ALKALINE |  LOW    |  HIGH  |  HIGH   |  HIGH   |         |        |         |         |         |         |  LOW     |
-------------------------------------------------------------------------------------------------------------------
                                    (PPM X 2 - LBS/ACRE 6 INCHES DEEP)

                    CROP AND YIELD RANGE: WHEAT (60-79 BU/A) GRAIN ONLY
                    ---- --- ----- -----
                    YOUR YIELD GOAL:     60  BU/A
                    SUGGESTED FERTILIZER RATE LBS/A:     70 -   0 -   0
                                                      ------------------
                                                        N     P2O5  K2O
   APPLY 1/3 OF THE ABOVE SUGGESTED NITROGEN PREPLANT (ALONG WITH ALL OF THE PHOSPHORUS
 AND POTASSIUM, IF SUGGESTED) AND INCORPORATE DURING FINAL SEEDBED PREPARATION.
   TOPDRESS THE REMAINING NITROGEN (PLUS ALL SULFUR, IF SUGGESTED) PRIOR TO JOINTING.


   BROADCAST 2 LBS/ACRE ZINC .

FURTHER INFORMATION AND ASSISTANCE CAN BE OBTAINED FROM YOUR COUNTY EXTENSION AGENT :
KENNETH WHITE
210 SO. MC DONALD, COURTHOUSE                             MCKINNEY TX.                    75069
```

Figure 17. Typical soil test report from the Texas A&M Soil Testing Laboratory with suggested fertilization of winter wheat grown for either grazing and grain or grain only at Prosper.

analysis. Sample uniform areas of the overall field unit(s). Stem tissue samples taken at the five to six leaf or tillering wheat growth stages can be tested in time to make necessary N fertilizer applications efficiently. If a N deficiency is detected after jointing, N fertilizer applications prior to booting will help avoid further winter wheat grain yield reductions.

After the wheat stem tissue nitrate-N level is obtained from the laboratory, Table 7 can be used to determine the base requirement of N fertilizer. When basal stem tissue nitrate-N concentrations fall below these levels, N fertilizer applications are required to avoid any further grain yield losses. Excessive stem nitrate-N levels can be an indication of excessive vegetative growth at the expense of grain yield that can result in an increased potential for moisture stress and fungal diseases. Nitrogen fertilizer application to N deficient plants will increase grain yield compared to unfertilized wheat, however, some yield loss will occur compared to wheat that is not allowed to become N deficient.

Stem nitrate-N levels will normally be very high at tillering, then decline rapidly following the jointing growth stage when nitrate-N reserves are converted and translocated from stem tissue to the developing wheat grain. Extended periods of cloudy weather and low solar radiation can result in a premature decline in basal stem tissue nitrate-N levels which may be mistaken for an N deficiency. Stem samples from wheat growing in water-logged soils can also be low indicating a N deficiency due to low concentrations of oxygen in water-logged soil that inhibits plant uptake of available soil-N by wheat roots. Furthermore, one to two weeks (or longer for ammonium-based N fertilizers that must undergo nitrification prior to plant uptake) following fertilizer application and incorporation into the soil by rainfall or tillage is necessary before fertilizer-N shows up as nitrate-N in wheat stem tissue.

Table 7. Predicting nitrogen (N) requirements of winter wheat using preplant soil and early season basal stem nitrate-N (NO3-N) analyses.

Sampling Date	Test Value	Suggested Fertilizer
ppm NO_3-N	lbs N/acre	lbs N/acre
Preplant Soil:		
0-6 in depth	> 30	None
	30 - 20	0 - 40
	20 - 10	40 - 80
	< 10	80 - 120
Basal Stem:		
@ 4-6 Leaf	> 3500	None
	3500 - 2000	0 - 40
	< 2000	40 - 80
@ Jointing	< 500	0 - 40

Multiply ppm NO_3-N by 4.4 to convert to parts per million nitrate (NO_3).
Multiply ppm NO_3-N by 2.0 to convert to lbs. NO_3-N/acre to a 6 inch soil depth.

References

Baur, A., D. Smika, and A. Black. 1983. Correlation of five wheat growth stage scales used in the Great Plains. USDA ARS AAT-NC-7. Northern Great Plains Research Lab., Mandan, ND. 17 pp.

Box, John. 1973. Crop residue to improve Texas soils. TX Agric. Exp. Sta. MP-807. Texas A&M University, College Station. 8 pp.

Doerge, T.A., R.L. Roth, and B.R. Gardner. 1991. Nitrogen fertilizer management in Arizona. Univ. of Arizona Special Project No. 89-EWQI-1-9102. Univ. of AZ, Tucson, AZ. 87 pp.

Donahue, R.L., R.W. Miller, and J.C. Shickluna. 1983. Soil fertility and plant nutrition. p. 208-239. In: Soils. An introduction to soils and plant growth. 5th Ed. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Fenn, Lloyd B. 1986. Increased agricultural benefits through cost effect utilization of urea fertilizer. TX Agric. Exp. Sta. MP-1608. Texas A&M University, College Station. 9 pp.

Follett, R.H., L.S. Murphy, R.L. Donahue. 1981. Fertilizers and Soil Amendments. Prentice-Hall, Inc., Englewood Cliffs, NJ. 557 pp.

Foth, H.D., L.V. Withee, H.S. Jacobs, and S.J. Thien. 1982. Microbial decomposition of organic residue in soils. p. 115-126. In: Laboratory manual for introductory soil science. 6th Ed. Wm. C. Brown Company Publishers. Dubuque, IW.

Gray, C., C.D. Welch, and R.J. Hodges. 1976. Time and methods of applying fertilizer for small grains. TX Agric. Ext. Service AGR 11-1, AGR 10. Texas A&M University, College Station. 1 pp.

Hipp, Billy W. 1987a. Influence of planting date on response of winter wheat to phosphorus. TX Agri. Exp. Sta. B-1564. Texas A&M University, College Station. 4 pp.

Hipp, Billy W. 1987b. Residual effects of clover on nitrogen nutrition of crops grown on Blackland soils. J. of Plant Nutrition, 10:1811-1817.

Hipp, Billy W., and Dwain Hooks. 1978. Influence of planting date and phosphorus application method on wheat response to phosphorus. TX Agri. Exp. Sta. PR-3526. Texas A&M University, College Station. 6 pp.

Hipp, Billy W., Tim C. Knowles, and Benny J. Simpson. 1992. Descriptions and uses of soils of the Texas Agricultural Experiment Stations at Dallas and Prosper. TX Agri. Exp. Sta. B-1705. Texas A&M University, College Station. 21 pp.

Hipp, B.W., and B.J. Simpson. 1988. Thirty-five years of farming systems research in the Texas Blackland. TX Agric. Exp. Sta. B-1604. Texas A&M University, College Station. 24 pp.

John Deere. 1991. John Deere tillage tool residue management guide. Datalizer Slide Charts, Inc., Addison, IL.

Knowles, T.C., T.A. Doerge, and M.J. Ottman. 1991. Improved nitrogen management in irrigated durum wheat using stem nitrate analysis. I. Nitrate uptake dynamics. II. Interpretation of nitrate-nitrogen concentrations. Agron J. 83:346-356.

Knowles, T.C., B.W. Hipp, P.S. Graff, and D.S. Marshall. 1993. Nitrogen nutrition of winter wheat in tilled and no-till sorghum and wheat residues. Agron. J. 85:886-893.

Knowles, T.C., B.W. Hipp, P.S. Graff, and D.S. Marshall. 1994. Timing and rate of top-dress nitrogen for rainfed winter wheat. J. Production Agriculture. 7:216-220.

Matocha, J. 1995. Study looks at value of legume crops. p. 6-7. In: Southwestern Farm Press. Volume 22, No. 2. (Jan. 19, 1995). Dallas.

Pigg, Calvin. 1994. No-till system slashes power needs. p. 1, 14-15. In: Southwest Farm Press. Volume 21, No. 3. (February 3, 1994). Dallas.

Soil Conservation Service. 1992. Picture your residue. USDA Soil Conservation Service Leaflet SCS-CRM-02.

Spence, C.O., and C.D. Welch. 1977. Phosphorus fertilization for wheat production on Blackland and Grand Prairie Soils. TX Agri. Exp. Sta. L-1530. Texas A&M University, College Station. 6 pp.

Taylor, Charles. 1993. Can chloride enhance wheat yield? Texas Farmer-Stockman. Dallas. June 1993. p. 6-7, 18.

Welch, C.D., C. Gray, J.E. Cole, G.D. Alston, and B.W. Hipp. 1977. Field crop fertilization on Texas Blackland and Grand Prairie soils. TX Agric. Exp. Sta. L-743. Texas A&M University, College Station. 4 pp.

Williams, R.L. 1992. Economic factors of small grain production. p. 167. In G. Rutz (ed.). Delta Agricultural Digest-1992. Farm Press Publications. Clarksdale, MS. 224 pp.

Texas Agricultural Experiment Station
The Texas A&M University System

Copies printed: 1,200