Nutrient Recommendations

Agronomic Crops

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Barley

Crop Highlights
• Target pH: 6.0 • Split N application to increase N-use efficiency in barley. Apply a small amount (25 to 30 lb N/ac) at planting or in late winter and the bulk of the N requirement in two applications in early Spring. Apply the first when growth resumes in the spring and the second at Feekes growth stage 5. • Use the fall soil nitrate test (FSNT) to determine whether the fall application of N can be reduced or eliminated. • Soil test more frequently when straw is removed from the field since soil P and K may decrease more rapidly than when straw is left behind to decompose. • Monitor crop for manganese (Mn) deficiency, **especially** when Mehlich-3 soil test Mn is less than 3.4 lb/ac.

Yield Goal

Barley yields are influenced by many factors, including the cultivars selected, planting date, winter weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure and crop management practices. **On most Delaware soils, typical barley yields in a good to average year range from 60 to 90 bu/ac. On black soils, silt loams and /or when irrigation is used, typical yields range from 85 to 150 bu/ac.**

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter ("black" soils) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 1. Recommended type of lime as a function of Mehlich-3 soil test Ca and Mg concentrations.

Soil Test Levels	Recommended Lime Type
M3-Mg less than 50 FIV	Dolomitic
M3-Mg between 50 and 100 FIV AND LESS than M3-Ca	Dolomitic
M3-Mg greater than 100 FIV	Calcitic
M3-Mg GREATER than 50 FIV AND GREATER than M3-Ca	Calcitic

Nitrogen

Nitrogen fertilization rates are based on regional research on crop response to N fertilizers and not on the results of a routine soil test.

The University of Delaware recommends a total nitrogen (N) rate of 60 to 100 lb N/ac per growing season. The higher end of the range should be utilized for sandy soils or for management systems where a single application will be made to compensate for higher leaching losses. In general, increasing N rate may increase grain production but may also increase lodging, thus reducing harvestable and economic yield. Split applications have been shown to increase N use-efficiency, thus requiring less total N to achieve the same grain yield. For best results, N should be split into two or more applications. Effective N management for winter barley is facilitated by soil and plant tissue sampling to ensure enough N to produce a healthy crop, but limit yield penalizing effects (e.g., disease and lodging) and leaching losses.

A small amount (up to 30 lb/ac of N) should be applied in the fall or in late winter to promote root growth and fall tillering. Avoid applying more than 30 lb/ac of N in the fall, as plants with excessive fall growth are susceptible to disease and winter kill; fall N applications are also susceptible to leaching below the root zone. A fall soil nitrate test (FSNT) run on a 6-inch composite soil sample is recommended to determine if enough soil N remains to reduce or eliminate the fall N application as follows:

- **NO_3-N <22 lb/ac:** Apply 25 to 30 lb/ac of N to establish the crop
- **NO_3-N >22 lb/ac:** No N fertilizer is needed to establish the crop

The remainder of the total N should be applied in the spring in two applications. The first should be made at “green up” when growth resumes (approximately Feekes growth stage 3) in the spring based on tiller density measurements as described in Table 2. Do not exceed an N application rate of 50 lb/ac at this stage if planning a spring split.

Table 2. Nitrogen rate recommendations for early spring green up application to barley at Feekes growth stage 2-3.

	Tiller Density (tillers/ft^2) at Feekes 2-3				
	<50	75	100	125	>150
lb N/ac	50	40	25	10	0

Make the second spring application just prior to the period of rapid N uptake at Feekes growth stage 5 (stem elongation) based on results of a whole plant tissue test as described in Table 3. Cut the whole plant ½ inch above the soil line at Feekes 5 growth stage and submit to a reputable lab for analysis. Do not exceed an N rate of 100 lb/ac at this stage, as it increases the risk of lodging.

Table 3. Nitrogen rate recommendations for second spring application to barley at Feekes growth stage 5.

	Percent N in Tissue from Whole Plant Sampled at Feekes 5				
	<2.50	**2.75**	**3.00**	**3.25**	**>3.5**
lb N/ac	100	75	50	25	0

When planting into fields where manure has been applied, determine the plant available N (PAN) for the manure application and reduce fertilizer N rates as appropriate.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test (Table 4). Soil test results are reported as a fertility index value (FIV).

Table 4. Broadcast phosphorus application rates for barley.

	M3-P (UD FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb P_2O_5/ac	140	120	100	80	60	40	30	30	30	20	20

1. If M3 soil test phosphorus (M3-P) is “Low” (e.g., 25 FIV or less), broadcast and plow down the recommended rate of phosphate prior to planting in the fall.
2. If M3-P is “Medium or “Optimum” (e.g., 26 to 100 FIV), phosphate can topdressed in the fall or the spring.
3. If M3-P is “Excessive” (e.g., greater than 100 FIV), the application of P in fertilizers or manures is NOT RECOMMENDED.
4. Soil test P may decline more rapidly when straw is removed than when straw is left behind as stubble since P removal from the site is greater. Growers may wish to soil test more frequently to monitor changes in soil test P.

Potassium

The need for potassium (K) fertilization is determined by a routine soil test (Table 5). Soil test results are reported as a fertility index value (FIV).

Table 5. Recommended potassium application rates for barley.

	M3-K (UD FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb K_2O /ac	140	120	100	80	60	40	30	30	30	20	20

1. Broadcast and incorporate or band potash prior to planting.
2. For banded applications, reduce the rates in Table 5 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb/ac of K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.
4. Soil test K may decline more rapidly when straw is removed than when straw is left behind as stubble since K removal from the site is greater. Growers may wish to soil test more frequently to monitor changes in soil test K.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 6); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 6. Recommended application rates of soluble magnesium to barley as a function of Mehlich-3 soil test Mg fertility index value.

Soluble Mg	M3-Mg (UD FIV)								
	0	5	10	15	20	25	30	35	40
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3 soil test Mg (M3-Mg) is less than 40 FIV.
2. If M3-Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3-Mg is less than 40 FIV and lime is not needed, apply soluble Mg according to the rates in Table 6.

Sulfur

Sulfur (S) deficiency is occasionally observed in barley grown on Delaware soils. Symptoms include reduced growth and a general yellowing of the plant. Use a tissue test run to confirm deficiency in season. Cut the whole plant ½ inch above the soil line at Feekes 5 growth stage and submit to a reputable lab for analysis.

1. If the N:S ratio in the plant tissue is greater than 15:1, apply 25 to 35 lb S/ac with the first N application in the spring.

Prediction of S deficiency is difficult. Currently available soil tests are not good predictors of S deficiency situations because only surface soil samples are analyzed. Many Delaware soils have a supply of plant available S in subsoil horizons that will not be detected in soil samples taken from shallower depths. Subsoil sampling to a depth of 24 inches is highly recommended as a means of identifying soils with subsoil reserves of S.

Long-term applications of ammonium sulfate or other acid-forming fertilizers may lower pH of the soil surface and require correction with lime. Monitor surface pH with a 0- to 2-inch soil sample, especially in no-till systems. Also remember that sulfate-S is available for crop uptake immediately after application. If a reduced form of S is applied (e.g., thiosulfate or elemental S), allow adequate time for oxidation of the applied S to the sulfate form to occur.

Manganese

Manganese (Mn) needs are predicted by an availability index (MnAI) that includes M3 soil test Mn (M3-Mn) and soil pH. Interpretation of MnAI is crop specific. Barley is a Mn sensitive crop. Soil test Mn results are reported in lb/ac.

$$\text{MnAI} = 101.7 - (15.2 \times \text{soil pH}) + (2.11 \times \text{M3-Mn})$$

Where:

MnAI = Mn availability index
Soil pH = Soil pH measured in water (1:1 V:V)
M3-Mn = Mehlich 3 soil test Mn in lb/ac

Table 7. Interpretation of manganese availability index for barley.

Mn Availability Index	Interpretation
Less than 25	Mn deficiency is likely at this soil pH and soil test Mn concentration
25 to 35	Mn deficiency is possible at this soil pH and soil test Mn concentration. Monitor the crop for symptoms, especially if liming has been recommended.
Greater than 35	Mn deficiency is unlikely.

1. If Mn deficiency is predicted or was observed in the previous growing season, broadcast Mn at a rate of 20 to 30 lb/ac.
2. Broadcast applications of acid forming fertilizers may correct Mn deficiency without the actual application of Mn in some cases but may be less effective than applications of Mn.
3. If Mn deficiency symptoms appear during the growing season or after an application of lime, a foliar application of 1.0 to 2.0 lb/ac actual Mn as Mn sulfate, Mn oxide or chelated Mn can alleviate the symptoms and restore yield potential. Foliar applications can be applied before fall dormancy or after growth resumes in the spring. ***Apply only when adequate growth is present to aid absorption of foliar Mn.***

NOTE: When using foliar application to correct Mn deficiency, growers may combine the treatment with a post emergence herbicide application to reduce the number of trips across the field. Sulfate containing forms of Mn (e.g., manganese sulfate [Techmangam] and manganese-lignin-sulfate) may be antagonistic to weed control with Roundup™. To overcome this antagonism, growers should add ammonium sulfate at a rate of 17 lb per 100 gallons of solution. Chelated-Mn (Mn-EDTA) has shown a slight degree of antagonism but little to no reduction in weed control was noted in the field studies.

Zinc

Zinc (Zn) deficiency is predicted by an availability index (ZnAI) that includes M3 soil test Zn, soil pH, and M3 soil test P. Soil test Zn results are reported in lb/ac. Zinc deficiency is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 8 to determine if Zn deficiency is predicted for this field.

Table 8. Interpretation of zinc availability index for barley.

Soil Test Criteria	Interpretation
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIV or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Zn deficiency is NOT predicted

If Zn deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast Zn sulfate or Zn oxide at a rate of 10 to 12 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 2 to 3 lb/ac elemental Zn. Broadcast applications should correct Zn deficiency for several years.
2. If a banded application is preferred, apply 6 to 8 lb/ac elemental Zn as Zn sulfate or Zn oxide or 1 to 2 lb/ac elemental Zn as Zn chelate (Zn-EDTA) in the fertilizer band. Banded applications are only effective in the growing season in which they are applied.
3. Foliar application of Zn sulfate or Zn oxide at a rate of 1 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 0.5 lb/ac elemental Zn in 20 to 50 gallons of water. **Apply only when adequate growth is present to aid in the adsorption of foliar Zn.** Foliar Zn application should be repeated if symptoms re-appear.

Boron

Boron (B) deficiency is not usually observed in barley. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Grain Corn

Crop Highlights
• Target pH: 6.0 • Split nitrogen (N) applications to increase N use efficiency in corn. Apply a small amount of N (20 to 25%) at planting and the bulk of the N requirement (75 to 80%) when the plants are 12 to 15 inches tall. • Use the pre-sidedress soil nitrate test (PSNT) for manured ground to calculate crop N needs in season • For irrigated corn where fertigation is possible, split N applications to increase N use efficiency. Apply a small amount (15 to 20%) at planting and split the remainder into equal increments to be applied with irrigation water from the 5 to 6 leaf stage through silking. Use the Leaf Chlorophyll Meter to monitor crop N needs in season and make small adjustments as needed. • Use the corn stalk nitrate test (CSNT) at the end of the season to monitor the success of the N management program. • Monitor crop for manganese (Mn) deficiency, especially when Mehlich-3 soil test Mn is less than 3.4 lb/ac.

Yield Goal

Corn yields are influenced by many factors, including the variety selected, planting date, weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure, and crop management practices. **Typical yield goals for corn grown for grain on Delaware soils are shown in Table 1.** Ranges reflect the variation in soil type, water availability, and tillage management.

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Table 1. Corn grain yield as a function of irrigation use and management level.

Production System	Grain Yield (bu/ac)
Dryland – Traditional Management	125 – 220
Irrigated - High Management	240 – 270
Irrigated - Intensive Management	270 – 300

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter (e.g., "black" soils; soil organic matter >6.0%) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 2. Recommended type of lime as a function of Mehlich-3 soil test calcium and magnesium concentrations.

Soil Test Levels	Recommended Lime Type
M3-Mg is less than 50 FIV	Dolomitic
M3-Mg between 50 and 100 FIV AND M3-Mg is less than M3-Ca	Dolomitic
M3-Mg greater than 100 FIV	Calcitic
M3-Mg is greater than 50 FIV AND M3-Mg is greater than M3-Ca	Calcitic

Nitrogen

Nitrogen fertilization rates are based on regional research on crop response to N fertilizers and not on the results of a routine soil test.

The University of Delaware nitrogen (N) recommendations for grain corn production are based on an N rate of 1 lb/ac per bushel of expected yield – e.g., for an expected yield of 175 bu/ac, the total N recommendation would be 175 lb/ac.

Split N applications can increase N use efficiency, thus requiring less total N to achieve the same grain yield. For most efficient N use, total N should be split into two or more applications during the growing season. Apply no more than 25% of total N at or just prior to planting. The remainder of the total N should be sidedressed when corn plants are 12 to 15 inches tall and the period of maximum N uptake is beginning. For irrigated fields where fertigation is possible, the remainder of the N can be split into equal increments and applied with irrigation water beginning at the 5 or 6 leaf stage and continuing through silking.

For fields with a history of manure use, use the pre-sidedress soil nitrate test (PSNT) to determine the elemental sidedress N rate for the field. Information about sampling for and interpreting a PSNT is available in the UD Extension Fact Sheet ***Nitrogen Management for Corn in Delaware: The Pre-sidedress Nitrate Test.***

For in-season monitoring of crop N status, growers may wish to use the leaf chlorophyll meter. Use of a chlorophyll requires establishment of an N-rich strip for calibration of the meter.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test (Tables 3-5). Soil test results are reported as a fertility index value (FIV). Phosphorus recommendations for corn are dependent upon the nutrient requirement of the crop as a function yield goal and crop management practices including tillage and nutrient application methods (e.g., banding, broadcast application or a combination of the two methods). Three management scenarios with the recommended application rates are presented.

Table 3. Recommended phosphorus rate for grain corn as a function of expected yield and Mehlich-3 soil test phosphorus (M3-P) when all phosphorus will be applied as a band application.

Yield	M3-P (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	lb P_2O_5/ac										
125	80	70	60	50	40	25	25	20	20	15	15
150	90	75	70	60	50	30	30	25	25	20	20
175	95	80	80	70	60	45	45	30	30	25	25
200	100	85	85	80	70	50	50	45	45	30	30
225	105	90	90	85	80	55	55	50	50	35	35
250	110	95	95	90	85	60	60	55	55	40	40
275	115	100	100	95	90	65	65	60	60	45	45
300	120	110	105	100	95	70	70	65	65	50	50

Table 4. Recommended phosphorus rate for grain corn as a function of expected yield and Mehlich-3 soil test phosphorus (M3-P) when all phosphorus will be applied as a broadcast application.

Yield	M3-P (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	lb P_2O_5/ac										
125	160	140	110	90	70	60	50	50	40	40	40
150	175	155	125	105	85	70	60	60	50	50	50
175	190	170	140	120	100	75	65	65	55	55	55
200	205	185	155	135	115	85	75	75	65	65	60
225	220	200	170	150	130	90	80	80	70	70	65
250	235	215	185	165	145	100	90	90	80	80	70
275	250	230	200	180	160	105	95	95	85	85	75
300	265	245	215	195	175	115	105	105	95	95	80

Table 5. Recommended phosphorus rate for grain corn as a function of expected yield and Mehlich-3 soil test phosphorus (M3-P) when applied as a broadcast + starter application.

Yield	M3-P (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	lb P_2O_5/ac										
	Starter Band										
All yields	40	40	35	35	30	30	25	25	20	20	20
	Broadcast Rate										
125	80	60	40	20	10	0	0	0	0	0	0
150	95	75	55	35	25	10	10	10	10	10	10
175	110	90	70	50	40	15	15	15	15	15	15
200	125	105	85	65	55	25	25	25	25	25	25
225	140	120	100	80	70	30	30	30	30	30	30
250	155	135	115	95	85	40	40	40	40	40	40
275	170	150	130	110	100	45	45	45	45	45	45
300	185	165	145	125	115	55	55	55	55	55	55

1. Select Table 3 when phosphate will be banded only. **This is the recommended practice for no-till systems and is suitable for all tillage schemes.**
2. Select Table 4 when phosphate will be applied as a broadcast application at or prior to planting. **Broadcast applications are NOT recommended for no-till fields.**
3. Select Table 5 when starter P will be applied, and the remainder of the P will be applied as a broadcast application.
4. If M3 soil test P is "Excessive" (e.g., M3-P >100 100 FIV), the application of P in fertilizers or manures is NOT RECOMMENDED.

Potassium

The need for potassium (K) fertilization is determined by a routine soil test (Table 6). Soil test results are reported as a fertility index value (FIV).

Table 6. Recommended potassium rate for grain corn as a function of expected yield and Mehlich-3 soil test potassium (M3-K).

Yield	M3-K (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	lb K_2O/ac										
125	110	95	80	60	40	40	40	40	40	40	40
150	140	120	100	80	60	45	45	45	45	45	45
175	170	145	120	95	70	55	55	55	55	55	55
200	190	165	140	110	80	60	60	60	60	60	60
225	210	190	160	140	115	70	70	70	70	70	70
250	230	205	180	155	130	75	75	75	75	75	75
275	250	220	200	170	145	85	85	85	85	85	85
300	270	240	220	185	160	95	95	95	95	95	95

1. Potassium (K) can be broadcast in the fall or spring or banded at planting.
2. For banded applications, reduce the rates in Table 6 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb/ac of K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 7); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 7. Recommended application rates of soluble magnesium for grain corn as a function of Mehlich-3 soil test magnesium (M3-Mg).

Soluble Mg	M3-Mg (UD FIV)								
	0	5	10	15	20	25	30	35	40
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3-Mg is less than 40 FIV
2. Use dolomitic limestone if M3-Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3-Mg is less than 40 FIV and lime is not needed, apply soluble Mg (Mg sulfate or Mg chloride) according to the rates in Table 4.

Sulfur

Sulfur (S) deficiency is frequently observed in corn grown on Delaware's sandy, highly leached, low-organic-matter soils. Deficiency is most likely to occur under irrigated production practices where intensive management is employed to obtain maximum yields. Deficiency is less common on high organic matter soils or those with a history of manure application, as both materials provide moderate amounts of plant-available S.

Prediction of S deficiency is difficult. Currently available soil tests are not good predictors of S deficiency situations because only surface soil samples are analyzed. Many Delaware soils have a supply of plant available S in subsoil horizons that will not be detected in soil samples taken from shallower depths. Subsoil sampling to a depth of 24 inches is highly recommended as a means of identifying soils with subsoil reserves of S.

Suspected S deficiency can be confirmed through tissue analysis of ear leaf samples collected at early silking. Tissue samples collected earlier in the season are not as good of an indicator of yield-limiting S deficiency because roots, may not have penetrated subsoil reserves at that time. In-season correction of S deficiency may be difficult. If the ear leaf S concentration is less than the critical value of 0.12% or the N:S ratio is greater than 15:1, S deficiency is occurring.

1. Apply 30 to 40 lb/ac of S as ammonium sulfate to correct the deficiency.

To prevent S deficiency in subsequent years, apply one of the following treatments:

1. Broadcast 30 to 40 lb/ac of S as ammonium sulfate (24% S) or gypsum (19% S) at planting.
2. Band 20 to 30 lb/ac of S as ammonium sulfate at planting.

Long-term applications of ammonium sulfate or other acid-forming fertilizers may lower pH of the soil surface and require correction with lime. Monitor surface pH with a 0- to 2-inch soil sample, especially in no-till systems. Also remember that sulfate-S is available for crop uptake immediately after application. If a reduced form of S is applied (e.g., thiosulfate or elemental S), allow adequate time for oxidation of the applied S to the sulfate form to occur.

Manganese

Manganese (Mn) needs are predicted by an availability index that includes M3 soil test Mn (M3-Mn) and soil pH. Interpretation of MnAI is crop specific. Corn is a moderately Mn sensitive crop. Soil test Mn results are reported in lb/ac.

$$MnAI = 101.7 - (15.2 \times \text{soil pH}) + (2.11 \times \text{M3-Mn})$$

Where:

MnAI = Mn availability index
Soil pH = Soil pH measured in water (1:1 V:V)
M3-Mn = Mehlich 3 soil test Mn in lb/ac

Table 8. Interpretation of manganese availability index for grain corn.

Mn Availability Index	Interpretation
Less than 17	Mn deficiency is likely at this soil pH and soil test Mn concentration
17 to 25	Mn deficiency is possible at this soil pH and soil test Mn concentration. Monitor the crop for symptoms, especially if liming has been recommended.
Greater than 25	Mn deficiency is unlikely.

1. Manganese deficiency is more likely for soils with a MnAI between 17 and 25 if soils were recently limed and the M3-Mn concentration is < 3.4 lb/ac.
2. If Mn deficiency is predicted or was observed in the previous growing season, broadcast 20 to 30 lb/ac elemental Mn.
3. In some cases, broadcast applications of acid forming fertilizers may correct Mn deficiency without the application of Mn; however, acid-forming fertilizers may be less effective than Mn fertilizers.
4. If Mn deficiency symptoms appear during the growing season or after an application of lime, a foliar application of Mn sulfate or Mn oxide at a rate of 1.0 to 2.0 lb/ac elemental Mn or chelated Mn (Mn-EDTA) at a rate of 0.5 to 1.0 lb/ac elemental Mn can alleviate the symptoms and restore yield potential. **Apply only when adequate growth is present to aid absorption of foliar Mn.**

NOTE: When using foliar application to correct Mn deficiency, growers may combine the treatment with a post emergence herbicide application to reduce the number of trips across the field. Sulfate containing forms of Mn (e.g., manganese sulfate [Techmangam] and manganese-lignin-sulfate) may be antagonistic to weed control with Roundup™. To overcome this antagonism, growers should add ammonium sulfate at a rate of 17 lb per 100 gallons of solution. Chelated-Mn (Mn-EDTA) has shown a slight degree of antagonism but little to no reduction in weed control was noted in the field studies.

Zinc

Zinc (Zn) deficiency is predicted by an availability index (ZnAI) that includes M3 soil test Zn, soil pH, and M3 soil test P. Soil test Zn results are reported in lb/ac. Zinc deficiency is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 9 to determine if Zn deficiency is predicted for this field.

Table 9. Interpretation of Zn availability index for grain corn.

Soil Test Criteria	Interpretation
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIV or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Zn deficiency is unlikely

If zinc deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast Zn sulfate or Zn oxide at a rate of 10 to 12 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 2 to 3 lb/ac elemental Zn. Broadcast applications should correct Zn deficiency for several years.
2. If a banded application is preferred, apply 6 to 8 lb/ac elemental Zn as Zn sulfate or Zn oxide or 1 to 2 lb/ac elemental Zn as Zn chelate (Zn-EDTA) in the fertilizer band. Banded applications are only effective in the growing season in which they are applied.
3. Foliar application of Zn sulfate or Zn oxide at a rate of 1 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 0.5 lb/ac elemental Zn in 20 to 50 gallons of water. **Apply only when adequate growth is present to aid in the adsorption of foliar Zn.** Foliar Zn application should be repeated if symptoms re-appear.

Boron

Boron (B) deficiency is occasionally observed in intensively managed, irrigated corn production. However, B applications are not a general recommendation for corn. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Grain Sorghum

Crop Highlights
• Target pH: 6.0 • Base nitrogen (N) application rates on the crop rotation in use. Sorghum has shown only minimal response to N when following an average soybean crop (e.g., 30 to 40 bu/ac yield) or another legume. Increase N rates when sorghum follows a corn or sorghum crop.

Yield Goal

Grain yield of sorghum is influenced by many factors, including the cultivars selected, planting date, winter weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure, and crop management practices. **On Delaware soils, 80 bu/ac is a realistic yield goal for grain sorghum production in a good to average year.**

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter (e.g., "black" soils; soil organic matter >6.0%) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 1. Recommended type of lime as a function of Mehlich-3 soil test calcium and magnesium concentrations.

Soil Test Levels	Recommended Lime Type
M3-Mg is less than 50 FIV	Dolomitic
M3-Mg between 50 and 100 FIV AND M3-Mg is less than M3-Ca	Dolomitic
M3-Mg greater than 100 FIV	Calcitic
M3-Mg is greater than 50 FIV AND M3-Mg is greater than M3-Ca	Calcitic

Nitrogen

Nitrogen fertilization rates are based on regional research on crop response to N fertilizers and not on the results of a routine soil test.

The University of Delaware nitrogen (N) recommendations for sorghum are based upon the crop rotation in use. **A total nitrogen (N) application rate of 50 to 75 lb/ac per growing season is recommended for a grain sorghum crop following corn or sorghum**. **When the sorghum crop is following an average soybean crop (e.g., 30 to 40 bu/ac yield) or another legume in the rotation, the N application rate should be reduced to 25 to 50 lb/ac per growing season.**

Nitrogen use will be most efficient when applied in a split application. A small amount of N (approximately 25%) should be applied at or prior to planting. The remainder of the N should be applied at the 5th leaf stage. If a single N application is desired, then N should be applied as close to planting as possible to reduce the potential loss of N by leaching prior to crop uptake. When planting into fields where manure has been applied, determine the plant available N (PAN) for the manure application and reduce fertilizer N rates as appropriate.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test (Table 2). Soil test results are reported as a fertility index value (FIV).

Table 2. Broadcast phosphorus application rates for grain sorghum.

	M3-P (UD FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb P_2O_5/ac	100	80	60	50	40	40	30	30	30	20	20

1. If M3 soil test P (M3-P) is “Low” or “Medium” (e.g., 50 FIV or less), broadcast and plow down the recommended rate of phosphate prior to seeding.
2. If M3-P is “Optimum” (e.g., 51 to 100 FIV), broadcast and incorporate phosphate prior to seeding or surface broadcast at or shortly after planting.
3. If M3-P is “Excessive” (e.g., greater than 100 FIV), the application of phosphorus in fertilizers or manures is NOT RECOMMENDED.
4. If P fertilizers are banded, reduce the rates in Table 2 by one-half.

Potassium

The need for potassium (K) fertilization is determined by a routine soil test (Table 3). Soil test results are reported as a fertility index value (FIV).

Table 3. Recommended potassium application rates for grain sorghum.

	M3-K (UD FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb K_2O/ac	150	120	90	70	50	30	30	20	20	20	0

1. Broadcast and incorporate or band potash prior to planting.
2. For banded applications, reduce the rates in Table 3 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb/ac K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 4); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 4. Recommended application rates of soluble magnesium as a function of Mehlich 3 soil test magnesium.

Soluble Mg	M3-Mg (UD FIV)								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3 soil test Mg is less than 40 FIV.
2. If M3-Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3-Mg is less than 40 FIV and lime is not needed, apply soluble Mg according to the rates in Table 4.

Sulfur

Sulfur (S) deficiency is occasionally observed in early in the season on sorghum grown on sandy Delaware soils. The use of ammonium sulfate as the N source or the addition of a small amount of ammonium sulfate to liquid UAN can prevent S deficiency from occurring.

Prediction of S deficiency is difficult. Currently available soil tests are not good predictors of S deficiency situations because only surface soil samples are analyzed. Many Delaware soils have a supply of plant available S in subsoil horizons that will not be detected in soil samples taken from shallower depths. Subsoil sampling to a depth of 24 inches is highly recommended as a means of identifying soils with subsoil reserves of S.

Long-term applications of ammonium sulfate or other acid-forming fertilizers may lower pH of the soil surface and require correction with lime. Monitor surface pH with a 0- to 2-inch soil sample, especially in no-till systems. Also remember that sulfate-S is available for crop uptake immediately after application. If a reduced form of S is applied (e.g., thiosulfate or elemental S), allow adequate time for oxidation of the applied S to the sulfate form to occur.

Manganese

Manganese (Mn) needs are predicted by an availability index that includes M3 soil test Mn (M3-Mn) and soil pH. Interpretation of MnAI is crop specific. Sorghum is a moderately Mn sensitive crop. Soil test Mn results are reported in lb/ac.

$$MnAI = 101.7 - (15.2 \times \text{soil pH}) + (2.11 \times \text{M3-Mn})$$

Where:

MnAI = Mn availability index
Soil pH = Soil pH measured in water (1:1 V:V)
M3-Mn = Mehlich 3 soil test Mn in lb/ac

Table 5. Interpretation of manganese availability index for grain sorghum.

Mn Availability Index	Interpretation
Less than 17	Mn deficiency is likely at this soil pH and soil test Mn concentration
17 to 25	Mn deficiency is possible at this soil pH and soil test Mn concentration. Monitor the crop for symptoms, especially if liming has been recommended.
Greater than 25	Mn deficiency is unlikely.

1. Manganese deficiency is more likely for soils with a MnAI between 17 and 25 if soils were recently limed and the M3-Mn concentration is <3.4 lb/ac.
2. If Mn deficiency is predicted or was observed in the previous growing season, broadcast 20 to 30 lb/ac elemental Mn.
3. In some cases, broadcast applications of acid forming fertilizers may correct Mn deficiency without the application of Mn; however, acid-forming fertilizers may be less effective than Mn fertilizers.
4. If Mn deficiency symptoms appear during the growing season or after an application of lime, a foliar application of Mn sulfate or Mn oxide at a rate of 1.0 to 2.0 lb/ac elemental Mn or chelated Mn (Mn-EDTA) at a rate of 0.5 to 1.0 lb/ac elemental Mn can alleviate the symptoms and restore yield potential. **Apply only when adequate growth is present to aid absorption of foliar Mn.**

NOTE: When using a foliar application to correct Mn deficiency, growers may combine the treatment with a post emergence herbicide application to reduce the number of trips across the field. Sulfate containing forms of Mn (e.g., manganese sulfate [Techmangam] and manganese-lignin-sulfate) may be antagonistic to weed control with Roundup™. To overcome this antagonism, growers should add ammonium sulfate at a rate of 17 lb per 100 gallons of solution. Chelated-Mn (Mn-EDTA) has shown a slight degree of antagonism but little to no reduction in weed control was noted in the field studies.

NOTE: Manganese toxicity has also been observed in grain sorghum grown on Delaware soils with low soil pH. Symptoms of Mn toxicity include generally stunted growth, yellowed or chlorotic leaves, or (in severe cases) a series of reddish-purple bands that run parallel to the leaf veins about ½ to ⅓ of the way back from the leaf tip. Suspected Mn toxicity can be confirmed by a tissue or soil pH test. When detected early, the problem may be corrected by broadcasting agricultural-grade lime at a rate of 1 ton/ac. Little can be done to correct Mn toxicity when identified later in the season. Take note of the area where Mn toxicity occurs in the field so that lime can be applied in that location following harvest to raise the pH for future crops.

Zinc

Zinc (Zn) deficiency is predicted by an availability index that includes M3 soil test Zn, soil pH, and M3 soil test P. It is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 6 to determine if Zn deficiency is predicted for this field.

Table 6. Interpretation of the zinc availability index.

Soil Test Criteria	Interpretation
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIV or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Zn deficiency is unlikely

If zinc deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast Zn sulfate or Zn oxide at a rate of 10 to 12 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 2 to 3 lb/ac elemental Zn. Broadcast applications should correct Zn deficiency for several years.
2. Foliar application of Zn sulfate or Zn oxide at a rate of 1 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 0.5 lb/ac elemental Zn in 20 to 50 gallons of water. **Apply only when adequate growth is present to aid in the adsorption of foliar Zn.** Foliar Zn application should be repeated if symptoms reappear.

Boron

Boron (B) deficiency is not usually observed in grain sorghum. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Rye and Oats

Crop Highlights
• Target pH: 6.0 • Split nitrogen (N) application to increase N use efficiency in rye and oats. Apply a small amount at planting or in late winter and the bulk of the N requirement when growth resumes in the spring. • Monitor crop for manganese (Mn) deficiency, **especially** when Mehlich-3 soil test Mn is less than 3.4 lb/ac.

Yield Goal

Rye and oat yields are influenced by many factors, including the cultivars selected, planting date, winter weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure and crop management practices. **On most Delaware soils, typical yields in a good to average year range from 40 to 50 bu/ac for rye and 100 to 150 bu/ac for oats.** Typical yields may be slightly higher for rye or oats grown on black soils (>6% organic matter) or silt loams, or if the crop is produced with irrigation.

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter (e.g., "black" soils; soil organic matter >6.0%) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 1. Recommended type of lime as a function of Mehlich-3 soil test calcium and magnesium concentrations.

Soil Test Levels	Recommended Lime Type
M3-Mg is less than 50 FIV	Dolomitic
M3-Mg between 50 and 100 FIV AND M3-Mg is less than M3-Ca	Dolomitic
M3-Mg greater than 100 FIV	Calcitic
M3-Mg is greater than 50 FIV AND M3-Mg is greater than M3-Ca	Calcitic

Nitrogen

Nitrogen fertilization rates are based on regional research on crop response to N fertilizers and not on the results of a routine soil test.

The University of Delaware recommends a total nitrogen (N) rate of 40 to 70 lb/ac per growing season for rye and 50 to 90 lb/ac for oats. When a single N application is planned, N should be topdressed in early spring when growth resumes (e.g., "green-up"). For greatest response, N should be split into two or more applications. Apply a small portion of the total N requirement at planting (25%) or in late winter (50%). Apply the remaining N (50 to 75%) in early spring when growth resumes ("green-up").

The higher end of the N range should be utilized for sandy soils or for management systems where a single N application will be made to compensate for higher leaching losses. Split applications have been shown to increase N use efficiency, thus requiring less total N to achieve the same grain yield. In general, increasing N rate may increase grain production, but may also increase lodging that may reduce harvestable and economic yield.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test (Table 2). Soil test results are reported as a fertility index value (FIV).

Table 2. Broadcast phosphorus application rates for rye and oats.

	M3-P (FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb P_2O_5/ac	140	120	100	80	60	40	30	30	30	20	20

1. If M3 soil test phosphorus (M3-P) is “Low” (e.g., 25 FIV or less), broadcast and plow down the recommended rate of phosphate prior to planting in the fall.
2. If M3-P is “Medium or “Optimum” (e.g., 26 to 100 FIV), phosphate can topdressed in the fall or the spring.
3. If M3-P is “Excessive” (e.g., greater than 100 FIV), the application of phosphorus in fertilizers or manures is NOT RECOMMENDED.
4. If P fertilizers are banded, reduce the rates in Table 2 by one-half.
5. Soil test P may decline more rapidly when straw is removed than when straw is left behind as stubble since straw removal also removes P from the site. Growers may wish to soil test more frequently to monitor changes in soil test P when straw is removed.

Potassium

The need for potassium (K) fertilization is determined by a routine soil test (Table 3). Soil test results are reported as a fertility index value (FIV).

Table 3. Recommended potassium application rates for rye and oats.

	M3-K (FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb K_2O /ac	140	120	100	80	60	40	30	30	30	20	20

1. Broadcast and incorporate or band potash prior to planting.
2. For banded applications, reduce the rates in Table 3 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb/ac of K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.
4. Soil test K may decline more rapidly when straw is removed than when straw is left behind as stubble since straw removal also removes K from the site. Growers may wish to soil test more frequently to monitor changes in soil test K.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 4); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 4. Recommended application rates of soluble magnesium as a function of soil test magnesium.

Soluble Mg	M3-Mg (FIV)								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3 soil test Mg is less than 40 FIV.
2. If M3 soil test Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3 soil test Mg is less than 40 FIV and lime is not needed, apply soluble Mg according to the rates in Table 4.

Sulfur

Sulfur (S) deficiency is occasionally observed in rye and oats grown on Delaware soils. Symptoms include reduced growth and a general yellowing of the plant. To confirm diagnosis, have a tissue test run. Cut the whole plant ½ inch above the soil line at Feekes 5 growth stage and submit to a reputable lab for analysis.

1. If the N:S ratio is greater than 15:1, apply 25 to 35 lb/ac of S with the first N application in the spring.

Prediction of S deficiency is difficult. Currently available soil tests are not good predictors of S deficiency situations because only surface soil samples are analyzed. Many Delaware soils have a supply of plant available S in subsoil horizons that will not be detected in soil samples taken from shallower depths. Subsoil sampling to a depth of 24 inches is highly recommended as a means of identifying soils with subsoil reserves of S.

Long-term applications of ammonium sulfate or other acid-forming fertilizers may lower pH of the soil surface and require correction with lime. Monitor surface pH with a 0- to 2-inch soil sample, especially in no-till systems. Also remember that sulfate-S is available for crop uptake immediately after application. If a reduced form of S is applied (e.g., thiosulfate or elemental S), allow adequate time for oxidation of the applied S to the sulfate form to occur.

Manganese

Manganese (Mn) needs are predicted by an availability index (MnAI) that includes M3 soil test Mn (M3-Mn) and soil pH. Interpretation of MnAI is crop specific. Rye and oats are Mn sensitive crops. Soil test Mn results are reported in lb/ac.

$$MnAI = 101.7 - (15.2 \times \text{soil pH}) + (2.11 \times \text{M3-Mn})$$

Where:

MnAI = Mn availability index
Soil pH = Soil pH measured in water (1:1 V:V)
M3-Mn = Mehlich 3 soil test Mn in lb/ac

Table 5. Interpretation of manganese availability index for rye and oats.

Mn Availability Index	Interpretation
Less than 25	Mn deficiency is likely at this soil pH and soil test Mn concentration
25 to 35	Mn deficiency is possible at this soil pH and soil test Mn concentration. Monitor the crop for symptoms, especially if liming has been recommended.
Greater than 35	Mn deficiency is unlikely.

1. If Mn deficiency is predicted or was observed in the previous growing season, broadcast 20 to 30 lb/ac elemental Mn.
2. In some cases, broadcast applications of acid forming fertilizers may correct Mn deficiency without the application of Mn; however, acid-forming fertilizers may be less effective than Mn fertilizers.
3. If Mn deficiency symptoms appear during the growing season or after an application of lime, a foliar application of Mn sulfate or Mn oxide at a rate of 1.0 to 2.0 lb/ac elemental Mn or chelated Mn (Mn-EDTA) at a rate of 0.5 to 1.0 lb/ac elemental Mn can alleviate the symptoms and restore yield potential. **Apply only when adequate growth is present to aid absorption of foliar Mn.**

NOTE: When using foliar application to correct Mn deficiency, growers may combine the treatment with a post emergence herbicide application to reduce the number of trips across the field. Sulfate containing forms of Mn (e.g., manganese sulfate [Techmangam] and manganese-lignin-sulfate) may be antagonistic to weed control with Roundup™. To overcome this antagonism, growers should add ammonium sulfate at a rate of 17 lb per 100 gallons of solution. Chelated-Mn (Mn-EDTA) has shown a slight degree of antagonism but little to no reduction in weed control was noted in the field studies.

Zinc

Zinc (Zn) deficiency is predicted by an availability index that includes M3 soil test Zn, soil pH, and M3 soil test P. It is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 6 to determine if Zn deficiency is predicted for this field.

Table 6. Interpretation of zinc availability index for rye and oats.

Soil Test Criteria	**Interpretation**
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIV or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Zn deficiency is unlikely

If zinc deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast Zn sulfate or Zn oxide at a rate of 10 to 12 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 2 to 3 lb/ac elemental Zn. Broadcast applications should correct Zn deficiency for several years.
2. Foliar application of Zn sulfate or Zn oxide at a rate of 1 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 0.5 lb/ac elemental Zn in 20 to 50 gallons of water. **Apply only when adequate growth is present to aid in the adsorption of foliar Zn.** Foliar Zn application should be repeated if symptoms re-appear.

Boron

Boron (B) deficiency is not usually observed in rye or oats. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Copper

Copper (Cu) deficiency has been observed in rye or oats when grown in other regions. If Cu deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Small Grain and Soybeans – Double-Cropped

Crop Highlights

- Target pH: 6.0
- Apply nitrogen (N) to the small grain crop only. Split N application to the small grain to increase N-use efficiency.
- Phosphorus (P) and potassium (K) recommendations are designed to meet the needs of **both** crops and can usually be applied in a single application.
- Monitor crop for manganese (Mn) deficiency, **especially** when Mehlich-3 soil test Mn is less than 3.4 lb/ac.

Yield Goal

The yields of small grains and soybeans grown in double-cropped rotation are influenced by many factors, including the cultivars selected, planting date, winter weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure, and crop management practices. The small grains most typically grown in this rotation are wheat and barley. **Typical yield goals for wheat followed by double-cropped soybean grown on Delaware soils under average to good conditions is 50 to 110 bu/ac for wheat and 40 to 50 bu/ac for soybean. Typical yield goals for barley followed by double-cropped soybean grown on Delaware soils under average to good conditions is 60 to 120 bu/ac for barley and 60 to 70 bu/ac for soybean.**

Production on “black” soils (>6.0% soil organic matter) or production under irrigation can increase soybean yield by several bushels per acre in good to average years.

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter (e.g., "black" soils; soil organic matter >6.0%) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 1. Recommended type of lime as a function of Mehlich-3 soil test calcium and magnesium concentrations.

Soil Test Levels	Recommended Lime Type
M3-Mg is less than 50 FIV	Dolomitic
M3-Mg between 50 and 100 FIV AND M3-Mg is less than M3-Ca	Dolomitic
M3-Mg greater than 100 FIV	Calcitic
M3-Mg is greater than 50 FIV AND M3-Mg is greater than M3-Ca	Calcitic

Nitrogen

Nitrogen fertilization rates are based on regional research on crop response to N fertilizers and not on the results of a routine soil test.

Nitrogen (N) is recommended only for the small grain crop in the double-cropped rotation. **The University of Delaware recommends a total N rate of 80 to 120 lb/ac for wheat and 60 to 90 lb/ac for barley per growing season.** For greatest response, N should be split into two or more applications. A small amount of N (20-35%) should be applied in the fall or in late winter. The remainder should be applied in the spring in two applications. The first should be made at “green up” when growth resumes in the spring and the second at Feekes growth stage 5. For more detailed information on N rates and timing, refer to the University of Delaware Nutrient Management Recommendations for single-crop barley and wheat.

Soybeans are leguminous plants and capable of fixing enough N to meet crop needs. **As such, the University of Delaware does not recommend application of N to double-cropped soybean under average yield conditions.** If soybeans have not been successfully grown on the field in previous years, treat the seed with a suitable inoculum just prior to planting or use inoculated seed.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test. Soil test results are reported as a fertility index value (FIV). Phosphorus recommendations are designed to meet the needs of both crops. The application rate should be selected from Table 2 below, based on the realistic soybean yield expected.

1. If M3 soil test P (M3-P) is “Low” (e.g., 25 FIV or less), broadcast and plow down the recommended rate of phosphate prior to seeding.
2. If M3-P is “Medium” or “Optimum” (e.g., 26 to 100 FIV), broadcast and incorporate phosphate prior to seeding or surface broadcast at or shortly after planting.
3. If M3-P is “Excessive” (e.g., greater than 100 FIV), the application of phosphorus in fertilizers or manures is NOT RECOMMENDED.
4. If P fertilizers are banded, reduce the rates in Table 2 by one-half.

Table 2. Broadcast phosphorus application rates for double-cropped small grain-soybean rotation based on realistic soybean yield.

Soybean Yield (bu/ac)	M3-P (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	---------- lb P_2O_5/ac ----------										
40	200	180	160	140	120	100	80	60	40	30	20

45	205	185	165	145	125	105	85	65	45	35	25
50	210	190	170	150	130	110	90	70	50	40	30
55	215	195	175	155	135	115	95	75	55	45	35
60	220	200	180	160	140	120	100	80	60	50	40
65	225	205	185	165	145	125	105	85	65	55	45
70	230	210	190	170	150	130	110	90	70	60	50

Potassium

The need for potassium (K) fertilization is determined by a routine soil test. Soil test results are reported as a fertility index value (FIV). Potassium (K) recommendations are designed to meet the needs of both crops. The application rate should be selected from Table 3 below, based on the realistic soybean yield expected.

Table 3. Recommended potassium application rates for double-cropped small grain – soybean rotations based on realistic soybean yield.

Soybean Yield (bu/ac)	M3-K (FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	---------- lb K_2O/ac ----------										
40	260	230	200	170	140	110	90	70	50	30	20
45	270	240	210	180	150	115	95	75	55	35	25
50	280	250	220	190	160	120	100	80	60	40	30
55	290	260	230	200	170	125	105	85	65	45	35
60	300	270	240	210	180	130	110	90	70	50	40
65	310	280	240	220	190	135	115	95	75	55	45
70	320	290	260	230	200	140	120	100	80	60	50

1. Broadcast and incorporate or band potash prior to planting the small grain crop.
2. For banded applications, reduce the rates in Table 3 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb/ac K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 6); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 4. Recommended application rates of soluble magnesium as a function of Mehlich-3 soil test magnesium.

Soluble Mg	M3-Mg (FIV)								
	0	5	10	15	20	25	30	35	40
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3 soil test Mg (M3-Mg) is less than 40 FIV.
2. If M3-Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3-Mg is less than 40 FIV and lime is not needed, apply soluble Mg according to the rates in Table 4.

Sulfur

Sulfur (S) deficiency is occasionally observed in wheat and barley grown on Delaware soils. Symptoms include reduced growth and a general yellowing of the plant. Use a tissue test run to confirm deficiency in season. Cut the whole plant ½ inch above the soil line at Feekes 5 growth stage and submit to a reputable lab for analysis.

1. If the N:S ratio in the plant tissue is greater than 15:1, apply 25 to 35 lb S/ac with the first N application in the spring.

Prediction of S deficiency is difficult. Currently available soil tests are not good predictors of S deficiency situations because only surface soil samples are analyzed. Many Delaware soils have a supply of plant available S in subsoil horizons that will not be detected in soil samples taken from shallower depths. Subsoil sampling to a depth of 24 inches is highly recommended as a means of identifying soils with subsoil reserves of S.

Long-term applications of ammonium sulfate or other acid-forming fertilizers may lower pH of the soil surface and require correction with lime. Monitor surface pH with a 0- to 2-inch soil sample, especially in no-till systems. Also remember that sulfate-S is available for crop uptake immediately after application. If a reduced form of S is applied (e.g., thiosulfate or elemental S), allow adequate time for oxidation of the applied S to the sulfate form to occur.

Zinc

Zinc (Zn) deficiency is predicted by an availability index (ZnAI) that includes M3 soil test Zn, soil pH, and M3 soil test P. Soil test Zn results are reported in lb/ac. Zinc deficiency is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 6 to determine if Zn deficiency is predicted for this field.

Table 6. Interpretation of zinc availability index.

Soil Test Criteria	Interpretation
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIV or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Zn deficiency is unlikely

If zinc deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast Zn sulfate or Zn oxide at a rate of 10 to 12 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 2 to 3 lb/ac elemental Zn. Broadcast applications should correct Zn deficiency for several years.
2. If a banded application is preferred, apply 6 to 8 lb/ac elemental Zn as Zn sulfate or Zn oxide or 1 to 2 lb/ac elemental Zn as Zn chelate (Zn-EDTA) in the fertilizer band. Banded applications are only effective in the growing season in which they are applied.
3. Foliar application of Zn sulfate or Zn oxide at a rate of 1 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 0.5 lb/ac elemental Zn in 20 to 50 gallons of water. **Apply only when adequate growth is present to aid in the adsorption of foliar Zn.** Foliar Zn application should be repeated if symptoms re-appear.

Boron

Boron (B) deficiency is not usually observed in wheat, barley, or soybean. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Soybean – Full Season

Crop Highlights
• Target pH: 6.0 • Monitor crop for manganese (Mn) deficiency, **especially** when Mehlich-3 soil test Mn is less than 3.4 lb/ac.

Yield Goal

Soybean yields are influenced by many factors, including the hybrids selected, planting date, winter weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure and crop management practices. **Typical yield goals for single-cropped, full-season soybeans grown on Delaware soils under dryland conditions range from 35 to 70 bu/ac. Production on black soils (>6% organic matter) or using irrigation or conservation tillage practices can increase yields up to 80 to 90 bu/ac in good to average years.**

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter (e.g., "black" soils; soil organic matter >6.0%) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 1. Recommended type of lime as a function of Mehlich-3 soil test calcium and magnesium concentrations.

Soil Test Levels	Recommended Lime Type
M3-Mg is less than 50 FIV	Dolomitic
M3-Mg between 50 and 100 FIV AND M3-Mg is less than M3-Ca	Dolomitic
M3-Mg greater than 100 FIV	Calcitic
M3-Mg is greater than 50 FIV AND M3-Mg is greater than M3-Ca	Calcitic

Nitrogen

Nitrogen fertilization rates are based on regional research on crop response to N fertilizers and not on the results of a routine soil test.

Soybeans are leguminous plants and capable of fixing enough nitrogen (N) to meet crop needs. **As such, the University of Delaware does not recommend application of N under average yield conditions.**

Late-season N application may be beneficial when yields consistently exceed 70 to 80 bu/ac. Under high yield conditions, consider applying a small amount of N (e.g., 20 to 30 lb/ac) through the irrigation system at pod fill (R2 to R4). Always avoid early season N applications, as N applied at this stage may delay nodulation and result in yield loss.

If soybeans have not been successfully grown on the field in previous years, treat the seed with a suitable inoculum just prior to planting or use inoculated seed.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test (Table 2). Soil test results are reported as a fertility index value (FIV).

Table 2. Broadcast phosphorus application rates for full-season soybean.

Yield (bu/ac)	M3-P (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	---------- lb P_2O_5/ac ----------										
35	110	90	70	50	40	35	35	25	25	15	15
40	120	100	80	60	50	40	40	30	30	20	20
45	130	110	90	70	60	45	45	35	35	25	25
50	140	120	100	80	70	50	50	40	40	30	30
55	150	130	110	90	80	55	55	45	45	35	35
60	160	140	120	100	90	60	60	50	50	40	40
65	170	150	130	110	100	65	65	55	55	45	45
70	180	160	140	120	110	70	70	60	60	50	50
75	190	170	150	130	120	75	75	65	65	55	55
80	200	180	160	140	130	80	80	70	70	60	60
85	210	190	170	150	140	85	85	75	75	65	65
90	220	200	180	160	150	90	90	80	80	70	70

1. If M3 soil test P (M3-P) is "Low" or "Medium" (e.g., 50 FIV or less), broadcast and plow down the recommended rate of phosphate prior to seeding.
2. If M3-P is "Optimum" (e.g., 51 to 100 FIV), broadcast and incorporate phosphate prior to seeding or surface broadcast at or shortly after planting.
3. If M3-P is "Excessive" (e.g., greater than 100 FIV), the application of P in fertilizers or manures is NOT RECOMMENDED.
4. If P fertilizers are banded, reduce the rates in Table 2 by one-half.

Potassium

The need for potassium (K) fertilization is determined by a routine soil test (Table 3). Soil test results are reported as a fertility index value (FIV).

Table 3. Recommended potassium application rates for full-season soybean.

Yield (bu/ac)	M3-K (UD FIV)										
	0	10	20	30	40	50	60	70	80	90	100
	---- lb K_2O/ac ----										
35	100	80	60	40	40	30	30	20	20	10	10
40	120	100	80	60	40	40	40	30	30	20	20
45	140	120	100	80	60	50	50	40	40	30	30
50	160	140	120	100	80	60	60	50	50	40	40
55	180	160	140	120	100	70	70	60	60	50	50
60	200	180	160	140	120	80	80	70	70	60	60
65	220	200	180	160	140	90	90	80	80	70	70
70	240	220	200	180	160	100	100	90	90	80	80
75	260	240	220	200	180	110	110	100	100	90	90
80	280	260	240	220	200	120	120	110	110	100	100
85	300	280	260	240	220	130	130	120	120	120	120
90	320	300	280	260	240	140	140	130	130	130	130

1. Broadcast and incorporate or band potash prior to planting.
2. For banded applications, reduce the rates in Table 3 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb /ac K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 6); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 4. Recommended application rates of soluble magnesium as a function of soil test magnesium.

Soluble Mg	M3-Mg (UD FIV)								
	0	5	10	15	20	25	30	35	40
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3 soil test Mg is less than 40 FIV.
2. If M3-Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3-Mg is less than 40 FIV and lime is not needed, apply soluble Mg according to the rates in Table 4.

Manganese

Manganese (Mn) needs are predicted by an availability index (MnAI) that includes M3 soil test Mn (M3-Mn) and soil pH. Interpretation of MnAI is crop specific. Soybean is a Mn sensitive crop. Soil test Mn results are reported in lb/ac.

$$MnAI = 101.7 - (15.2 \times \text{soil pH}) + (2.11 \times \text{M3-Mn})$$

Where:

MnAI	= Mn availability index
Soil pH	= Soil pH measured in water (1:1 V:V)
M3-Mn	= Mehlich 3 soil test Mn in lb/ac

Table 5. Interpretation of manganese availability index for full season soybean.

Mn Availability Index	Interpretation
Less than 25	Mn deficiency is likely at this soil pH and soil test Mn concentration
25 to 35	Mn deficiency is possible at this soil pH and soil test Mn concentration. Monitor the crop for symptoms, especially if liming has been recommended.
Greater than 35	Mn deficiency is unlikely.

1. If Mn deficiency is predicted or was observed in the previous growing season, broadcast 20 to 30 lb/ac elemental Mn.
2. Broadcast applications of acid forming fertilizers may correct Mn deficiency without the elemental application of Mn in some cases but may be less effective than applications of Mn.
3. If Mn deficiency symptoms appear during the growing season or after an application of lime, a foliar application of Mn sulfate or Mn oxide at a rate of 1.0 to 2.0 lb/ac elemental Mn or chelated Mn (Mn-EDTA) at a rate of 0.5 to 1.0 lb/ac elemental Mn can alleviate the symptoms and restore yield potential. **Apply only when adequate growth is present to aid absorption of foliar Mn.**

NOTE: When using foliar application to correct Mn deficiency, growers may combine the treatment with a post emergence herbicide application to reduce the number of trips across the field. Sulfate containing forms of Mn (e.g., manganese sulfate [Techmangam] and manganese-lignin-sulfate) may be antagonistic to weed control with Roundup™. To overcome this antagonism, growers should add ammonium sulfate at a rate of 17 lb per 100 gallons of solution. Chelated-Mn (Mn-EDTA) has shown a slight degree of antagonism but little to no reduction in weed control was noted in the field studies.

Zinc

Zinc (Zn) deficiency is predicted by an availability index (ZnAI) that includes M3 soil test Zn, soil pH, and M3 soil test P. Soil test Zn results are reported in lb/ac. Zinc deficiency is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 6 to determine if Zn deficiency is predicted for this field.

Table 6. Interpretation of zinc availability index for full season soybean.

Soil Test Criteria	Interpretation
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIV or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Zn deficiency is unlikely

If zinc deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast Zn sulfate or Zn oxide at a rate of 10 to 12 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 2 to 3 lb/ac elemental Zn. Broadcast applications should correct Zn deficiency for several years.
2. If a banded application is preferred, apply 6 to 8 lb/ac elemental Zn as Zn sulfate or Zn oxide or 1 to 2 lb/ac elemental Zn as Zn chelate (Zn-EDTA) in the fertilizer band. Banded applications are only effective in the growing season in which they are applied.
3. Foliar application of Zn sulfate or Zn oxide at a rate of 1 lb/ac elemental Zn or Zn chelate (Zn-EDTA) at a rate of 0.5 lb/ac elemental Zn in 20 to 50 gallons of water. **Apply only when adequate growth is present to aid in the adsorption of foliar Zn.** Foliar Zn application should be repeated if symptoms re-appear.

Boron

Boron (B) deficiency is not usually observed in soybean. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.

Wheat

Crop Highlights
• Target pH: 6.0 • Split N application to increase N-use efficiency in wheat. Apply a small amount (15 to 30 lb N/ac) at planting or in late winter and the bulk of the N requirement in two applications in early Spring. Apply the first when growth resumes in the spring and the second at Feekes growth stage 5. • Use the fall soil nitrate test (FSNT) to determine whether the fall application of N can be reduced or eliminated. • Monitor crop for manganese (Mn) deficiency, **especially** when Mehlich-3 soil test Mn is less than 3.4 lb/ac.

Yield Goal

Wheat yields are influenced by many factors, including the cultivars selected, planting date, winter weather, soil type and water-holding capacity, nutrient and water availability, weed, insect and disease pressure and crop management practices. **On most Delaware soils, typical wheat yields in a good to average year range from 60 to 80 bu/ac. On black soils, silt loams, or when irrigation is used, typical yields range from 80 to 125 bu/ac.**

Delaware growers should use field history to determine the yield goal for each field and use that information to adjust management decisions and fertility programs accordingly. Delaware nutrient management law requires the use of optimal rolling average for determining the yield goal for a specific field when field history is available. To calculate the optimal rolling average yield, see the UD Extension Fact Sheet ***Estimating Yield Goal for Crops***.

Soil pH and Liming

Target pH: 6.0 for most soils

Soils that are high in organic matter ("black" soils) have a lower target pH (5.6) because organic matter moderates some of the negative effects of excessive soil acidity (e.g., aluminum toxicity).

The lime recommendation for a specific field is calculated from the soil pH and Adam-Evans buffer pH measurements using the steps outlined in the UD Extension Fact Sheet ***Calculating the Lime Requirement Using the Adams-Evans Soil Buffer***. Avoid over-liming to prevent deficiency of micronutrients such as manganese (Mn).

The recommended liming source is dependent upon Mehlich-3 (M3) soil test calcium (Ca) and magnesium (Mg) reported as a University of Delaware fertility index value (FIV) and can be determined using Table 1.

Table 1. Recommended type of lime as a function of Mehlich-3 soil test Ca and Mg concentrations.

Soil Test Levels	Recommended Lime Type
Soil Test Mg less than 50 FIV	Dolomitic
Soil Test Mg between 50 and 100 FIV AND LESS than Soil Test Ca	Dolomitic
Soil Test Mg greater than 100 FIV	Calcitic
Soil Test Mg GREATER than 50 FIV AND GREATER than Soil Test Ca	Calcitic

Nitrogen

The University of Delaware recommends a total nitrogen (N) rate of 80 to 120 lb N/ac per growing season. The higher end of the range should be utilized for sandy soils or for management systems where a single application will be made to compensate for higher leaching losses. In general, increasing N rate may increase grain production but may also increase lodging, thus reducing harvestable and economic yield. Split applications have been shown to increase N use-efficiency, thus requiring less total N to achieve the same grain yield. For best results, N should be split into two or more applications. Effective N management for winter wheat is facilitated by soil and plant tissue sampling to ensure sufficient N to produce a healthy crop, but limit yield penalizing effects (e.g., disease and lodging) and leaching losses.

A small amount (up to 30 lb/ac of N) should be applied in the fall or in late winter to promote root growth and fall tillering. Avoid applying more than 30 lb/ac of N in the fall, as plants with excessive fall growth are susceptible to disease and winter kill; fall N applications are also susceptible to leaching below the root zone. A fall soil nitrate test (FSNT) run on a 6-inch composite soil sample is recommended to determine if enough soil N remains to reduce or eliminate the fall N application as follows:

- **NO_3-N <16 lb/ac:** Apply 15 to 30 lb N/ac to establish the crop
- **NO_3-N >16 lb/ac:** No N fertilizer is needed to establish the crop

The remainder of the total N should be applied in the spring in two applications. The first should be made at “green up” when growth resumes (approximately Feekes growth stage 3) in the spring based on tiller density measurements as described in Table 2.

Table 2. Nitrogen rate recommendations for early spring greenup application to wheat at Feekes growth stage 2-3.

	Tiller Density (tillers/ft^2) at Feekes 2-3						
	<60	68	75	83	90	98	>105
lb N/ac	60	50	40	30	20	10	0

Make the second spring application just prior to the period of rapid N uptake at Feekes growth stage 5 (stem elongation) based on results of a whole plant tissue test as described in Table 3. Cut the whole plant ½ inch above the soil line at Feekes 5 growth stage and submit to a reputable lab for analysis.

Table 3. Nitrogen rate recommendations for second spring application to wheat at Feekes growth stage 5.

	Percent N in Tissue from Whole Plant Sampled at Feekes’ 5						
	<2.0	2.5	3.0	3.5	4.0	4.5	>5.0
lb N/ac	120	100	80	60	40	20	0

Crops receiving spring in in two applications often produce higher yields than when spring N is applied as a single application. Logistics may force a grower to make only a single application at greenup instead of splitting the spring applications. If a tiller count at greenup is >105 tillers/ft^2, the single spring application should be made at Feekes 5 based on a tissue analysis (Table 3). If the greenup tiller count shows immediate need for N, apply N immediately based on the NO_3-N analysis of a soil sample taken to a depth of 3 feet (Table 4).

Table 4. Nitrogen rate recommendations for a single early spring greenup application to wheat at Feekes growth stage 2-3.

	Soil NO_3-N to 3-foot depth in Jan/Feb (lb/ac)						
	<25	**50**	**75**	**100**	**125**	**150**	**>165**
lb N/ac	120	100	80	60	40	20	0

When planting into fields where manure has been applied, determine the plant available N (PAN) for the manure application and reduce fertilizer N rates as appropriate.

Phosphorus

Phosphorus (P) fertilization is based on the results of a routine soil test (Table 5). Soil test results are reported as a fertility index value (FIV).

Table 5. Broadcast phosphorus application rates for wheat.

	M3-P (UD FIV)										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb P_2O_5/ac	140	120	100	80	60	40	30	30	30	20	20

1. If M3 soil test phosphorus (M3-P) is “Low” (e.g., 25 FIV or less), broadcast and plow down the recommended rate of phosphate prior to planting in the fall.
2. If M3-P is “Medium or “Optimum” (e.g., 26 to 100 FIV), phosphate can topdressed in the fall or the spring.
3. If M3-P is “Excessive” (e.g., greater than 100 FIV), the application of P in fertilizers or manures is NOT RECOMMENDED.
4. Soil test P may decline more rapidly when straw is removed than when straw is left behind as stubble since P removal from the site is greater. Growers may wish to soil test more frequently to monitor changes in soil test P.

Potassium

The need for potassium (K) fertilization is determined by a routine soil test (Table 6). Soil test results are reported as a fertility index value (FIV).

Table 6. Recommended potassium application rates for wheat.

	UD FIVs										
	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
lb K_2O /ac	140	120	100	80	60	40	30	30	30	20	20

1. Broadcast and incorporate or band potash prior to planting.
2. For banded applications, reduce the rates in Table 5 by one-half.
3. To avoid salt injury to seedlings, do not band more than 75 lb/ac of K_2O at planting. When N and K_2O are banded together, the sum of the N rate and the K_2O rate should not exceed 75 lb/ac.
4. Since most wheat is followed by a double crop, sufficient K for both crops can be applied to the wheat to meet the needs of both crops. This will reduce application costs plus allow the grower purchase K at the time of the year when fertilizer K prices are typically at their yearly low.

5. Soil test K may decline more rapidly when straw is removed than when straw is left behind as stubble since K removal from the site is greater. Growers may wish to soil test more frequently to monitor changes in soil test K.

Magnesium

The need for magnesium (Mg) fertilization is determined by a routine soil test (Table 7); Mg needs are often met by liming. Soil test results are reported as a fertility index value (FIV).

Table 7. Recommended application rates of soluble magnesium to wheat as a function of Mehlich-3 soil test Mg fertility index value.

Soluble Mg	**UD FIVs**								
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
lb soluble Mg/ac	80	70	60	50	40	30	20	10	0

1. Magnesium (Mg) is recommended when M3 soil test Mg (M3-Mg) is less than 40
2. If M3-Mg is less than 40 FIV and lime is recommended, use dolomitic limestone.
3. If M3-Mg is less than 40 FIV and lime is not needed, apply soluble Mg according to the rates in Table 6, below.

Sulfur

Sulfur (S) deficiency is occasionally observed in wheat grown on Delaware soils. Symptoms include reduced growth and a general yellowing of the plant. To confirm diagnosis, have a tissue test run. Cut the whole plant ½ inch above the soil line at Feekes 5 growth stage and submit to a reputable lab for analysis.

1. If the N:S ratio in plant tissue is greater than 15:1, apply 25 to 35 lb S/ac with the first N application in the spring.

Prediction of S deficiency is difficult. Currently available soil tests are not good predictors of S deficiency situations because only surface soil samples are analyzed. Many Delaware soils have a supply of plant available S in subsoil horizons that will not be detected in soil samples taken from shallower depths. Subsoil sampling to a depth of 24 inches is highly recommended as a means of identifying soils with subsoil reserves of S.

Long-term applications of ammonium sulfate or other acid-forming fertilizers may lower pH of the soil surface and require correction with lime. Monitor surface pH with a 0- to 2-inch soil sample, especially in no-till systems. Also remember that sulfate-S is available for crop uptake immediately after application. If a reduced form of S is applied (e.g., thiosulfate or elemental S), allow adequate time for oxidation of the applied S to the sulfate form to occur.

Manganese

Manganese (Mn) needs are predicted by an availability index (MnAI) that includes M3 soil test Mn (M3-Mn) and soil pH. Interpretation of MnAI is crop specific. Wheat is a Mn sensitive crop. Soil test Mn results are reported in lb/ac.

$$MnAI = 101.7 - (15.2 \times \text{soil pH}) + (2.11 \times \text{M3-Mn})$$

Where:

MnAI = Mn availability index
Soil pH = Soil pH measured in water (1:1 V:V)
M3-Mn = Mehlich 3 soil test Mn in lb/ac

Table 8. Interpretation of Mn availability index for wheat.

Mn Availability Index	Interpretation
Less than 25	Mn deficiency is likely at this soil pH and soil test Mn concentration
25 to 35	Mn deficiency is possible at this soil pH and soil test Mn concentration. Monitor the crop for symptoms, especially if liming has been recommended.
Greater than 35	Mn deficiency is unlikely.

1. If Mn deficiency is predicted or was observed in the previous growing season, broadcast Mn at a rate of 20 to 30 lb/ac.
2. Broadcast applications of acid forming fertilizers may correct Mn deficiency without the actual application of Mn in some cases but may be less effective than applications of Mn.
3. If Mn deficiency symptoms appear during the growing season or after an application of lime, a foliar application of 1.0 to 2.0 lb/ac actual Mn as Mn sulfate, Mn oxide or chelated Mn can alleviate the symptoms and restore yield potential. Foliar applications can be applied before fall dormancy or after growth resumes in the spring. ***Apply only when adequate growth is present to aid absorption of foliar Mn.***

NOTE: When using foliar application to correct Mn deficiency, growers may combine the treatment with a post emergence herbicide application to reduce the number of trips across the field. Sulfate containing forms of Mn (e.g., manganese sulfate [Techmangam] and manganese-lignin-sulfate) may be antagonistic to weed control with Roundup™. To overcome this antagonism, growers should add ammonium sulfate at a rate of 17 lb per 100 gallons of solution. Chelated-Mn (Mn-EDTA) has shown a slight degree of antagonism but little to no reduction in weed control was noted in the field studies.

Zinc

Zinc (Zn) deficiency is predicted by an availability index (ZnAI) that includes M3 soil test Zn, soil pH, and M3 soil test P. Soil test Zn results are reported in lb/ac. Zinc deficiency is most common on soils with a pH of 6.5 or higher and high soil test P concentrations but may also be induced by environmental conditions such as cold, wet soils that may limit root growth. Zinc deficiency symptoms often appear early in the season and disappear as root growth increases or environmental conditions improve. See Table 9 to determine if Zn deficiency is predicted for this field.

Table 9. Interpretation of zinc availability index for wheat.

Soil Test Criteria	Interpretation
M3-Zn is less than 1.9 lb/ac	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is higher than 7.0	Zn deficiency is predicted
M3-Zn is less than 3.1 lb/ac **AND** soil pH is 6.6 or higher **AND** M3-P is 100 FIVs or higher	Zn deficiency is predicted
M3-Zn is 3.2 lb/ac or higher	Soil should be sufficient in Zn

If Zn deficiency is predicted by the availability index or was observed the previous year, one of the following treatments can be applied:

1. Broadcast 10 to 12 lb/ac actual Zn as Zn sulfate or Zn oxide or 2 to 3 lb/ac actual Zn as Zn chelate. Broadcast applications should correct Zn deficiency for several years.

2. Foliar application of 1 lb/ac actual Zn as Zn sulfate or Zn oxide or 0.5 lb/ac actual Zn as Zn chelate in 20 to 50 gallons of water. ***Apply only when adequate growth is present to aid in the adsorption of foliar Zn.*** Application should be repeated if symptoms re-appear.

Boron

Boron deficiency is not usually observed in wheat. If B deficiency symptoms appear, contact your county agent for assistance with diagnosis and corrective recommendations.