

Ohio Agronomy Guide

15th Edition

Bulletin 472



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COLLEGE OF FOOD, AGRICULTURAL,
AND ENVIRONMENTAL SCIENCES

Ohio Agronomy Guide, 15th Edition

To: Ohio Farmers and Agricultural Industry Personnel

From: The Authors



The agronomic crop scientists at The Ohio State University are pleased to present the 15th edition of the Ohio Agronomy Guide. First published in 1966, the Ohio Agronomy Guide continues to serve as the official compilation of adaptive research results and recommendations from research and educational programs.

Ohio agronomic research programs are designed to determine responses of various crops and cropping systems to management practices and resource inputs, as well as to understand the basic biological and chemical mechanisms responsible for these responses. This basic research thrust allows us to model cropping systems and predict their behavior under a variety of management schemes. Our aim is also to continue developing technologies and cropping systems that are efficient in capturing solar energy, sustainable over time, and environmentally compatible.

This 15th edition contains updates to the previous publication. Additionally, three new chapters have been added: “Considerations for Using Cover Crops” (Chapter 10), “Conducting On-Farm Research” (Chapter 11), and “Precision Agriculture” (Chapter 12). We will continue to supplement the information in this guide with other publications and fact sheets as necessary. For additional details and assistance, contact your local county Extension educator or one of the authors. We welcome your suggestions and input for improvement of both this publication and our research and educational programs.

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Chapter 1

Ohio's Climate and Soil

By Mr. Jim Noel and Dr. Ed McCoy



OHIO IS SITUATED between the Appalachian Mountains to the east, the Gulf of Mexico to the south and the Great Lakes to the north. In addition, the Ohio Valley is near the jet stream where the warm moisture air to the south collides with the colder and drier air from Canada. This is a perfect setup for a storm track through the region. For Ohio, this means frequent periods of wet conditions mixed with short but intense dry periods in an overall active

weather and climate environment. This active environment yields severe storms, floods, droughts, and almost the entire climate spectrum.

Mean annual air temperatures for Ohio are in the lower 50s but have steadily increased from about 50 degrees Fahrenheit prior to 1975 to near 52 degrees Fahrenheit today (Figure 1-1).

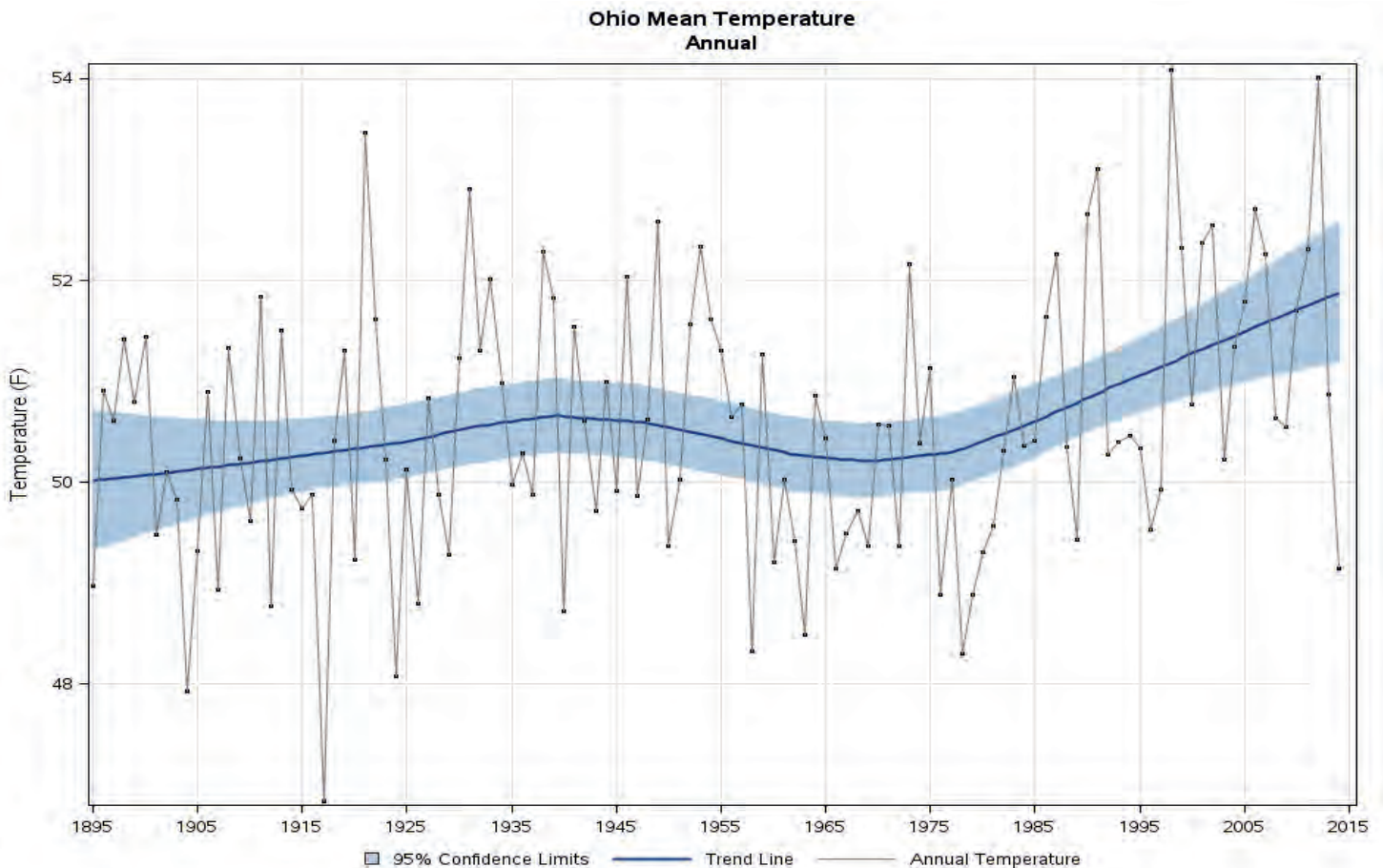


Figure 1-1. Ohio mean annual temperatures 1895-2015.

Source: NOAA NCEI, ncdc.noaa.gov/temp-and-precip/state-temps/.

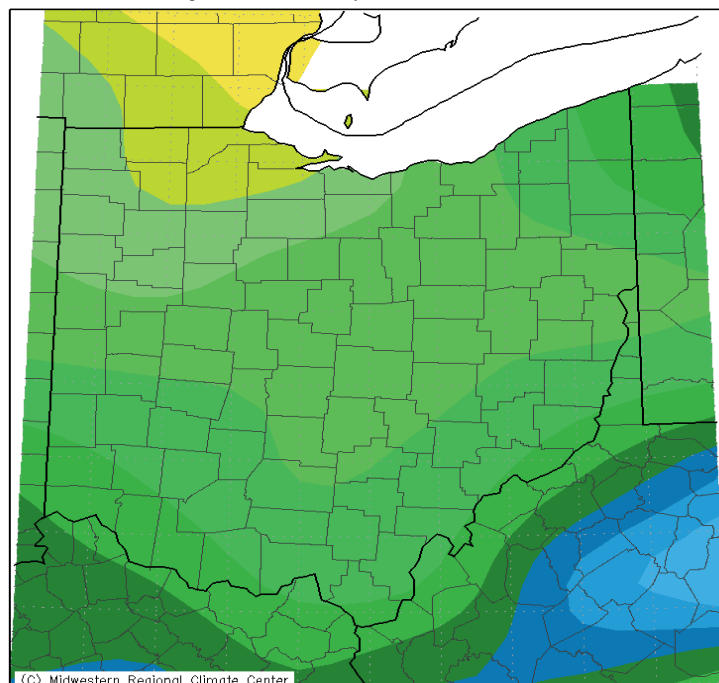
Typical winter maximum temperatures are in the 30s (lower north and upper south) to the 80s in summer (lower north and upper south). Typical winter minimum temperatures are in the upper teens in northern Ohio to the 20s in southern Ohio. Minimum temperatures reach a peak in the summer in the 60s (lower north to upper south).

Normal annual precipitation ranges from below 35 inches in northwest Ohio to just below 45 inches near the Ohio River (Figure 1-2).

Figure 1-2. Ohio annual precipitation. Source: NOAA Midwest Regional Climate Center. Illinois State Water Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, mrcc.isws.illinois.edu/.

Accumulated Precipitation (in): January 1 to December 31

Averaged over 30 years: 1981 to 2010



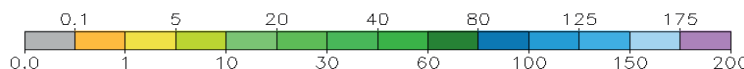
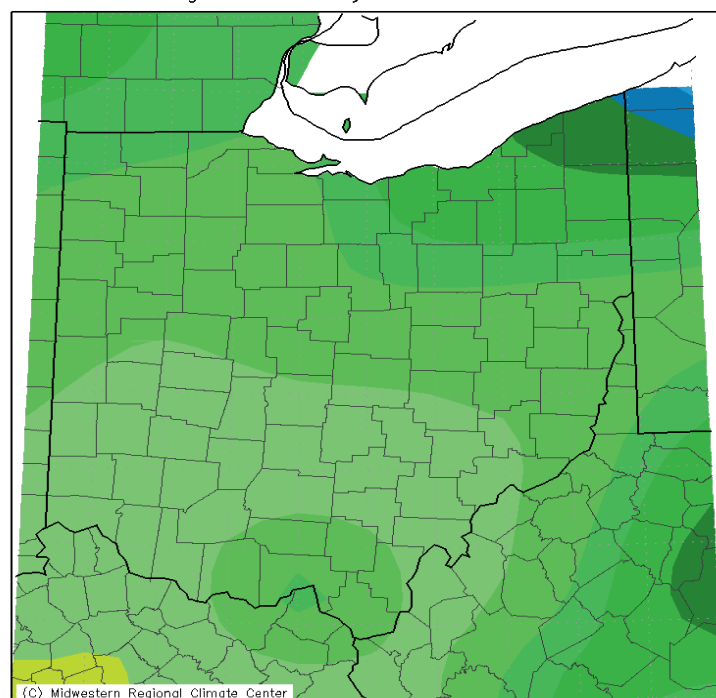
Midwestern Regional Climate Center
cli-MATE: MRCC Application Tools Environment
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Ohio's annual snowfall is greatly impacted by a combination of lake effect snow off the Great Lakes, especially Lake Erie, and the storm track up the Ohio Valley. Snowfall ranges from below 20 inches in southern Ohio to 30 to 50 inches in northern Ohio. Snowfall tops 80 inches annually in lake effect areas of northeast Ohio (Figure 1-3. mrcc.isws.illinois.edu/).

Figure 1-3. Ohio annual snowfall. Source: NOAA Midwest Regional Climate Center. Illinois State Water Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, mrcc.isws.illinois.edu/.

Accumulated Snowfall (in): January 1 to December 31

Averaged over 30 years: 1981 to 2010



Midwestern Regional Climate Center
cli-MATE: MRCC Application Tools Environment
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In autumn, the median date of the first freeze ranges from before October 10th in northwest Ohio to after October 20th in parts of southern Ohio and near Lake Erie around Cleveland (Figure 1-4).

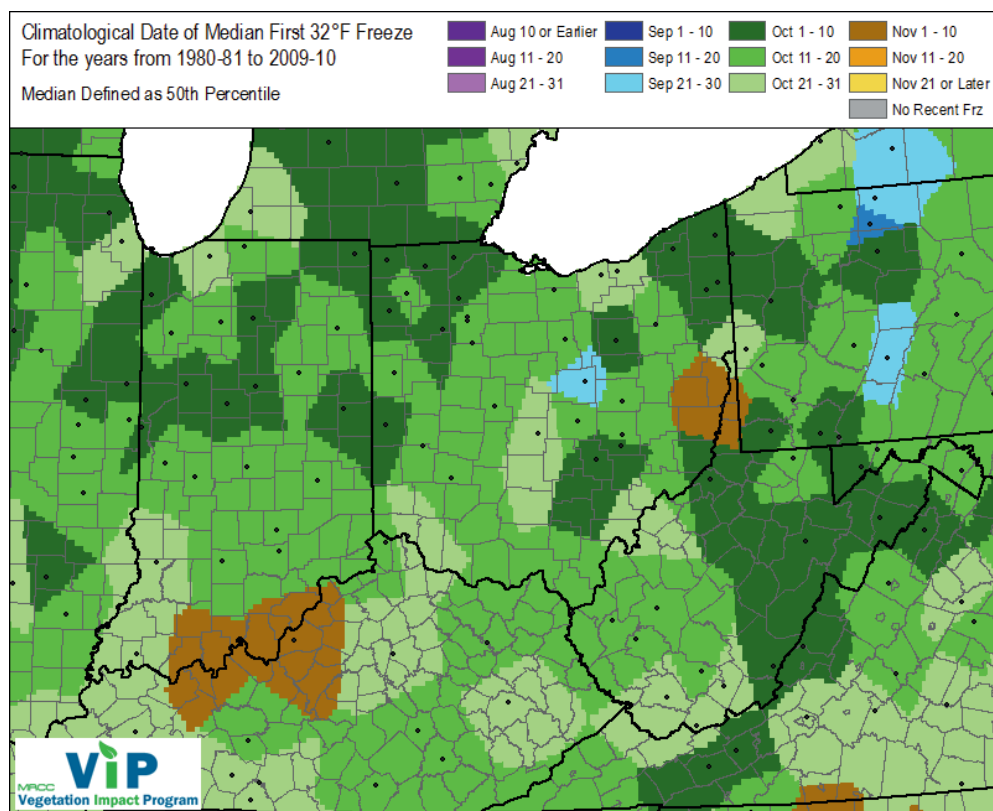


Figure 1-4. Ohio median date for first freeze autumn (32 F). Source: NOAA Midwestern Regional Climate Center. Illinois State Water Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, mrcc.isws.illinois.edu.

In spring, the median date of the last freeze ranges from around April 15th in southern Ohio to April 25th in northern Ohio. However, in far northwest Ohio and northeast Ohio this date often is not reached until early May (Figure 1-5).

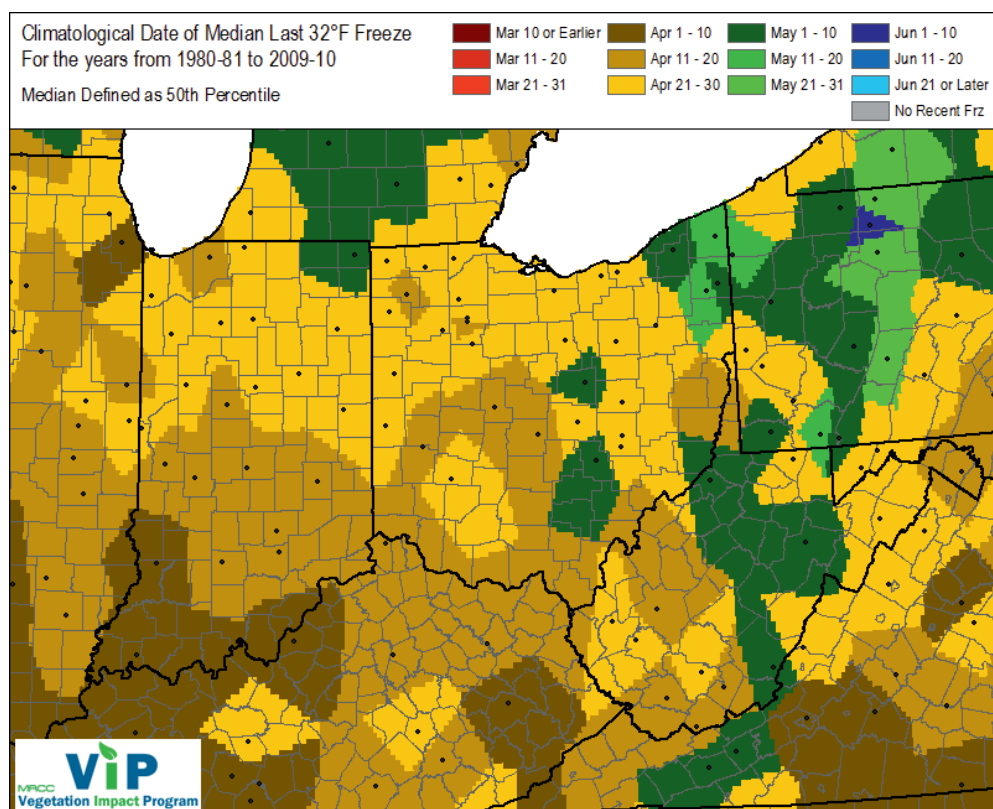


Figure 1-5. Ohio median date for last freeze spring (32 F). Source: NOAA Midwestern Regional Climate Center. Illinois State Water Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign.

Droughts in Ohio from a climate perspective tend to be short in duration compared to other parts of the country and world. Ohio typically experiences drought on a time-scale most often less than one year in duration and tend to have a fast onset, be intense, and then quickly end. This has a lot to do with the location of Ohio relative to moisture sources such as the Gulf of Mexico and the Atlantic Ocean. Further, the active jet stream nearby tends to keep droughts short-lived in Ohio. Droughts most often occur in Ohio in the warm season when high temperatures combine with excessive evapotranspiration loss for onset of rapid drought.

During the growing season from April to September, soils transition from wet to drier. Most soils in Ohio are saturated during March and early April. Although growing season

rainfall varies from 18 to 26 inches on average, it may not be adequate for maximum yield unless effective water management practices are used throughout the growing season. Soil moisture declines during June, July, and August; by the end of August, available soil moisture is usually reduced by 80 percent or more.

Some agronomic crops (such as corn) progress through the various growth stages in response to heat units or growing degree days (GDD). Table 1-1 shows the GDD for several sites in Ohio starting at various dates in May through the 10 percent frost date in the fall. The information in this table is useful in predicting when corn hybrids with varying heat unit requirements will reach various growth stages.

Table 1-1: Growing Degree Days (GDD) for Various Sites in Ohio from Several Dates in May Through the 10 Percent Frost Date in the Fall.

Station Name	Day in May					Station Name	Day in May				
	1	8	15	22	29		1	8	15	22	29
Akron-Canton	2324	2250	2176	2102	2028	Dorset	1977	1915	1852	1790	1728
Ashland	2650	2570	2489	2408	2327	Eaton	2769	2678	2588	2497	2407
Athens	2763	2663	2563	2463	2363	Elyria	2682	2603	2524	2445	2368
Barnesville	2391	2311	2231	2152	2072	Fernhank Dam	3324	3215	3107	2998	2889
Bellefontaine	2779	2691	2603	2514	2426	Findlay	2598	2518	2437	2357	2276
Bowling Green	2805	2718	2630	2542	2454	Franklin	2896	2796	2696	2596	2496
Bucyrus	2525	2444	2363	2282	2201	Fredricktown	2372	2293	2213	2134	2054
Cadiz	2820	2731	2642	2553	2464	Fremont	2828	2741	2655	2568	2481
Caldwell	2814	2718	2621	2524	2427	Gallipolis	3160	3045	2931	2816	2701
Cambridge	2676	2582	2488	2395	2301	Geneva	2525	2460	2395	2330	2265
Canfield	2277	2208	2138	2069	2000	Greenville	2707	2621	2535	2449	2365
Carpenter	2791	2691	2590	2489	2388	Hamilton	3132	3024	2915	2807	2698
Celina	2782	2687	2592	2497	2401	Hillsboro	2931	2835	2738	2642	2546
Centerburg	2501	2416	2331	2246	2161	Hiram	2460	2409	2338	2267	2196
Chardon	2434	2366	2298	2230	2162	Hoytville	2623	2535	2447	2359	2272
Charles Mill	2245	2176	2106	2037	1968	Ironton	3359	3240	3121	3002	2884
Chillicothe	3158	3049	2940	2831	2722	Irwin	2574	2487	2400	2313	2226
Chilo	3099	2994	2890	2785	2681	Jackson	2739	2638	2536	2434	2332
Chippewa Lake	2389	2313	2237	2161	2085	Kenton	2604	2523	2443	2362	2281
Cincinnati-Abbe	3391	3283	3175	3067	2959	Lancaster	2750	2654	2557	2461	2364
Circleville	3023	2917	2811	2704	2598	Lima	2706	2617	2529	2441	2353
Columbus-OSU	2777	2683	2590	2496	2403	London	2755	2665	2576	2487	2398
Coshocton	2787	2691	2596	2500	2404	Marietta	2918	2818	2719	2619	2520
Dayton	3237	3125	3014	2903	2792	Marion	2721	2629	2538	2447	2356
Defiance	2570	2489	2408	2327	2246	Marysville	2630	2545	2460	2375	2291
Delaware	2726	2637	2547	2457	2367	McConnelsville	2898	2805	2712	2618	2525
Dennison	2491	2405	2319	2233	2147	Millersburg	2528	2444	2360	2276	2192

Table 1-1 Continued

Station Name	Day in May				
	1	8	15	22	29
Millport	2182	2111	2041	1971	1901
Mineral Ridge	2513	2433	2354	2274	2194
Montpilier	2684	2580	2495	2411	2327
Napoleon	2692	2610	2528	2446	2365
NC-Substation	2510	2427	2344	2261	2179
Newark	2636	2545	2455	2365	2275
New Lexington	2595	2504	2412	2321	2229
Norwalk	2569	2490	2411	2332	2254
Oberlin	2618	2539	2459	2380	2301
Painesville	2642	2575	2509	2442	2376
Pandora	2518	2435	2351	2268	2185
Paulding	2651	2567	2484	2400	2317
Peebles	2898	2795	2691	2587	2483
Philo	2885	2784	2682	2581	2480
Plymouth	2569	2491	2412	2333	2254
Portsmouth	3476	3353	3231	3109	2987
Put-in-Bay	3087	3013	2939	2865	2791
Ravenna	2185	2112	2040	1967	1894
Sandusky	3030	2946	2863	2779	2696
S. Charleston	2617	2505	2394	2283	2172
Senecaville Dam	2497	2408	2319	2229	2140
Sidney	2653	2567	2481	2395	2308
Springfield	3103	3002	2900	2799	2697
Steubenville	2837	2747	2657	2567	2477
Tiffin	2762	2675	2587	2500	2412
Tom Jenkins	2150	2072	1994	1916	1838
Upper Sandusky	2721	2632	2543	2453	2364
Urbana	2622	2535	2449	2362	2276
Van Wert	2778	2688	2598	2509	2419
Warren	2559	2479	2398	2318	2237
Washington CH	2909	2812	2716	2619	2523
Wauseon	2516	2439	2362	2285	2208
Waverly	2917	2811	2706	2600	2495
Wilmington	2958	2856	2754	2653	2551
Wooster	2350	2277	2205	2132	2059
Xenia	2893	2794	2695	2596	2496
Zanesville	2351	2266	2181	2096	2011

Soil Formation and Soil Properties

Soils are continuous over the earth’s surface, except on steep and rugged mountains, areas of perpetual ice and snow, extreme deserts, and salt flats. Soils are formed by the weathering of parent materials that are deposited or accumulate by geological activity. The two major stages in soil formation are (1) the accumulation of parent material, and (2) the differentiation of horizons within the soil profile.

Soil characteristics depend on the interrelationships of five soil-forming factors: (1) physical and mineralogical composition of the parent material; (2) climate under which the material was accumulated and has existed since accumulation; (3) plant and animal life in and on the soil; (4) relief, or lay of the land; and (5) length of time weathering has acted on the soil material. Because different factors dominate in different regions, many different kinds of soil are formed.

Four basic changes occur in the soil system: (1) additions, (2) removals, (3) transfers, and (4) transformations. The intensity of soil-forming processes, now and in the past, has determined the degree of layer or horizon differentiation and the soil properties and characteristics we observe today. Soils are identified, described, and classified by their physical and chemical property characteristics which are measured and determined by using laboratory tests.

Soil Properties and Crop Management

The physical and chemical properties of a soil greatly affect crop yields. The following soil properties determine how well a crop performs on a given soil and the best cultural and management practices to use for its production.

- Organic matter content
- Soil texture
- Subsoil pH
- Water in the soil available to plants
- Slope of the topography
- Natural soil drainage

Organic Matter Content

Excluding muck and peat soils, the amount of organic matter in mineral soils ranges from about 1 to 20 percent in the topsoil. Most Ohio soils range from 1 to 6 percent. The organic matter content in most light-colored soils is between 1.5 and 3 percent, while a large proportion of the dark-colored soils contains between 3 and 6 percent. Organic matter content decreases markedly with soil depth.

In light-colored soil, the organic matter content below the plow layer is usually between 0.5 and 1 percent, and at depths of 20 or 30 inches only trace amounts exist. In dark-colored soils, the organic matter content is commonly

between 1 and 3 percent immediately below the plow layer and decreases with depth to less than 0.5 percent at 24 inches of depth.

Soil organic matter provides nitrogen, phosphorus, and some micronutrients for crop production as the organic matter is oxidized or decays. The level of organic matter in the soil cannot be changed easily. Most crops produce less than 4 tons of dry matter per acre annually, which is less than 0.4 percent of the total soil mass in 8 inches depth over an acre. Only a small portion of the crop dry matter will actually become organic matter. If large volumes of manure—200 to 300 tons per acre—were applied annually, a significant change in organic content might be achieved, particularly in coarse-textured soils.

Historically, when forages were part of the crop rotation, nutrient release and soil tilth increased due to the season-long production of roots. Currently, well fertilized, high-yielding grain crops return large volumes of residue to the soil and are a source of nutrients. On medium-textured soils low in organic matter, crop residues are usually more beneficial when left on the surface than when incorporated. During the growing season this surface residue reduces the formation of soil crusts and results in increased water infiltration and higher crop yields. Crop residue on the surface of fine-textured soils such as silty clay loam, clay loam may delay planting by delaying soil drying.

Soil Texture

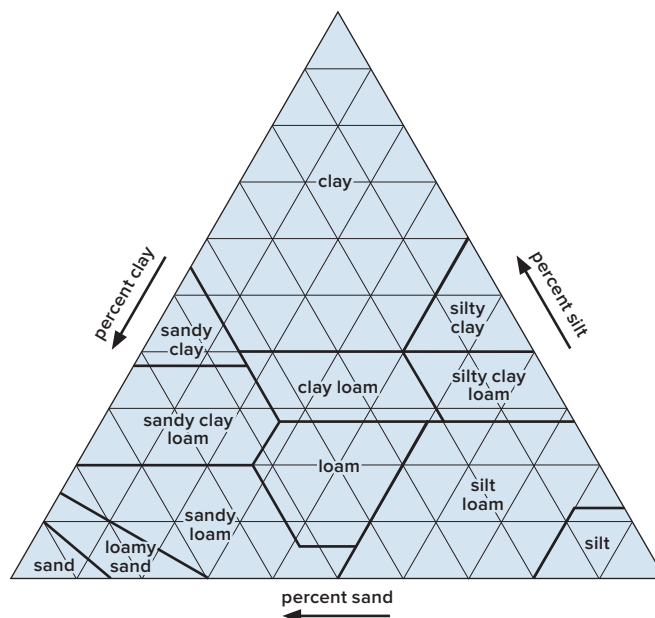
The relative amounts of sand, silt and clay in the soil determines soil texture. The soil texture classes, in order of decreasing particle sizes (coarse to fine), are as follows:

1. Sand
2. Loamy sand
3. Sandy loam
4. Loam
5. Silt loam
6. Silt
7. Sandy clay loam
8. Clay loam
9. Silty clay loam
10. Sandy clay
11. Silty clay
12. Clay



Figure 1-6 shows the ranges of sand, silt, and clay in each soil texture class. Sand is the largest soil particle, ranging in diameter from 0.08 to 0.002 inch; clay is the smallest particle, with a diameter of less than 0.00008 inch.

Figure 1-6. The soil texture triangle.



The soils on Ohio farmland predominately have textures classified as loam, silt loam, and clay loam as seen in Table 1-2.

Table 1-2: Acreage of Soils with Various Textures on Ohio Farmland.

Soil Texture Class	Acreage	Percentage of Farmland
Sand, loamy sand, loamy fine sand	670,666	3
Sandy loam, fine sandy loam	312,729	1
Loam, silt loam	17,844,103	77
Silty clay loam, clay loam	3,574,255	15
Silty clay, clay	986,708	4

The surface area of soil particles is also important and varies with soil particle size as indicated in Table 1-3. As the soil particle size decreases, surface area in a given volume of soil increases. Soil surface area determines the amount of nutrients that can be held in the soil. Clay has a large surface area and has negatively charged particles. These negative charges are measured as exchange activity for cations such as Ca⁺⁺, K⁺, and others, and collectively is called the cation exchange capacity (CEC).

Table 1-3: Soil Particle and Surface Area.

Particle Size	Surface Area (sq ft/lb of soil)
Sand	100
Silt	400
Clay	10,000

Soils containing more than 50 percent silt usually have a weak structure and crust easily. This crust contributes to water runoff, sedimentation problems, and reduced gas exchange. A rough soil surface or a residue cover, however, can mitigate this problem. Crop residues should remain on the surface during the fall and early winter to improve water intake and recharge soil moisture on adequately drained soils. During the growing season, runoff will occur if the soil surface is not porous enough to allow water intake. Shallow cultivation of row crops reduces soil crusting and increases water intake and gas exchange where residue cover is absent. A residue cover on at least 80 percent of the surface is more effective than cultivation for these purposes.

Clay or fine-textured soils may crust, but the crust typically fractures on drying because some types of clay change volume when they dry, and this also improves soil structure. Soil moisture recharge on clay-textured soils usually produces no serious problem. However, plowing late in the spring, when soil moisture is high, may produce soil clods and prevent the preparation of a desirable seedbed. In the absence of weeds, cultivation of these fine-textured soils during the growing season is not necessary for rapid water intake and gas exchange.

Soil texture also influences plowing depth. If the soil texture is fairly uniform to a depth of 12 inches, little alteration of the soil's physical condition may be gained from deep plowing. If the soil texture changes considerably from a silt loam to a clay texture at 8 to 10 inches, some caution should be exercised in increasing the plowing depth. Gradually plowing deeper and mixing these two materials is more desirable than plowing an additional depth of 3 to 4 inches in one year.

Subsoil pH

Naturally occurring alkaline parent materials become acidic as a result of leaching over long periods of time. Water moving through the soil, particularly in late winter and spring, removes soluble cations (such as Ca⁺⁺ and Mg⁺⁺) from the soil profile. After the cations have been leached, the removal of these basic elements exceeds the rate of production by weathering and the soil becomes acidic. The degree of soil acidity is, therefore, a result of the reaction of the soil parent material, the amount of water moving through the soil, and the length of time the water has been moving through the soil.

Soil reaction, commonly expressed as pH, is a measure of the intensity of acidity or alkalinity. Most Ohio soils have values ranging from pH 4.0 to pH 8.5. In strip mine spoils in southeastern Ohio, the pH may be as low as 2.0. The pH, or degree of acidity, of subsoils varies greatly among Ohio soils. Soils formed from similar parent material tend to have similar pH values (Table 1-4).

Terms commonly used to describe soil pH are as follows:

Below 4.5	Extremely acidic
4.5-5.0	Very strongly acidic
5.1-5.5	Strongly acidic
5.6-6.0	Medium acidic
6.1-6.5	Slightly acidic
6.6-7.3	Neutral
7.4-7.8	Mildly alkaline
7.9-8.4	Moderately alkaline
8.5-9.0	Strongly alkaline

Table 1-4: Soil pH by Depth for Two Soil Series.

Soil Series	Soil Depth (Inches)	Soil pH
Blount silt loam	0-9	6.4
	9-12	5.4
	12-21	5.4
	21-29	6.1
	29-33	7.2
Kokomo silty clay loam	0-7	6.1
	7-10	6.1
	10-14	6.3
	14 - 20	6.5
	20 - 29	7.1
	29 - 42	7.5

Plowing deeper than 7 or 8 inches on the light-colored Blount soil often lowers the pH of the plow layer due to the incorporation of the more acidic layer below. The pH of the new plow depth will be somewhat lower than the original plow layer because of the mixing of two soil layers having two different pH values.

Materials from which the Ohio soils developed had a wide range in pH. The parent materials in western and northwestern Ohio have high pH values and contain as much as 50 percent calcium carbonate or its equivalent. Eastern and southeastern Ohio soils, however, have developed mainly from acidic sandstones and shale, which have pH values as low as 5.0. Some bedrock strata associated with coal beds contain iron sulfates and are strongly acidic when first exposed to air. This oxidation of the iron sulfates may result in soil pH values as low as pH 2.0.

Soil Water Available to Plants

Water in the soil is held in voids, or pore spaces, and as thin films on the surface of soil particles. Normally the soil consists of about 50 percent pore space. When this pore

space is completely filled with water, the soil is saturated. When no more water will drain from the large soil pores—which occurs within one or two days after rainfall—the moisture level is described as being at field capacity. Much of the moisture held in the soil at this level is available for uptake by growing plants.

Soil moisture is considered low when it is present only in very small pores. Because water in small pores is held tightly, the energy available to roots for removing water is not sufficient to extract it at the rate that it is being transpired. When this condition exists, the plant leaves wilt or curl, and this soil moisture level is called the wilting point. The amount of soil water between field capacity and the wilting point is the available water-supplying capacity of the soil. Available water-supplying capacity is designated as inches of water per inch of soil, or as a percent by weight. This water is available to plants when root development and aeration are adequate for optimum plant growth.

An acre inch of water is approximately 27,000 gallons. Soils have available water capacities of from 4 to 8 inches in 4 feet of soil. As shown in Figure 1-7, texture influences the amount of water held in the soil. In this chart, the vertical distance between the wilting point and field capacity for each soil texture determines the available water supplying capacity. A silt loam or loam texture soil holds the largest amount of available water per inch of soil.

The moisture available for crop use includes the amount of water held by the soil as well as factors that influence how water moves into and through the soil. During the growing season, high-intensity rainfall infiltrates slowly into soils with textures having the greatest water-holding capacity. Fine sandy loam and silt loam soils, for example, have low infiltration rates. A lack of adequate clay, which is important for the development of a durable structure, contributes to low infiltration. Other factors that reduce infiltration include continued tillage of these soils, an increase in rainfall, and a sealing of the soil surface (which also increases runoff). Figure 1-8 illustrates the rate of infiltration of both fine- and medium-textured soils on corn seedbeds when the soils are initially dry.

Blount and Canfield are medium-textured soils with weak structure. The breaking down of the soil structure by raindrop impact greatly reduces the water infiltration rate. Hoytville soil, a fine-textured soil containing considerable clay and organic matter, maintains a high infiltration rate at the soil surface. The infiltration rate of the fine-textured soil is adequate to enable the infiltration of essentially all water from rainfalls of high intensity and short duration.

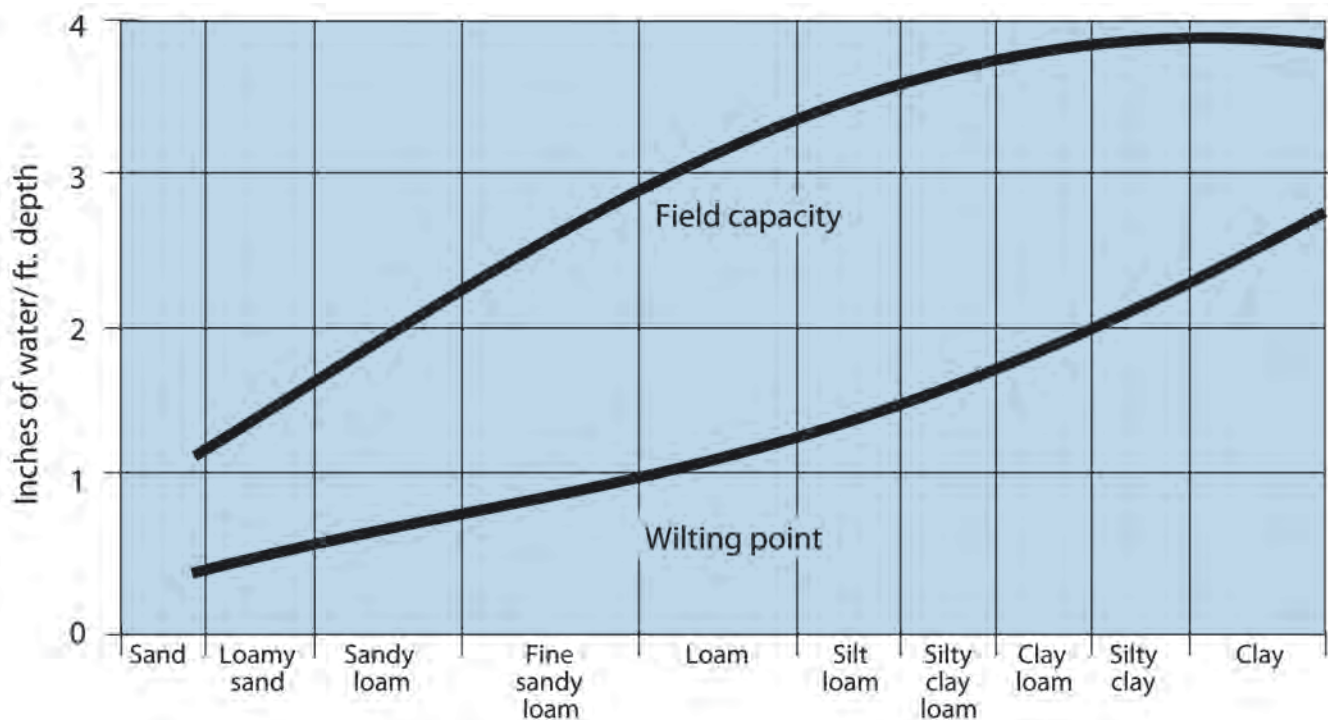
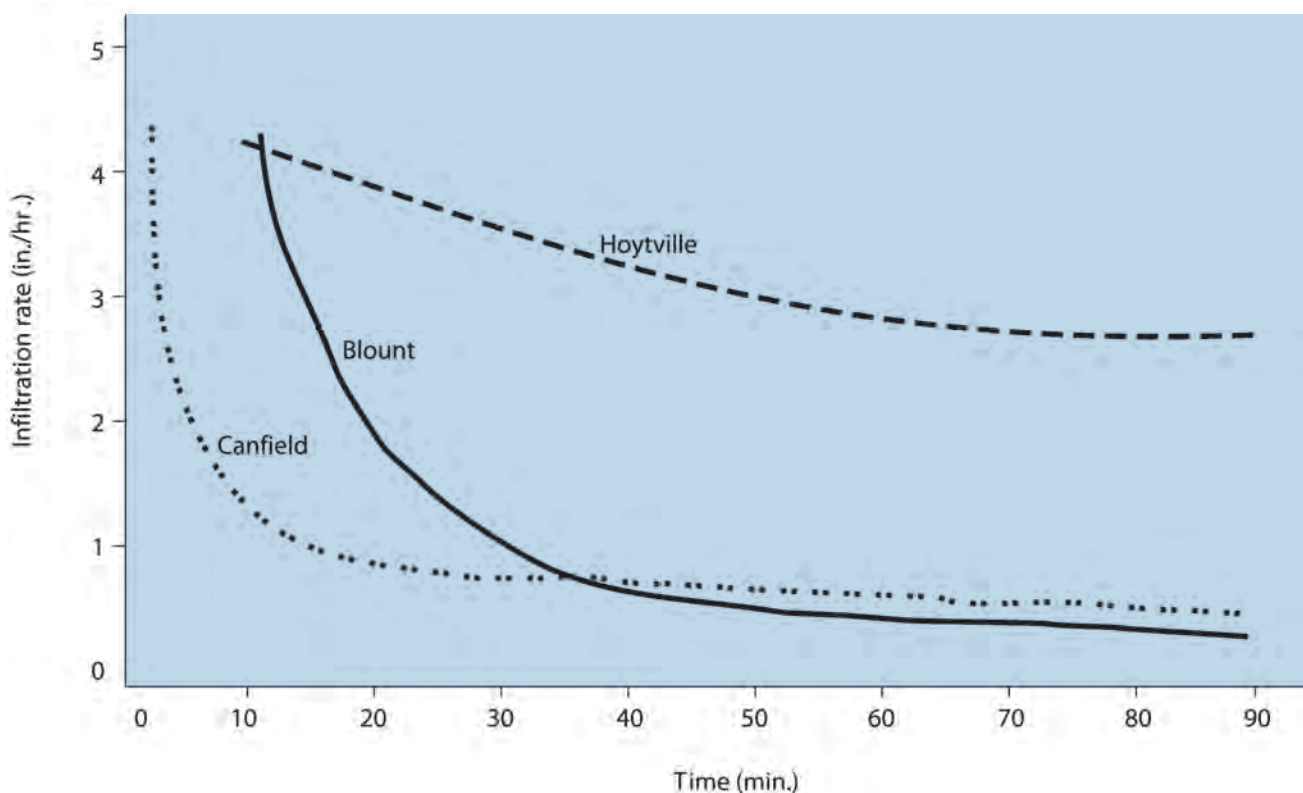


Figure 1-7. Available water capacity for 10 soil textures in inches of water per foot of soil.

Figure 1-8. Soil texture and rate of infiltration (OARDC).



Slope of the Topography

The topography of an area influences soil movement, soil depth, internal soil drainage, and other soil properties. Topography must be considered when determining the soil management practices and conservation measures for farming operations. Most agricultural soils in Ohio are on slopes ranging from nearly level to 18 percent (18 feet of height per 100 feet horizontal distance).

Movement of materials applied to the soil surface is directly related to its slope. Sloping topography contributes to movement of surface-applied material primarily because of low infiltration rates and surface runoff, either from frozen or crusted surfaces lacking adequate residue cover or surface roughness. Nearly level topography, where soil usually drains poorly, may also result in surface movement of materials by water when a saturated condition in the soil causes low infiltration and high runoff.

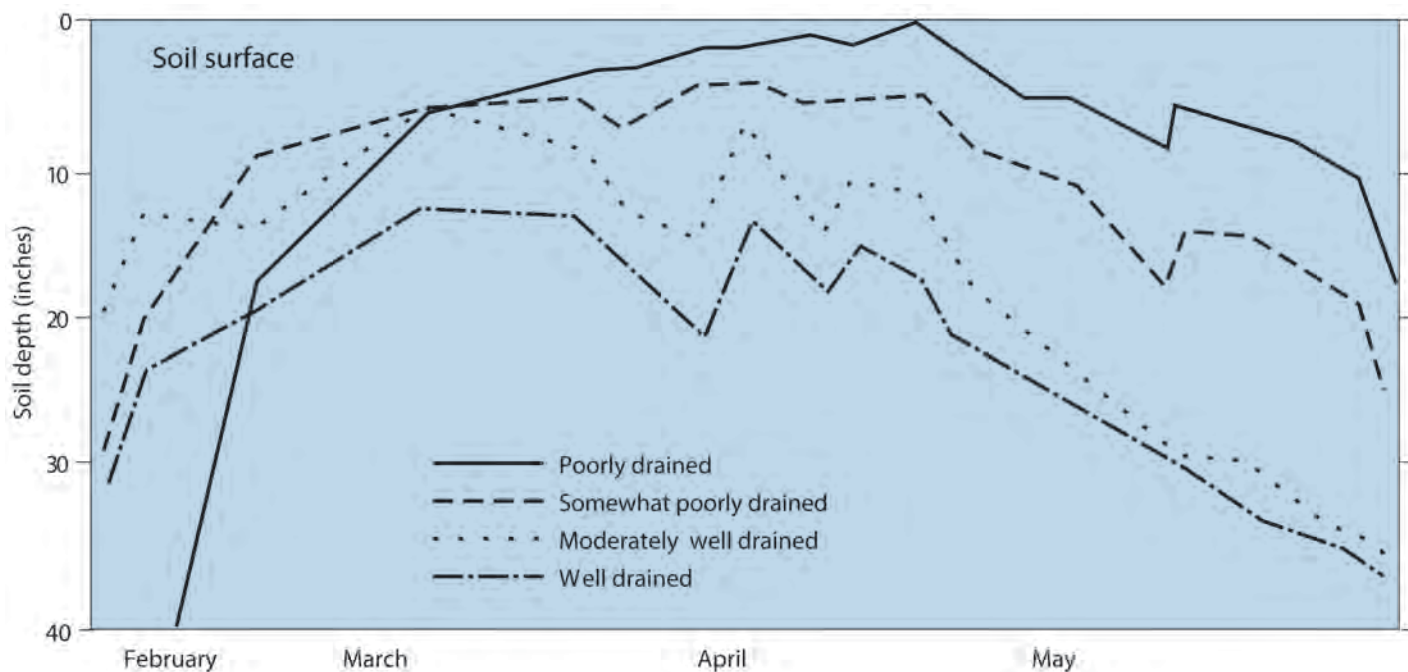
Slope aspect or direction of exposure may also influence surface runoff. Southern exposures have fluctuating temperatures, which affect freezing and thawing, while slopes with a northern exposure have more uniform temperatures during winter and spring. The slope also influences vegetative growth during summer. Southern slopes are warmer and drier, while northern slopes are cooler and have higher soil moisture contents.

Natural Soil Drainage

Most Ohio topsoils hold 1 to 2 inches of water in the plow layer. When the downward rate of water movement is restricted by fine-texture subsoils, hard pans or other impervious material, a saturated zone develops in which voids in the soil, normally containing air, fill with water. Saturated soil or poor drainage causes many problems and limits the uses of many soils. In the early history of Ohio, approximately 200 years ago, the extensive Black Swamp of northwestern Ohio was covered by swamp vegetation. After large ditches were used to drain this part of the state, it became an important agricultural area. Adequate soil drainage is the largest soil management problem in Ohio agriculture. Approximately 57 percent of the soils used for cropland in Ohio have a natural drainage limitation.

Not all Ohio soils, however, are poorly drained. The rate of water movement through some soils is adequate to prevent the buildup of a saturated zone of water within the root zone. These soils are commonly called well-drained soils. In moderately well-drained soils, saturated zones are present only during short periods in the spring. Other soils are referred to as somewhat poorly drained, depending on the location of the saturated zone in the soil and the length of time it is present. Figure 1-9 shows the occurrence of saturated zones in well-drained, moderately well-drained, somewhat poorly drained, and poorly drained Ohio soils during winter and spring.

Figure 1-9. Saturated zones of water in Ohio soils by depth and season. (Adapted from *Summary of Soil and Water Studies*, Ohio Department of Natural Resources, Division of Lands and Soil.)



For crop production to be profitable, soil drainage problems must be eliminated, using appropriate drainage measures, such as land smoothing and tiling.

Ohio Soil Regions

Ohio is divided into 12 soil regions (Figure 1-10). These regions are principally delineated by parent material properties and glaciation. Soil properties of Region 1 have been influenced by water impoundment during glaciation, which resulted in deposits of fine sediment in deeper areas of historic lakes and coarse sediments near lake margins. Textures of these soils range from fine (clay) to coarse (sand).

Soils in Region 2 have been influenced by successive levels of impounded water. The lake-plain soils of northeastern and northwestern Ohio were deposited at about the same time. The lake-plain soils of northeastern Ohio range from fine to coarse texture, but are generally more acidic than northwestern Ohio soils.

Soils of Region 3 were developed in glacial till containing considerable limestone material and clay. Textures of these soils range from medium (silt) to fine (clay). Soils of Region 4 reflect a lesser influence of clay compared with the fine-textured soils of Region 1. The glacial till is medium textured. The amount of silty material in these soils increases from the north to the south, with values of 65 to 70 percent silt in the plow layer being common in the southern part of this region.

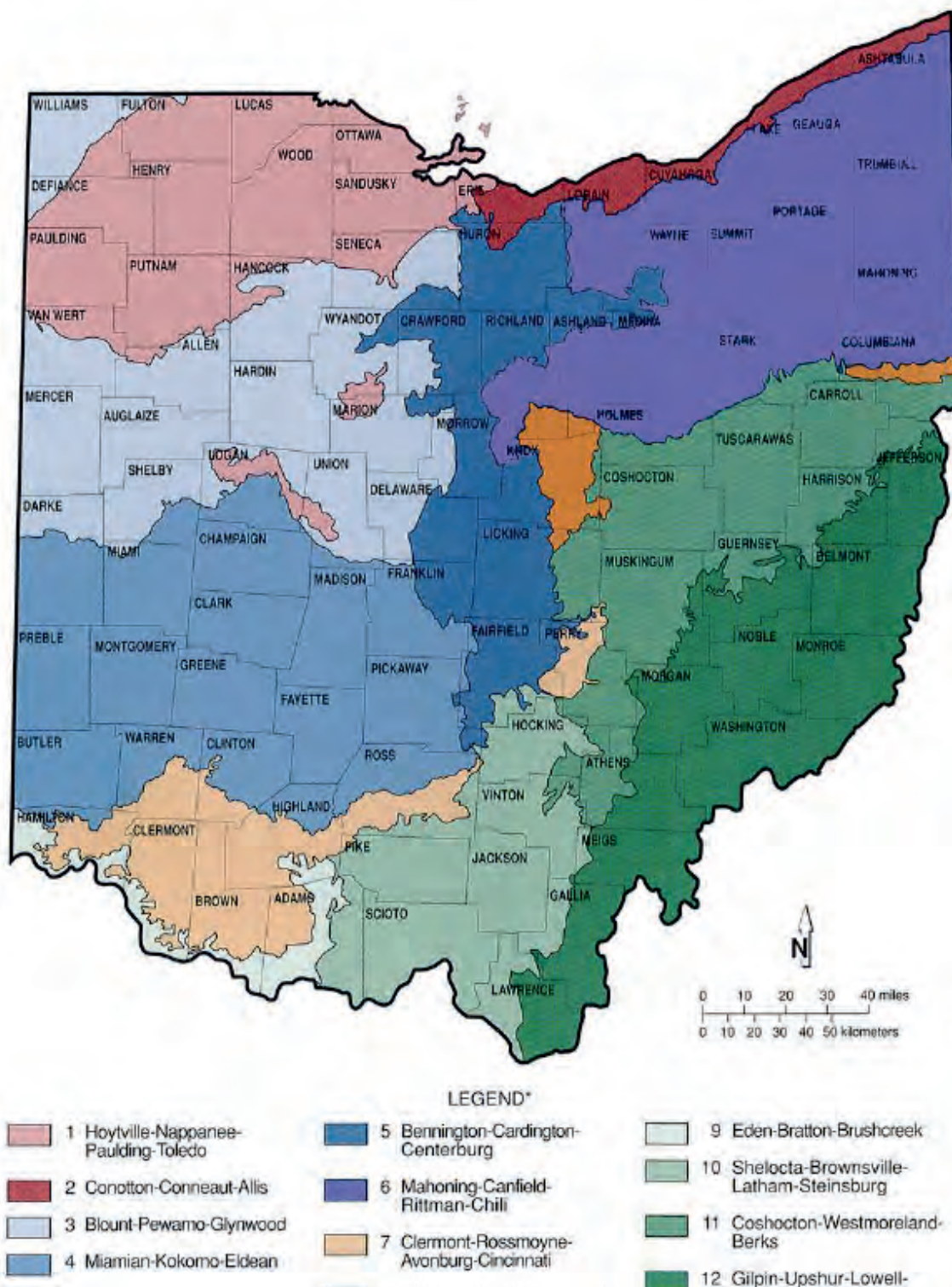
The glacial till in Region 5/6 is predominately medium textured, with some areas of fine texture. Calcium carbonate (lime) content of the glacial till increases from east to west with the eastern area containing mostly sandstone and shale fragments, and the western area containing considerable limestone. Two soil properties peculiar to some of the soils in this area are the high content of extractable aluminum, which increases lime requirements, and dense, medium-textured subsoil *pans*.

Region 7 is oldest glaciated area in Ohio. The soils in this region are extensively weathered and extend to a considerable depth. Topsoil usually extends to a depth of 10 to 12 inches; total soil depth may exceed 8 feet although soil below the 5-foot depth contributes little to plant growth. The topography in many areas of this region is relatively flat and has inadequate drainage, which results in slow or very slow water movement through the subsoil.

Region 9 soils are found in parts of Adams, Brown, and Highland counties. These soils were developed on sloping to steep, rolling topography in unglaciated areas of limestone and shale bedrock.

Regions 10 through 12 contain the residual soils of Ohio. Glaciation has had little influence on the soils in this area, with the exception of the alluvial or terrace soils formed from the movement of glacially derived material downstream into valleys. This soil region is in the foothills of the

Figure 1-10. Ohio soil regions. Source: ODNR.



*Soil regions are identified by the names of the soil series that are most common in each region.

Appalachian plateau, and topography ranges from nearly level to extremely steep. These soil regions are developed on weathered materials derived from sandstone, shale, and limestone. Because considerable mass movement of material has occurred on these slopes, many of the soils are mixtures of bedrock materials.

Available Data on Soil Properties

Find complete information on Ohio soils at the NRCS website: nrcs.usda.gov/wps/portal/nrcs/main/oh/soils/.

Chapter 2

Soil and Water Management

By Dr. Steve Culman, Dr. Ryan Haden and Dr. Jon Witter



Soil and water are two critical components of crop production. Agronomic crops depend on soil for physical support and to provide the water and nutrients necessary for optimum performance. The characteristics of Ohio soils can vary tremendously from location to location, even within the same field, and as soil characteristics change, management practices may have to be modified for optimum production and environmental protection. Producers should know how soil properties influence production and which management practices are best suited to the particular soil series found on their farms. Characteristics of the soil series found in Ohio can be found in the Soil Survey bulletins usually available from local Soil and Water Conservation District, OSU Extension or Natural Resource Conservation Service offices. Information for individual soil series is also available online at: agri.ohio.gov/divs/SWC/SWC.aspx.

Efficient water management is perhaps the most important aspect of crop production. Crop yields are affected adversely by the presence of too much or too little water, and unfortunately, many Ohio producers are faced with both problems in the same year. In a typical year, precipitation exceeds crop water use in winter, spring, and autumn. During the spring, excess soil water may even interfere with field operations and early crop development. During summer months, however, crop needs often exceed precipitation, and the crop must rely on water stored in the soil from previous rains. Therefore, an ideal water management system permits maximum intake and storage of water in the soil profile, but also provides a means of draining any excess water quickly from the soil.

Drainage—The Critical Factor

Drainage class is probably the most important soil characteristic influencing choice of management options, and failure to consider drainage when planning production programs is a common reason for poor crop performance. The term “drainage” refers to how long during the year soils are saturated at or near the soil surface. Many subsoils in Ohio transmit water very slowly. When water enters the soil faster than it can be removed (as can happen in winter and early spring when vegetation is dormant and evapotranspiration is minimal), it may become trapped in the soil due to the low permeability of the subsoil, and a zone of saturation may form at or near the soil surface. The presence of such a saturated zone can affect root health, soil fertility, and the ability to work the soil safely. Due to

the importance of this phenomenon, all Ohio soil series are classified by drainage. The more common drainage classes include:

Well-drained soils. These soils rarely become saturated near the surface. They generally occur on sloping sites, where significant runoff reduces the amount of water infiltrating the soil. They do not usually require drainage improvements and can be worked relatively early in the spring, but can be sensitive to drought during the summer.

Somewhat poorly drained soils. These soils often become saturated near the soil surface for moderate lengths of time particularly in late winter and early spring. They are often modified by drainage improvements to allow earlier field work, improve root health, and reduce nitrogen losses due to denitrification. These soils are extremely widespread in the crop-producing regions of Ohio.

Poorly drained and very poorly drained soils. These soils readily become saturated at or near the surface and may remain saturated or even flooded well into the spring or early summer. They are also prone to becoming resaturated or flooded during heavy summer storms. They occur on level or depressed areas on the landscape. A common characteristic of these soils is a relatively high concentration of organic matter in the topsoil, giving them dark-colored surface horizons and excellent productivity when drained artificially. Without drainage improvements, however, they are prone to much-delayed planting, denitrification, manganese deficiency, poor root development, depressed nodule activity in legumes, and serious root diseases. These soils can be Ohio’s most or least productive ones, depending on how well they are managed.

Drainage improvement, though expensive, is among the most profitable actions a crop producer can take. Improving drainage on more poorly drained soils expands production options, reduces many problems, and usually improves yields in wet and dry years alike. Crop rooting, soil biological activity, fertility, and water use efficiency can all be improved by removing excess water from soils. Drainage can be improved in a number of ways—by grading land to eliminate low spots and promote managed runoff, installing surface drains and ditches to collect water and channel it safely off the field, and by installing perforated plastic pipe below the soil surface to collect and remove excess water from the soil profile. Installing such practices and structures requires detailed analysis and procedures.

Producers are urged to consult drainage contractors and specialists for assistance.

Two-Stage Drainage Ditches

Agricultural drainage channels serve as outlets for sub-surface drainage systems (i.e., tile lines) that are common in fields with poorly drained soils. Drainage ditches have traditionally been constructed with trapezoidal cross-sections (Figure 2-1A) and uniform slopes. Unfortunately, in some cases, this practice is not self-sustaining and requires regular “dipping” or “clean out” to maintain drainage capacity or costly reconstruction of channel banks to eliminate bank failures and erosion.

In some cases, trapezoidal ditches evolve to a two-stage form developing an inset channel (i.e., the first stage) within the larger trapezoidal channel (Figure 2-1B). Research has shown the inset channel that forms is self-flushing as drainage water is concentrated within the narrow channel, keeping soil particles from depositing within the inset channel. The small floodplains, which form from deposited sediments that eventually vegetate, anchor the ditch sideslope and reduce the likelihood of failing ditch banks. Research has shown that these floodplains provide important water quality benefits.

In channels where a two-stage geometry has formed, and there is a need to increase drainage capacity, the landowner may elect to widen the channel at the interface between the first and second stages (Figure 2-1C). Implementing the two-stage ditch approach eliminates or reduces the need for regular maintenance; however, it is more costly to construct initially and typically requires additional land to construct. In some states, including Ohio, cost-share programs may be available to offset construction costs. In some cases, the additional costs are offset partially or entirely by a reduction in long-term maintenance costs.

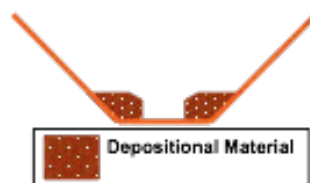
Managing Soil Structure

Maintaining good soil structure is a fundamental aspect of managing productive and fertile soils. In soil, organic matter, mineral soil particles and roots group together to form larger physical units called aggregates. Aggregates start small and eventually form into larger clusters, but both small and large aggregates play a major role in how friable or easily crumbled a soil is. Aggregates are the site of where organic matter is stored (sequestered) in soil, so building organic matter is largely related to building good soil structure. Good structure is ideal for promoting good seed-soil contact and germination, development of extensive root systems that allow for optimum water and nutrient utilization, and free water and air movement

A. Trapezoidal Channel



B. Two-Stage Channel (Natural)



C. Two-Stage Channel (Constructed)

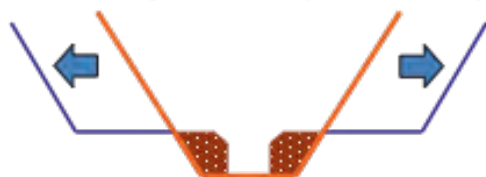


Figure 2-1. Two-stage drainage ditches.

through the root zone. There are several conditions that can develop when soil structure is degraded. These conditions include surface crusting, surface and subsurface compaction, and creation of large, unmanageable clods. None of these are desirable for crop production.

Surface soils with relatively low organic matter and high silt concentrations often form hard, impermeable crusts that interfere with seedling emergence and restrict the intake of mid-season rainfall. Important agricultural soils, including Blount, Canfield, Cardington, Crosby and Fincastle, fall into this category. Hard crusts form when raindrop impact destroys weak aggregates at the soil surface, causing the surface to disintegrate and dry into a solid, impermeable mass. Young seedlings may not be able to generate force sufficient to break through the crust and may be trapped and die underground. Maintaining good soil structure helps facilitate emergence and increase stand significantly.

Crops growing on crusted soils may suffer moisture stress if the soil has not stored enough water prior to crusting to support the crop until maturity. On such soils, preventing or eliminating crusting can increase water infiltration and yield, often significantly.

Using a tillage system that leaves crop residue on the surface also reduces crusting. Residues reduce direct raindrop impact and promote biological activity at the soil surface, which maintains permeability and promotes greater infiltration (see Table 2-1). Increasing mid-season infiltration is a major reason why no-till practices increase yields to the extent they do on well-drained soils subject to crusting.

Driving on soils when they are too wet can cause compacted layers to develop in the soil profile. Such layers can restrict crop rooting depths and reduce percolation of excess water following rain. This situation can cause the upper layer of the soil to become saturated more quickly than normal, and may also prevent roots from obtaining nutrients and water from deeper in the soil during dry periods. Both effects are detrimental to yield. Compaction problems seem to be increasing in Ohio, likely a result of heavier equipment and loads, coupled with warmer winters that reduce opportunities for deep freezing and thawing.

Surprisingly, much compaction occurs when soils are moist, not saturated. Unfortunately, this condition is common in mid-spring and fall, when timely fieldwork is critical. Because it is almost impossible to avoid working in fields when they are sensitive to compaction, producers need to take as many steps as possible to minimize damage to the soil. These include inflating tires to proper pressure, using float tires, reducing axle loads (particularly during harvest), and limiting the area driven upon (i.e., controlling traffic).

Most Ohio soils contain significant quantities of clay and are subject to smearing and clod formation if they are worked when wet. Working wet soils can often create very

large clods that may persist and interfere with production throughout the growing season. Poor seed-soil contact (and impaired germination) is a major problem that results from planting into a cloddy soil. Planting into wet soils may also create other unfavorable conditions, including smeared seed furrows that are impenetrable by young roots (sidewall compaction), or furrows that reopen upon drying, exposing the seed and severely limiting germination. Planting should always be delayed until soils are crumbly and good seed-soil contact can be obtained.

Efficient Water Use

Ohio is not usually considered to be a dry state, but periods of dry weather are often capable of stressing crops and reducing yields. Rainfall usually exceeds crop water use during spring and early summer. However, in most areas of the state, late-season water use by crops exceeds what is supplied by precipitation, creating the potential for stress unless a reserve of moisture has been accumulated from previous rains. Several practices can help make the best use of the water available throughout the growing season.

Practices that promote vigorous rooting allow plants to explore the soil to a maximum extent and utilize much of the water in the soil profile. Obviously, practices that limit compaction will limit the occurrence of impenetrable zones in the soil. Subsurface drainage improvements on wet soils allow roots to penetrate more deeply into the soil and make better use of water deeper in the profile. Rotating crops can also promote more extensive rooting by reducing root predation by soil insects and pathogens, and possibly by reducing the concentrations of autotoxic substances in the soil.

Crop residues on the soil surface do more than increase infiltration on crusting soil; they also reduce evaporation of soil water. This results in more soil water being potentially available for crop use. Adopting tillage and cropping systems that leave significant quantities of residues on the soil surface is beneficial, particularly on well-drained soils; however, on more poorly drained sites, such systems are most effective when used in conjunction with a drainage system that quickly removes excess water as it accumulates. Yield reductions can occur if too much water accumulates in the soil.

Proper timing of forage harvests can save large quantities of water for later growth. As forage crops approach the recommended stages for cutting, the amount of dry matter produced for every gallon of water used declines rapidly. Water is being used to maintain plants, rather than to support further accumulation of useful forage. Harvesting at the recommended time reduces the total amount of water used by that cutting, conserving moisture to support future growth.

Matching plant densities to soil conditions helps convert the water available into the best possible yields. Whereas

high densities may be appropriate on soils rarely subject to drought—such as Kokomo or Pewamo—densities on sands, eroded knobs, and other drought-prone soils should be lower. This allows the overall population of plants to make the most grain per gallon of water available. When planting at low densities, it is important to plant varieties that have an acceptable yield potential at lower populations.

Irrigation

Irrigation is not widely used on field crops in Ohio, but a more frequent occurrence of erratic rainfall and yield losses due to moisture stress over the past 20 years have caused more producers to consider it. Some factors to evaluate before investing in irrigation include:

1. **Water Supply.** Irrigation requires that a water supply deliver an adequate volume of water at an adequate rate over a period of time, without reducing other individuals' reasonable use of the resource. Groundwater resources in many parts of Ohio are marginal in their ability to supply sufficient water, and surface supplies may be either inaccessible or of low use quality. The availability of more than sufficient water should be assured before investing in irrigation.
2. **Continuing Need.** An idle irrigation device is an extremely expensive insurance policy. Most parts of Ohio are as likely to experience overly wet as overly dry growing seasons. Only farmers with a predictable and consistent history of water shortage normally recoup the investment in irrigation. Historically, traditional irrigation has been consistently profitable only for high-value crops.
3. **Efficiency of Operation.** Irrigation is probably better suited to the farmer with a few large (rather than many small) fields. Most currently used systems are best adapted to larger fields with regular borders. The cost of providing water at multiple sites and the time and effort involved in moving a system must be evaluated.
4. **Compatibility with Other Objectives.** Some farmers may be able to justify irrigation as a water management practice in certain fields if they are also using irrigation equipment to dispose of liquid manure. The main considerations are providing an adequate water source and ease of operation.

Soil Conservation

Soil erosion remains a major concern in Ohio and throughout the world. Erosion reduces field productivity and contributes significantly to water quality problems. The most common form of erosion is sheet or interrill erosion, which removes a thin, almost invisible layer of topsoil from the field. Recent advances in crop production such as improved varieties, improved cultural practices, and increased use of fertilizers have masked the decline in inher-

ent soil productivity resulting from sheet erosion. Muddy streams, gullying, and the continued growth of clay knobs in some fields, however, are evidence of Ohio's significant erosion problems.

Most Ohio fields can tolerate erosion at rates of 3 to 5 tons of soil per acre per year because new soil is constantly being formed from underlying parent material. Many fields, however, are eroding at much higher rates. The rate of erosion is affected by many factors, including rainfall timing and intensity, tillage and cropping practices, soil physical characteristics, and slope (both length and angle). Such factors affect both water and wind erosion (particularly important in northwestern Ohio).

Even if erosion rates are below tolerable limits, it is often desirable to reduce erosion further. On the lake-plain soils of northwestern Ohio, for example, erosion rates are normally far below those considered hazardous to productivity. However, a large portion of the soil eroded in this region finds its way into streams and causes sediment-related problems. This sediment may also carry large quantities of plant-available phosphorus that can accelerate eutrophication, causing algal blooms, odor and taste problems, hypoxia, and other deteriorations of water quality. In such cases, erosion control measures are needed to maintain clean water as well as to preserve the soil resource.

Controlling soil erosion should be a high priority in any crop production system. Different situations require different approaches. The best method or combination of methods should be chosen in each case. Further information and technical assistance is available from OSU Extension (extension.osu.edu/), Natural Resources Conservation Service (nrcs.usda.gov), and the Ohio Department of Natural Resources and affiliated local Soil and Water Conservation Districts (water.ohiodnr.gov/).

Conservation Practices

CONTOUR CROPPING reduces erosion, and is most effective on deep, permeable soils and on gentler slopes (2 to 6 percent) that are less than 300 feet long. The effectiveness of contouring diminishes greatly on steeper or longer slopes because of frequent break over of rows by runoff water. Contouring can reduce erosion losses up to 50 percent compared with up-and-down-hill tillage on slopes of from 2 to 6 percent. On steeper slopes (18 to 24 percent) contour cropping without supplementary practices reduces erosion losses by only about 10 percent. Grass waterways are usually necessary to carry the runoff water safely from the contour rows.

STRIP-CROPPING, the practice of alternating contour strips of sod and row crops, is even more effective than contouring alone, reducing erosion to one-fourth of that resulting from up-and-down-hill tillage. Strip widths and sequencing should be governed by slope angle and length.

TERRACES are channels and ridges built across slopes to intercept and divert runoff water, shortening the effective length of a slope. They are generally more effective than either contouring or strip-cropping and are designed especially for longer slopes. Most terraces in Ohio are designed with gradual slopes to lead water safely into grass waterways or other suitable outlets. The number and spacing of terraces depend on the soil type, slope, and cropping practices. Terraces should be designed by qualified soil conservation technicians. New, improved designs allow easier farming with modern machinery, and reduce the number of point rows.

GRASS WATERWAYS are natural or constructed outlets or waterways protected by grass cover. They serve as safe outlets for runoff water from contour rows, terraces, and diversions. Natural drainage areas are good sites for waterways and often require a minimum of shaping to produce a good channel. They should be designed to be wide and flat to accommodate farm machinery, and be able to carry the runoff safely from the watershed above.

Conservation Tillage and No-Till

Basics of Conservation Tillage

Conservation tillage systems leave at least 30 percent of the soil surface covered with a plant-residue mulch (remains of the previous crop or a cover crop) after planting. This is achieved using tillage tools that do not invert the soil (chisel plows, disks, field cultivators, etc.), but rather shatter or mix it shallowly. Often, a field can be prepared for planting with only one pass of a tillage tool. Many producers adopt conservation tillage because it saves time and fuel, while reducing labor requirements; however, the mulch left on the soil surface also provides significant erosion control.

Drainage

Because the residue cover associated with no-till reduces evaporation of soil water, eliminating one avenue for removal of excess moisture, drainage improvements may be needed on many soils to obtain the best yields in a no-till system. Yields under no-till often are more adversely affected by poor drainage than those under conventional tillage. A combination of tile and surface drainage is ideal on soils requiring drainage; however, any drainage improvements are usually beneficial.

Soils

Soil characteristics greatly influence the crop yields obtained using no-till and other forms of conservation tillage. While it may be possible to produce a good crop using these systems on any field, maximum returns are normally achieved by matching the proper tillage systems to the soil at hand. In general, as soil drainage becomes better, tillage can be reduced further.

Well-drained soils, such as Wooster, Fox, Miamian-Celina or Morley-Glynwood, often become moisture deficient as the growing season progresses. The mulch provided by no-till planting normally conserves some water and maintains infiltration on these soils by reducing crusting. As a result, the yield potentials of such soils are usually higher under no-till than under moldboard plowing. Intermediate tillage, such as chisel plowing, usually produces yields intermediate between moldboard plowing and no-till.

Somewhat poorly drained soils, such as Blount, Crosby, and Fincastle, can be no-tilled with careful management. These soils produce the best yields under no-till if they are systematically drained and crops are rotated. If drainage is not provided, chisel-plowing may provide the best yields under conservation tillage. If adequate drainage and residue are present, yields produced with conservation tillage should be equal, on the average, to those obtained by plowing, though different systems may produce the highest yields in different years. These soils crust severely, and in some cases, use of a carefully managed cover crop may be necessary when planting into soybean stubble to ensure adequate surface protection and infiltration. This latter point is most important during the first few years of no-till on such soils.

Poorly drained soils that respond to subsurface drainage improvements, such as Kokomo, Pewamo, and Hoytville, may be adapted to no-till production. Improved drainage and crop rotation are essential to producing top yields. If drainage and rotation are not used, yields under no-till may be much lower than had the field been plowed. No-till soybeans may be successful if drainage and rotation recommendations are followed and precautions for preventing Phytophthora root rot are taken. Soils such as these are considered to be among the most productive in Ohio when plowed, and will produce very high yields under conservation tillage, as well, if managed properly.

Wet, poorly drained soils, such as undrained Hoytville, or soils that do not normally respond well to tile, such as Clermont, Mahoning and Paulding, are not normally recommended for no-till because surface residue often creates severe moisture excesses. Ridge planting may offer a more attractive alternative on such soils because the elevated ridge dries more quickly in the spring, and may allow for significantly earlier planting, which can raise yield potentials. Crop rotation is a must on these soils to avoid low yields, regardless of tillage system used.

Compaction Considerations

No-till and ridge-planting systems should not be used in fields with zones of significant soil compaction. While repeated use of no-till in a cash grain rotation may alleviate a compaction problem, eventually, a producer may go broke waiting for the effect, which can take several years. Compaction should be eliminated before initiating no-till. Following a controlled traffic pattern can prevent future compaction problems.

Cover Crops

A well-managed cover crop is beneficial in certain no-till situations. The purpose of the cover crop is to provide extra residue where little residue is present after harvest. The extra residue improves erosion control and also reduces soil crusting.

A cover crop should always be planted after a corn silage harvest on soils prone to erosion and crusting, particularly if a no-till planting is anticipated the next year. The use of a cover crop after corn harvest for grain is of questionable value and is not normally recommended because the corn stover usually provides enough residue for erosion and crust control. Cover crops may be needed following a soybean harvest if residue levels are not high enough to provide adequate erosion or crusting control, though the benefit of this practice may vary from field to field and should be evaluated on an individual basis. The need for a cover crop for crusting control should decline after several cycles of a corn-soybean rotation because organic matter builds at the soil surface, which will tend to reduce crusting.

Fall-seeded small grains make good cover crops. In Ohio, rye is the most popular. Rye should be killed when it is no more than 20-inches tall in the spring, unless one plans to harvest the cover crop for straw or feed prior to planting soybeans. Any time corn is planted into a grass cover of any kind, the field should be watched carefully for army-worm activity in May and June. Fall-seeded oats (that die over the winter) are often used as an alternative when only a light residue addition is wanted.

For more information regarding cover crops, see “Chapter 10, Considerations for Using Cover Crops.”

Planting

Planting is a critical operation in conservation tillage. Planter operation should be checked and corrected frequently. Not all planters plant under all conditions when adjusted by the book, and experience is often a better guide.

Evaluate soil and residue conditions carefully before planting. Soil should be slightly moist and crumble when squeezed. Planting in too-dry soil may cause penetration problems, too shallow planting, and failure of the seed slot to close. Planting into too-wet soil may result in poor seed-soil contact or seed furrows that reopen upon drying. All of these factors may reduce plant stands. Generally, farmers should delay no-till planting until late morning to allow residues moistened by dew to dry. Wet residues may be jammed into the seed slot, causing poor seed-soil contact and germination.

Seeding depth is important. In recent years, too shallow planting has produced poor root system development. Plant corn 1.5- to 2-inches deep and soybeans $\frac{3}{4}$ - to 1-inch deep. Running the coulter $\frac{1}{2}$ - to $\frac{3}{4}$ -inch deeper than the desired seeding depth and then making appropriate ad-

justments of the seeding mechanism should aid in accomplishing these objectives.

Where to place rows is a continuing question. In general, new rows should be planted where material from old rows, particularly row stumps, will not interface with depth control. Row middles are subject to compaction by repeated wheel traffic and planting into them should be avoided if stand establishment or crop development have been a problem in the past.

Fertilization

Fertilization practices for no-till or ridge planting are often similar to those recommended for conventional tillage. In particular, soil testing and plant tissue analysis should guide nutrient management. Some management recommendations for specific nutrients are given below.

PHOSPHORUS With corn, row placement of phosphorus generally increases yields at lower soil test levels. At adequate soil test levels, and in almost all cases with soybeans, broadcasting is an acceptable production practice from a yield standpoint; however, row placement of phosphorus is encouraged, even in maintenance programs, as a water quality management practice.

POTASSIUM Crop response to row placement of potassium has been more inconsistent than for phosphorus. Farmers using a row fertilizer program can include some potassium; however, in nearly all cases, broadcasting is an acceptable practice. Farmers are encouraged to pay close attention to potassium management in no-till and ridge planting, because potassium deficiency occurs more frequently in these systems than in plow-based ones.

NITROGEN Nitrogen management for no-till or ridge planted corn can be a critical part of the production program. Surface broadcasting of large quantities of urea and UAN solutions should be avoided to prevent the possibility of significant nitrogen loss. Detailed nitrogen management is discussed in OSU Extension Bulletin E-2567, *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa* (agcrops.osu.edu/publications/tri-state-fertility-guide-corn-soybean-wheat-and-alfalfa).

LIME It is important to maintain surface pH levels no lower than pH 6.0. This can be accomplished by frequently adding small amounts of lime to the soil surface. The lime should be applied in the fall and disked in lightly, if possible, to ensure quicker reaction.

Soil Testing

Because some nutrients and acidity tend to accumulate at the surface of the soil in no-till fields, the methods used to sample are important. Two separate samples are recommended:

1. Zero to 4 inches for soil pH and lime requirements. Generally, other analyses at this depth are not needed.

2. Zero to 8 inches for all nutrient requirements. This sample should include the entire zero- to 8-inch depth, and the probe should penetrate as closely to 8 inches as possible. Avoid fertilizer bands.

Weed Control

Specific chemical weed control recommendations can be found in the *Weed Control Guide, Extension Bulletin 789*, available at all County Extension offices and online at CFAES publications at: estore.osu-extension.org/.

Weed control may be the most critical phase of any no-till program. Many farmers notice a shift in weed species as they progress into no-till, most likely an increase in annual grasses and perennial broadleaves. Farmers should watch their fields carefully and modify their herbicide programs as shifts occur.

Most no-till and ridge planting systems require a material that burns down existing vegetation at planting, except for early planted corn where no green vegetation is present. A fairly wide choice of burndown material is available; choice is usually dictated by time of year, stage of weed and crop growth, and weed species present. Careful selection and use of burndown materials helps avoid costly clean-up treatments later in the season.

Farmers just beginning in ridge planting should use a complete no-till program for weed control. Over time, many have found that their cultivation practice allows them to modify herbicide programs and reduce rates considerably. The ability to do this is dependent on weed pressure and response of soil to cultivation (whether it crumbles or slabs). Farmers attempting to reduce herbicide rates in ridge systems should do so only on the basis of their own experience, not on the advice of others.

Considerations for Crop Production on Mine soils

Corn production for grain or silage is possible on land reclaimed to modern standards after being surface-mined for coal in eastern and southeastern Ohio. Corn grain yields and silage production is often lower compared to production on unmined soil. A significant factor implicated in the lower yields is that rooting tends to be shallower and more restricted on mine soil than on unmined soil, magnifying adverse effects of any moisture stress that might occur.

Keys to successful corn production on reclaimed land include: (1) selection of an acceptable mine soil; (2) split-application of the nitrogen to improve N-use efficiency; (3) no-till planting into forage sod or stalk cover to conserve soil moisture; and (4) rotation of corn with forages and application of manure or organic amendments to improve soil physical properties. Given the sensitivity of the crop to moisture stress, success with corn on mine soils also depends greatly on the amount and distribution of precipitation.

Fairpoint, Farmerstown and Morrystown mine soils have proven most adaptable to corn production. In contrast, Bethesda is not recommended for corn. For corn, one should select only those sites where the mixed topsoil-upper subsoil placed over the spoil is of silt-loam or silty-clay loam texture, avoiding surface layers with high clay content because they often produce poor stands.

Split application of nitrogen (one-half at planting and remainder sidedressed four to five weeks later) can double the efficiency of nitrogen fertilizer on mine soils. An opportunity for increased denitrification on mine soils (due to early season wetness) means that application of all N at planting time often promotes severe N losses. Fertilizing and liming according to soil test results provides corn with adequate phosphorus, potassium, calcium, and magnesium. No micronutrient problems have been identified for corn production on mine soils.

Both conventional plow tillage and no-till planting have been successfully used on mine soils. No-till is preferable because retention of previous crop residue is valuable for conserving soil moisture on mine soils, which tend to be droughty after drying in the spring. Also, no-till decreases the number of rocks brought to the surface. A forage-sod mulch and no-till planting usually provides the best soil and water environment for corn.

Rotating corn with forages on mine soils is encouraged because soil structure rapidly improves under forage cover. Severe compaction sometimes occurs when the soil or topsoil material is moved when too wet during the reclamation process. Compaction restricts depth of rooting. Chisel ripping may not alleviate problems. Severely compacted areas are best kept in continuous forage production.

Forages should be grown at least two seasons before beginning corn production. Heavy repeated applications of manure and/or municipal biosolids increase soil fertility and can enhance the structure of mine soils.

Very early planting is not recommended for mine soils because of their restricted internal drainage. Seed emergence may be delayed in wetter, cooler mine soils, similar to corn response on natural soils with poor internal drainage. When planting on mine soils, farmers should select high-yielding, adapted hybrids with strong emergence when grown on poor to moderately well-drained natural soils. Other desirable hybrid characteristics include good stalk strength and flexible ear size and number. Other aspects of corn production in mine soils should follow current Extension recommendations for natural soils.

Seasonal precipitation can affect soybean yields significantly on both the light-colored, natural soils and mine soils in eastern Ohio. Farmers might expect soybean yields on mine soils to be about 65 percent of those obtained on natural ones. With careful planting, plant densities should be similar to those obtainable on unmined sites. Narrow-row planting is recommended.

Farmerstown, Fairpoint and Morristown mine soils have proven more satisfactory for soybeans than the more acidic Bethesda mine soil. No consistent nutrient problems have been associated with the production of soybeans on properly managed mine soils. Mine soils will likely lack sufficient populations of Rhizobia bacteria, so seed inoculation will usually be necessary to ensure nodule formation and nitrogen fixation in soybean (and other legume) roots.

Table 2-1: Effect of Tillage and Soil Cover on Water Infiltration for a Dry Wooster Silt Loam Soil Under Simulated Rainfall (OARDC, 1964). The Wooster Soil Crusts Severely.

Tillage system and residue cover	Infiltration rate after 1 hr cm/hr	Total infiltration after 1 hr cm
Plowed, disked, cultivated, bare	0.66	1.80
No-till, bare	0.28	1.22
No-till, 40% cover	1.17	2.34
No-till, 80% cover	2.64	4.39

Chapter 3 Soil Fertility

By Dr. Edwin Lentz, Dr. Steve Culman, and Dr. Ryan Haden



Elements Essential for Plant Growth

Higher plants require 17 nutrient elements to complete their life cycle (Table 3-1). These essential nutrients fall into three distinct groups: primary macronutrients, secondary macronutrients, and micronutrients. Primary macronutrients are the elements needed in the largest quantity and include nitrogen (N), phosphorus (P), and potassium (K). Secondary macronutrients include calcium (Ca), magnesium (Mg), and sulfur (S). Micronutrients are needed in even lower concentrations and include iron (Fe), manganese (Mn), boron (B), chlorine (Cl), zinc (Zn), copper (Cu), molybdenum (Mo), and nickel (Ni).

Table 3-1: Essential Elements Required by Plants, Their Chemical Symbol, the Form Taken Up by the Plant and Their Concentrations in the Plant.

Element	Chemical Symbol	Form Taken Up	Concentration
Carbon	C	CO ₂	45%
Hydrogen	H	H ₂ O	6%
Oxygen	O	H ₂ O	45%
Primary Macronutrients			
Nitrogen	N	NH ₄ ⁺ , NO ₃ ⁻	1 to 5%
Phosphorus	P	H ₂ PO ₄ ⁻ , HPO ₄ ²⁻	0.1 to 0.4%
Potassium	K	K ⁺	1 to 2%
Secondary Macronutrients			
Calcium	Ca	Ca ²⁺	0.5%
Magnesium	Mg	Mg ²⁺	0.2%
Sulfur	S	SO ₄ ²⁻	0.15 to 0.2%
Micronutrients			
Iron	Fe	Fe ²⁺ , Fe ³⁺	50 to 200 ppm
Manganese	Mn	Mn ²⁺	20 ppm
Boron	B	H ₃ BO ₃	10 to 50 ppm
Chlorine	Cl	Cl ⁻	100 ppm
Zinc	Zn	Zn ²⁺	20 to 50 ppm
Copper	Cu	Cu ²⁺	20 ppm
Molybdenum	Mo	MoO ₄ ²⁻	0.1 to 0.2 ppm
Nickel	Ni	Ni ²⁺	0.01 to 0.02 ppm

The carbon (C), hydrogen (H) and oxygen (O) utilized by a plant comes from carbon dioxide and water. Little can be done to control the availability of these three except through drainage, irrigation, and modification of the physical condition of the soil. On a dry matter basis, carbon, hydrogen, and oxygen make up over 94 percent of the plant biomass. This means the remaining six percent of the biomass is made up of the other 14 nutrients. Even though their amounts seem small, deficiency of only one essential element can limit the growth potential of a plant.

Removal of the primary and secondary macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) by various crops is reported in Table 3-2. The values listed in the table indicate average nutrient removal and represent only those nutrients found in the harvested portion of the crop. The values reported are not the quantities of nutrients needed to generate the crop yields shown. Keep in mind crop nutrient content can vary widely under different growing conditions, and soil nutrient

Table 3-2: Approximate Amounts of Primary Macronutrients Removed by Various Crops.

Crop (Removal Units)	N	P ₂ O ₅	K ₂ O
Alfalfa (lb/ton)	57*	13	50
Corn (lb/bu)			
Grain	0.9	0.4	0.3
Stover	0.7	0.2	1.1
Corn-silage (lb/ton)	9.4	3.2	8.0
Cool-season grasses (lb/ton)	40	13	50
Oats (lb/bu)			
Grain	0.7	0.3	0.2
Straw	0.4	0.2	1.0
Sorghum-grain (lb/bu)			
Grain	0.8	0.2	0.2
Stover	0.6	0.4	1.7
Soybean (lb/bu)	3.8*	0.8	1.4
Sugarbeets (lb/ton)	4	2	5
Wheat (lb/bu)			
Grain	1.3	0.6	0.4
Straw	0.4	0.1	0.7

* Inoculated legumes fix nitrogen from the air.

availability is determined by various fixation and release mechanisms.

Fixation and release mechanisms that control soil nutrient availability are strongly influenced by soil pH. Figure 3-1 shows the relative availability of 12 essential nutrients at different pH levels for mineral soils.

4Rs of Nutrient Management

The 4Rs provide a useful framework for how we think about nutrient management. The 4Rs stand for: 1) Right source, 2) Right rate, 3) Right time, and 4) Right place. All fertilizer recommendations need to consider these four components and how they influence one another. All nutrients have specific behavior in the soil, and the 4Rs help identify which of the four components are most important. For example, when managing nitrogen fertilizer, the rate, timing, and placement are very important. However the specific source of nitrogen fertilizer is less important, but has implications for how and when the nitrogen fertilizer is applied (timing and placement). The 4R concept is not a particularly new idea, rather just a convenient framework for thinking about how we can manage nutrients more effectively in agronomic systems. Specific components of the 4Rs will be addressed in individual nutrients listed below.

Figure 3-1. Relative availability of elements essential to plant growth at different pH levels for mineral soils.

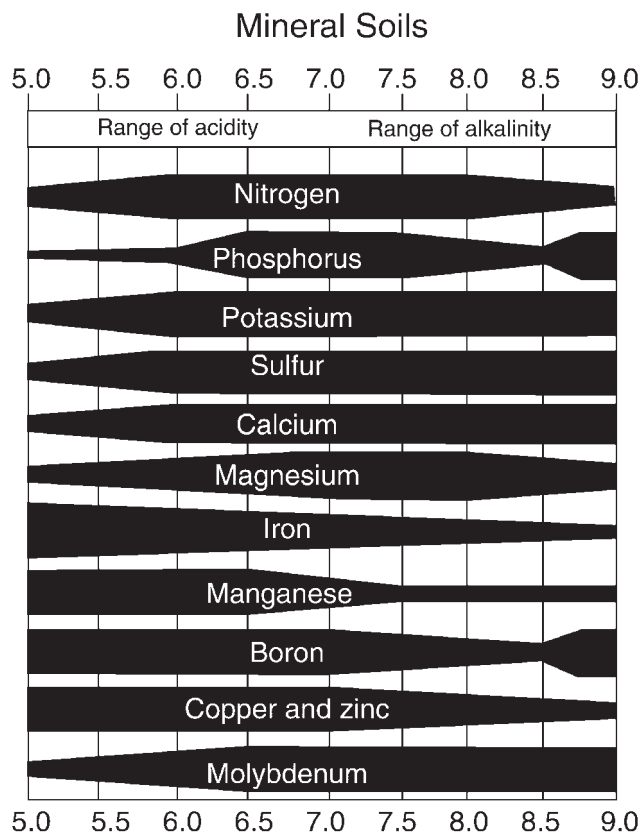


Table 3-3: Formula, Form and Percent Nutrient Content of Various Mineral Fertilizers.

Fertilizer Source	Formula	Form	----- % -----							Other
			N	P ₂ O ₅	K ₂ O	Ca	Mg	S		
Anhydrous Ammonia	NH ₃	Gas ¹	82	-	-	-	-	-	-	-
Aqua Ammonia	NH ₄ OH	Liquid	20-32	-	-	-	-	-	-	-
Ammonium Chloride	NH ₄ Cl	Solid	25-26	-	-	-	-	-	-	66% Cl
Ammonium Nitrate	NH ₄ NO ₃	Solid	33-34	-	-	-	-	-	-	-
Ammonium Polyphosphate	Variable	Solid	10	34	-	-	-	-	-	-
Ammonium Sulfate	(NH ₄) ₂ SO ₄	Solid	21	-	-	-	-	-	24	-
Ammonium Thiosulfate	(NH ₄) ₂ S ₂ O ₃	Liquid	12	-	-	-	-	-	26	-
Calcium Ammonium Nitrate	Variable	Solid	21-27	-	-	8	-	-	-	-
Calcium Sulfate (Gypsum)	CaSO ₄	Solid	-	-	-	23	-	18	-	-
Diammonium Phosphate	(NH ₄) ₂ HPO ₄	Solid	18	46	-	-	-	-	-	-
Magnesium Sulfate (Epsom Salt)	MgSO ₄	Solid	-	-	-	-	10	13	-	-
Monoammonium Phosphate	NH ₄ H ₂ PO ₄	Solid	10-12	48-61	-	-	-	-	-	-
Potassium Chloride	KCl	Solid	-	-	60	-	-	-	-	45

continued on next page

(Table 3-3 continued) Formula, Form and Percent Nutrient Content of Various Mineral Fertilizers, Continued.

Fertilizer Source	Formula	Form	N	P ₂ O ₅	K ₂ O	Ca	Mg	S	Other
----- % -----									
Potassium Magnesium Sulfate	K ₂ SO ₄ + 2 MgSO ₄	Solid	-	-	21	-	10-11	21-22	-
Potassium Nitrate	KNO ₃	Solid	13	-	44	-	-	-	-
Potassium Sulfate	K ₂ SO ₄	Solid	-	-	48	-	-	17-18	-
Single Superphosphate	Variable	Solid	-	16-20	-	18-21	-	11-12	-
Sodium Nitrate (Chilean Nitrate)	NaNO ₃	Solid	16	-	-	-	-	-	26% Na
Sulfur (Elemental)	S	Solid	-	-	-	-	-	50-99	-
Triple Superphosphate	Ca(H ₂ PO ₄) ₂	Solid	-	44-48	-	13-15	-	-	-
Urea	CO(NH ₂) ₂	Solid	46	-	-	-	-	-	-
Urea Ammonium Nitrate	CO(NH ₂) ₂ + NH ₄ NO ₃	Liquid	28-32	-	-	-	-	-	-

¹ Liquid under pressure

Primary Macronutrients

NITROGEN (N) Most nitrogen contained in soil is in the organic form. One percent organic matter represents approximately 1000 pounds nitrogen per acre in the top 6 inches of soil. Despite the abundance, most nitrogen in organic matter is unavailable to the crop. Organic nitrogen must be mineralized (converted into ammonium) by soil microbes to become plant available. The rate of mineralization is controlled by soil pH, moisture, temperature, and aeration, and is highly variable. Crops grown on organic soils (greater than 20 percent organic matter) typically require less fertilizer nitrogen than crops grown on mineral soils due to mineralization of organic nitrogen. Ammonium present in a warm, well aerated soil is quickly converted to nitrate. Soil nitrate is highly mobile and is susceptible to both denitrification (clay soils) and leaching (sandy soils) losses.

Fertilizer nitrogen sources can be classified into three categories: inorganic, synthetic organic, and natural organic. There is little difference between sources of nitrogen when properly applied at equivalent rates. Common fertilizer nitrogen sources and their analysis are presented in Table 3-3. To assure maximum agronomic and economic production, nitrogen should be managed such that losses are minimized. Best management practices that decrease the potential for nitrogen loss include: 1) subsurface injection or dribble banding of liquid nitrogen rather than broadcast application; 2) incorporation of surface applied urea (conventional till) or application coinciding with a rainfall event (no-till); and 3) spring application of nitrogen for spring crops rather than late fall application. If nitrogen is to be applied in the fall for a spring crop, anhydrous ammonia should be selected and should only be applied if the soil temperature is below 50 degrees (other sources

of nitrogen for fall application are not promoted). There is a risk, however, that warm, wet conditions may prevail in the spring which can lead to significant losses of nitrogen, requiring later additions of nitrogen to maximize production. Spring-applied nitrogen should be applied as close to planting as possible (anhydrous should be applied at least two weeks prior to planting). Urea applied in no-till production systems should coincide with an expected rainfall event. Volatilization losses of urea fertilizers without adequate incorporation (by tillage or rainfall) can be significant. Liquid nitrogen formulations should preferably be injected below the soil surface or dribbled in a band to minimize volatilization losses.

Rates of nitrogen fertilizer for corn were historically based on realistic yield goals determined from historical production levels. However, the uncertainty of nitrogen dynamics have caused states in the North Central Region to adopt a different approach—a simple economic model for developing a nitrogen rate in corn. The **Maximum Return To Nitrogen (MRTN)** takes into account a ‘typical’ yield response curve, the price of nitrogen fertilizer, and the price of corn grain. This model strives to maximize farmer profitability, not maximize corn productivity. A simple interface to generate nitrogen rate recommendations exists at the follow web address: cnrc.agron.iastate.edu/. The justification for this approach is laid out in this regional publication: extension.iastate.edu/Publications/PM2015.pdf.

PHOSPHORUS (P – P₂O₅) Ohio soils can contain between 500 to 1500 pounds of phosphorus per acre, most of which is unavailable. The level of available phosphorus is quite variable across the state, and field levels of phosphorus can be determined by soil test. Historical management and soil pH (of mineral soils) determine how much phosphorus is plant available. Phosphorus is taken up by the

plant in two primary forms ($H_2PO_4^-$ and HPO_4^{2-}) which is controlled by soil pH. As soils become more acidic, $H_2PO_4^-$ is the primary species taken up, but excessive soil acidity can result in phosphorus deficiency as aluminum and iron concentrations increase, “fixing” phosphorus. Conversely, as soils become more basic or alkaline, HPO_4^{2-} is the primary species taken up, but high pH can result in phosphorus deficiency as calcium phosphate precipitates. Plants take up both phosphorus forms indiscriminately, so there is no specific pH level that results in maximum phosphorus availability. In general, soil pH should be maintained between 6.0 and 7.5 to maximize plant available phosphorus. Sources of phosphorus and their nutrient content are found in Table 3-3.

Despite the fact that plants take up the ortho form of phosphorus, poly-based forms of phosphorus are just as effective at satisfying plant needs. Poly forms of phosphorus added to the soil are actually converted to ortho forms relatively quickly.

POTASSIUM (K – K_2O) Ohio soils contain between 10,000 to 20,000 ppm potassium per acre. Despite this high amount, only a small portion is actually plant available. Exchangeable (adsorbed to soil CEC—Cation Exchange Capacity) and solution potassium make up the plant-available portion. Potassium availability is dependent upon soil mineralogy and rainfall. Soils that develop from minerals high in potassium (feldspars and micas) have naturally high potassium fertility levels. Soils that developed under high rainfall conditions can be quite deficient in potassium because it has been leached out of the soil. Sources of potassium and their nutrient content are found in Table 3-3.

Potassium chloride is the primary source of potassium fertilizer used commercially. It is readily soluble and contains approximately 60 percent potassium.

Secondary Macronutrients

CALCIUM (CA) Calcium is one of the most abundant nutrient elements found in the soil and is rarely deficient in Ohio. Calcium availability is strongly tied to soil pH, and soils that are maintained at adequate pH (>5.0) levels should have adequate calcium. If calcium is deficient, addition of lime to increase soil pH will remedy the problem. The primary source of calcium is lime, either calcitic or dolomitic. Both of these lime types contain relatively high concentrations of calcium. Sources of calcium and their analysis are shown in Table 3-3.

MAGNESIUM (MG) Magnesium deficiencies, while rare, can occur, primarily in the eastern half of the state. Like calcium, magnesium availability is strongly tied to soil pH. Soils with neutral or basic pH should have adequate magnesium. If soil magnesium and pH is low, use of dolomitic lime to neutralize soil acidity will remedy the problem. If magnesium is low and the pH is near neutral, application of one-half to one ton of 12 percent magnesium (dolomitic) lime will provide enough magnesium for maximum plant production. This will not result in over-liming of medium- or

fine-textured soils. Other sources of magnesium fertilizer are reported in Table 3-3.

SULFUR (S) Sulfur deficiencies are rare, but deficiencies are increasingly being reported. Forage production systems on sandier soils low in organic matter are especially susceptible to sulfur deficiencies. Much like nitrogen, the primary form of sulfur in the soil is found in the organic fraction, and the form taken up by higher plants is highly mobile. For every 1 percent of organic matter, there is approximately 140 pounds of sulfur, which like nitrogen, must be mineralized to be plant available. Historically, sulfur was deposited in large quantities from rainfall primarily due to industrial activities. However, emission standards have resulted in a sharp decrease in sulfur deposition from the atmosphere. As this trend continues, sulfur fertilization may become more important. Fertilizer sulfur is available from many different sources which are reported in Table 3-3.

Micronutrients

Micronutrient levels across the state are adequate for maximum plant production and deficiencies are rare. Specific field environments and soil conditions increase the potential of finding a micronutrient deficiency, namely sandy soils with low organic matter (Table 3-4). If a micronutrient is found to be deficient, remember that over-application of most micronutrients can result in toxicity. Plant tissue analysis is the best way to determine if a plant has a micronutrient deficiency.

Table 3-4: Crop and Soil Conditions Where Micronutrient Deficiencies May Occur.

Micronutrient	Soils	Crops
Boron (B)	Sandy or highly weathered low-organic-matter-content soils	Alfalfa, clover
Copper (Cu)	Acidic peats or mucks with pH <5.3 and black sands	Wheat, oats, corn
Manganese (Mn)	Alkaline soils, peats or mucks of northwestern Ohio	Soybeans, wheat, oats, sugar beets, corn
Molybdenum (Mo)	Soils with pH less than 5.5	Alfalfa, clover, soybeans
Zinc (Zn)	Low organic matter content, soils with high pH and high available phosphorus, mucks or some peats	Corn, soybeans

MOLYBDENUM (MO) and **BORON (B)** can reach toxic levels even when applied in small quantities. Recommendations should be followed closely when either of these elements are being applied. Boron should not be applied in the row for corn or soybean. Manganese (Mn) toxicity

occurs on many soils in eastern Ohio when pH nears 6.0. Alfalfa and soybean are especially sensitive to excess manganese. Foliar-applied manganese in excess of recommended amounts, or in small quantities of water, may burn leaves of wheat, oats and sugar beets.

Micronutrient deficiencies are strongly influenced by soil pH. Soils that are acidic (<6.5) should have adequate levels of most of the micronutrient metals (iron, manganese, zinc, boron, copper, and nickel). Molybdenum behaves just the opposite of the other micronutrients; its availability increases as soil pH increases.

Animal Manure

Animal manure is a good source of plant nutrients and contains many of the elements essential for plant growth. It is especially important to farming operations that include livestock enterprises. It provides those operators the opportunity to utilize the waste produced efficiently. Soils should be tested prior to applying manure. Because the nutrient value of manure is closely related to the dietary regimen, which can result in vastly different nutrient levels, manure should be tested to determine its nutrient value prior to land application. Manure should be analyzed for total solids, total nitrogen, ammonium nitrogen, phosphorus, potassium, calcium, and magnesium. Other nutrient analyses should be available upon request. To determine application rates and recommendations of rates based on soil test nutrient levels and manure levels, see OSU Extension Bulletin 604 available at the County Extension office and available on the internet: agcrops.osu.edu/sites/agcrops/files/imce/fertility/bulletin_604.pdf. Ohio State Extension has also developed an Excel-based Manure Nutrient Rate and Value Calculator, available at agcrops.osu.edu/fertilityresources.

Calculating Fertilizer Rates

Once the analysis of a specific fertilizer material is known (typically displayed as a percent), rates of application can be calculated using the following equation:

$$\text{Pounds of fertilizer material needed} = \frac{\text{nutrient rate (pounds per acre)}}{\text{percent analysis of material}}$$

For example, if the soil test calls for 150 pounds of magnesium and a dolomitic liming material is used that is 12 percent magnesium, the rate of lime required is 1,250 pounds per acre (150/0.12). This calculation works for all fertilizer materials.

Ohio State soil fertility resources can be found here: agcrops.osu.edu/fertilityresources.

Lime and Liming Materials

Proper use of both lime and fertilizer is necessary for optimal crop yields. To optimize production, soil acidity should be corrected prior to fertilizer application.

Liming benefits soil in the following ways:

- Increases soil pH and the availability of nutrients.
- Supplies calcium and magnesium.
- Increases microbial activity and mineralization rates.
- Reduces harmful concentrations of aluminum, manganese and iron.

Liming Materials

Agricultural liming materials used for correcting soil acidity include all calcium and magnesium oxides, hydroxides, carbonates, silicates or combinations sold for agricultural purposes. Commonly found liming materials are presented in Table 3-5.

Table 3-5: Total Neutralizing Power (TNP), Fineness, Moisture, and Effective Neutralizing Power (ENP) of Various Liming Materials That Can Be Found in Ohio.

Grade	TNP (%)	Fineness % Passing Mesh Size			Moisture (%)	ENP (lbs/ton)
		60	20	8		
Aglime superfine	100	100	100	100	0	2000
Dolomitic hydrated aglime	140	100	99	76	0	2520
Calcitic aglime	99	99	60	37	4	1168
Dolomitic aglime	105	97	95	90	4	1953
Wastewater lime	102	100	100	100	74	530

Liming materials are labeled based on their effective neutralizing power (ENP). When comparing liming materials and their associated cost, ENP provides a good way to identify the most economical source. The Ohio Department of Agriculture requires all liming materials sold in Ohio to have an ENP listed. The ENP of a liming material considers the material equivalence, purity, fineness of grind and percent moisture. Particle size of liming materials impacts their effectiveness at neutralizing soil acidity and their speed of reaction. Ag liming materials typically contain particles of differing sizes which results in longer-term acid neutralization. Smaller particles react more quickly while larger particles dissolve slowly, affecting soil pH over a longer period. This is why liming is typically not necessary every year. The ENP of a material is listed in pounds of ENP per ton of material. Aglime is the reference lime and has an ENP of 2000 pounds per ton.

Determination of Lime Requirement

Soil pH measures the active soil acidity or alkalinity. Lime requirement is determined using the buffer pH (BpH), which measures potential soil acidity. Clay soils with a relatively high CEC have a greater ability to buffer changes in soil than sandy soils, thus more lime is required to change the soil pH in a clay soil. The lower the buffer pH, the greater the lime requirement. Table 3-6 shows the relationship between buffer pH and lime requirement to various pH levels. For organic soils, pH not buffer pH, is used to determine lime requirement.

Table 3-6: Tons of Aglime (Effective Neutralizing Power (ENP) of 2,000 Lbs/Ton) Needed to Raise the Soil pH to the Desired pH Level Based on the Shoemaker-McLean-Pratt (SMP) Buffer pH and an Incorporation Depth of 8 Inches.

Buffer pH*	Desired pH levels				
	Mineral Soils			Organic Soils	
	6.8	6.5	6.0	Soil pH	5.3
	Tons agricultural limestone/acre			Tons/acre	
6.8	0.9	0.8	0.7	5.2	0.0
6.7	1.6	1.4	1.1	5.1	0.5
6.6	2.2	2.0	1.6	5.0	0.8
6.5	2.9	2.5	2.0	4.9	1.3
6.4	3.6	3.1	2.5	4.8	1.7
6.3	4.2	3.6	3.0	4.7	2.1
6.2	4.9	4.2	3.4	4.6	2.5
6.1	5.6	4.7	3.9	4.5	2.9
6.0	6.2	5.3	4.4	4.4	3.3
5.9	6.9	5.9	4.7		
5.8	7.6	6.4	5.2		
5.7	8.3	7.0	5.7		
5.6	8.9	7.5	6.1		
5.5	9.8	8.1	6.6		
5.4	10.3	8.7	7.1		
5.3	11.0	9.2	7.5		
5.2	11.6	9.8	8.0		
5.1	12.4	10.4	8.5		
5.0	13.0	11.0	8.9		
4.9	13.7	11.6	9.4		
4.8	14.4	12.1	9.8		

* Lime test index (LTI), which may be reported in place of buffer pH, is buffer pH times 10.

Lime Recommendations

Lime recommendations presented in Table 3-6 are in tons of material per acre and assume a liming material with an ENP of 2000.

Recommendations should be adjusted if:

- Another grade of liming material is to be used.
- Depth of plowing is different from that indicated (8 inches).
- A different crop is planted.

Adjustments for the Type of Liming Material

Although the activity of liming materials in the soil is the same, liming materials do differ. The following example assumes a three-ton-per-acre lime requirement. If a liming material that has an ENP of 2000 pounds per ton is used, simply apply 3 tons of that material per acre. But let's assume that a liming material that has an ENP of 1500 pounds per ton is chosen. To compute the new recommendation, multiply the lime requirement by the adjustment for the material ENP:

$$3 \text{ tons per acre} * (2000 \text{ lbs/ton} / 1500 \text{ lbs/ton}) = \mathbf{4 \text{ tons per acre}}$$

If a liming material with an ENP of 1500 pounds per ton is used to meet a lime requirement of 3 tons per acre, 4 tons of the liming material should be applied per acre. Note that materials with ENPs less than 2000 pounds per ton will increase final liming rate of material needed, while materials with ENPs greater than 2000 pounds per ton will decrease rate of total material needed.

Adjust for the Depth of Tillage

Liming rates are based on an 8-inch depth. If plowing depth is different from 8 inches, the lime requirement must be adjusted. To adjust the lime requirement, simply use a multiplier to change the lime requirement. Multipliers for differing depths of tillage are presented in Table 3-7. For example, assume that the lime requirement is 4 tons per acre, but the depth of tillage is only 6 inches. Multiply 4 tons per acre by 0.75:

$$4 \text{ tons per acre} * 0.75 = \mathbf{3.0 \text{ tons per acre}}$$

It only requires 3 tons of lime per acre to achieve the desired change in soil pH to a depth of 6 inches.

Table 3-7: Adjustments in Liming Rate for Depth of Tillage.

Tillage Depth (inches)	Multiplying Factor
3	0.38
6	0.75
7	0.88
Base 8	1.00
9	1.13
10	1.25
11	1.38
12	1.5

No-Till Adjustments

Lime adjustments for no-till cultural practices are also based on tillage depth. Two soil samples are recommended for no-till row crop cultural practices: 1) shallow sample (zero- to 4-inch depth) and 2) deep sample (zero- to 8-inch depth). If lime is required only for the shallow sample, decrease the lime requirement from Table 3-6 by half. The deep lime requirement remains the same. When lime is applied to the surface, it should be lightly incorporated. If the slope of the field is steep enough to cause erosion, do not incorporate at all. When lime is not incorporated, do not use urea fertilizer for a year after lime application. Ammonium nitrate, anhydrous ammonia or banded 28 percent solution are suitable nitrogen materials for this case.

Other Adjustments in Lime Recommendations

A minimum lime requirement of 2 tons per acre is recommended for forage legumes if the soil pH is 6.2 or less, even if the buffer pH value is higher than 6.8 and lime would typically not be recommended.

Sandy soils can be so weakly buffered that a soil pH may be below optimal range, but the buffer pH value is greater than 6.8. In this scenario, a one ton per acre lime requirement should be used if soil pH is 0.3 pH units below the desired soil pH. A two ton per acre lime requirement should be used if soil pH is 0.6 pH units below the desired soil pH.

Acidic Subsoils

Most of the soils in eastern Ohio, and light colored soils of western Ohio, have acidic subsoils. If there is any question about the pH of the subsoil, the subsoil should be sampled and tested separately.

When lime applications are necessary to correct subsoil acidity, the lime requirement to increase pH to 6.8 should be used. The pH level in the topsoil should be 6.8 or above to promote downward movement of the lime. Only where the surface pH is maintained near 6.5 will the subsoil pH increase. Lime moves down through the profile slowly, so raising subsoil pH can take several years to see results.

Lime recommendations of more than 4 tons per acre should be applied as a split application to achieve a more thorough mixing of the lime with the soil. Half the lime should be applied prior to tillage and half before subsequent tillage. For best results, lime should be applied at least six months before seeding. This allows the lime time to neutralize soil acidity. When a maintenance application is recommended, it can be applied any time in the cropping sequence.

Organic Soils (Muck and/or Peat)

Organic soils usually do not benefit from liming unless the

pH of the soil in the root zone is below 5.3. If the pH of the surface is near 5.3, but the subsurface pH is 4.0 or below, it may be necessary to lime and deep plow. A favorable pH to a minimum depth of two feet should be maintained to accommodate root penetration. In general, lime does not move downward further than plow depth in an organic soil. The pH of organic soils should be determined on samples taken to depths of 24 inches.

High Organic Matter Soils

Usually the most desirable pH range for organic soil is 5.3 to 5.8. When the organic matter content of soils is between 10 and 20 percent, the pH should be shifted as indicated in Table 3-8.

Table 3-8: The Desired pH for High-Organic-Matter Mineral Soils.

Percentage of Organic Matter	Desired pH
10	6.0
15	5.8
20 or higher	5.3 to 5.8

Diagnostic Methods

Soil Testing

Soil testing provides information about the nutrient level of the soil and the amounts of lime and fertilizer necessary to optimize production. Typical soil analysis includes:

- Soil pH and buffer pH.
- Cation exchange capacity (CEC).
- Organic matter.
- Available phosphorus, potassium, calcium and magnesium.

Additional soil analysis can include:

- Sulfur.
- Micronutrients.
- Soluble salts.
- Nitrate and ammonium.
- Heavy metals.

Several testing labs are available in and around Ohio (to view a list of testing labs, visit: agcrops.osu.edu/FertilityResources). Most soil testing labs report soil nutrient levels in parts per million (ppm). The *Tri-State Fertilizer Guide* uses both ppm and pounds per acre to identify critical nutrient concentrations. Make certain that similar units are being compared. To convert from ppm to pound per acre, simply multiply ppm by 2. For most crops and soils, optimum soil test values should be within the ranges indicated in Table 3-9.

Table 3-9: Optimum Soil Test Values for Most Crops in Ohio.

Soil pH		Lime Test Index
6.3 to 7.0	and/or	68-70 for mineral soils
5.3 to 5.8	and/or	68-70 for organic soils
Soil Nutrients		Soil Test Value
Available P	15-40 ppm	(30-80 lb per acre)
Exchangeable K	100-200 ppm	(200-400 lb per acre)
Exchangeable Ca	200-8,000 ppm	(400-16,000 lb per acre)
Exchangeable Mg	50-1,000 ppm*	(100-2,000 lb per acre)
Available Mn	10-20 ppm	(20-40 lb per acre)
Available B	0.25 ppm plus	(0.5 lb per acre plus)
Available Zn	1.5 ppm plus	(3 lb per acre plus)

* These limits vary widely depending upon Cation Exchange Capacity, calcium to magnesium ratio and percent base saturation.

Soil Sampling

When collecting soil samples, growers should first determine what sampling scheme is the most appropriate for their fertilizer management regime and technology. These sampling schemes include: whole field sampling, grid sampling, and zone sampling. Growers that apply a single uniform rate of fertilizer or lime to an individual field typically follow the “whole field” soil sampling approach. To collect

a representative sample using the “whole field” approach in a field of less than 25 acres, about 20 to 25 soil cores (8-inches deep) should be collected randomly and then mixed thoroughly to form a single composite sample for the field. This composite sample can then be submitted to a testing lab in an approved container or bag. Soil samples should typically be collected every two to three years depending upon soil conditions and crop rotation. Soil samples should be collected about the same time each year (either fall or spring) to avoid extreme changes in soil test information. If lime application is necessary, samples should be collected in the fall. Soil samples should not be taken during the growing season (with the exception of the pre-sidedress soil nitrate test).

In order to take advantage of the GPS guidance systems and other precision technologies that are now available for newer tractors, many growers have begun to sample soils using more intensive grid and zone sampling schemes (Table 3-10). These approaches provide higher resolution soil fertility information within each field and thus enable growers and crop consultants to develop prescription maps for variable lime and fertilizer application. Grid sampling involves taking point samples at regular intervals across a field, typically using a systematic grid cell size of about 2.5 acres each (360 feet x 360 feet). Within each grid cell, six to eight soil cores should be randomly collected and mixed in the sample container prior to lab analysis. The zone sampling approach is more expensive and labor intensive than whole field sampling, but is often more economical than grid sampling. Under this approach, the farmer will delineate several management zones within each field based on yield maps, soil type, and their personal knowledge of the field’s management history. Within each management zone, 10 to 15 soil cores should be randomly collected and mixed in the sample container prior to lab analysis. Many COOPs and crop consultants here in Ohio now offer grid and zone sampling services to

Table 3-10: Comparison of the Pros and Cons of Various Soil Sampling Schemes (adapted from LaBarge et al., 2012).

	Whole Field Sampling	Grid Sampling	Zone Sampling
PROS	Easy and fast sampling.	Well suited to newer precision ag equipment.	Well suited to newer precision ag equipment.
	Inexpensive analysis.	Produces high resolution prescription maps.	Moderate sampling time and labor.
	Well suited to older equipment without precision ag technologies.	Identifies low- and high-fertility spots.	Less expensive analysis than grid sampling.
CONS		Good for evaluating non-mobile nutrients P, K and pH.	Produces moderate resolution prescription maps.
		Ideal for fields with unknown history, past manure use and variable soil type.	Identifies zones requiring special management.
	Does not account for in-field variability in soil fertility.	Labor and time intensive sampling.	Good for evaluating non-mobile nutrients P, K and pH.
	Does not allow for the most efficient use of fertilizer or lime.	Expensive analysis.	Zone delineation requires more time and data.
		Fertility zone may not represent yield results.	Requires detailed knowledge of field history.

facilitate the development of prescription maps for farms. For more detailed information about each of these sampling schemes, growers should consult the following OSU Fact Sheet: ohioline.osu.edu/factsheet/AGF-513.

Soil pH and Buffer pH

Soil pH measures the active acidity/alkalinity of the soil solution. The buffer pH provides a measure of the active and potential soil acidity, and determines the lime requirement. The buffer pH may be reported as lime test index or LTI, which is the buffer pH multiplied by 10. The lower the buffer pH, the higher the lime requirement. Sandy soils typically have higher buffer pH values than clay soils.

Cation Exchange Capacity

Cation exchange capacity (CEC) measures the capacity of a soil to adsorb cations, including hydrogen (H⁺), calcium (Ca²⁺), magnesium (Mg²⁺), and potassium (K⁺). Other cations including aluminum (Al³⁺) and iron (Fe³⁺) are also adsorbed, but in slightly acidic to neutral soil their amounts are small enough to be ignored. In slightly acidic to neutral soils, calcium and magnesium take up approximately 80 percent of the CEC while potassium only occupies less than 5 percent. In acidic soils, aluminum and hydrogen can begin to occupy a larger percentage of the CEC.

To determine the CEC of a soil use the following equation:

$$\text{CEC} = \text{ppm Ca}/200 + \text{ppm Mg}/121 + \text{ppm K}/390 + 1.2 * (7 - \text{BpH})$$

The CEC of a soil depends largely on the soil texture and the amount of organic matter present. The larger the CEC value the more cations the soil is capable of adsorbing, which decreases leaching. Attempts to increase the CEC of a soil by adding clay or organic matter are impractical due to the amounts that would be necessary cause a change. Liming acidic soils only affects the CEC slightly.

The normal range in CEC for different soil textures is as follows:

Soil Textures	Common CEC Range (meq/100 g soil)
Coarse (sands)	1 to 5
Medium (silts)	5 to 20
Fine (clays)	20 to 30
Organic soils	30 plus

Percent base saturation of the soil CEC usually falls within the following ranges:

Element	Range in Percent Saturation*
Calcium	40 to 80
Magnesium	10 to 40
Potassium	1 to 5

*Assuming pH value is in recommended range.

Available Phosphorus

The amount of phosphorus that is and will become available to plants is measured by mixing an acidic solution with the soil that dissolves aluminum phosphate precipitates. Available phosphorus of acid soils in the North Central Region was historically measured using the Bray-Kurtz-P1 (Bray P1) procedure, but over the past few decades commercial soil testing labs in Ohio have adopted Mehlich-3 P as the most common and widely soil phosphorus extractant. Mehlich-3 is a universal extractant and is used to measure soil phosphorus, base cations, and even micronutrients. Mehlich-3 has proven to be a reliable extractant in non-calcareous soils in Ohio, but it extracts more phosphorus than Bray P1. For more on the relationship between Bray P and Mehlich-3P, see: agcrops.osu.edu/FertilityResources.

Exchangeable Calcium, Magnesium and Potassium

Unlike phosphorus, calcium, magnesium and potassium are not precipitated with other ions of the soil, but is adsorbed on the CEC of the soil or trapped between soil mineral layers. The exchangeable amounts of these base cations were historically measured using an ammonium acetate extraction solution. However, the Mehlich-3 universal extractant has become the most commonly used base cation extractant in Ohio. Mehlich-3 extractable calcium, magnesium, and potassium are roughly equivalent to ammonium acetate extractable calcium, magnesium, and potassium, so no conversion is required when comparing these two extractants.

Calcium to Magnesium Ratio

The calcium to magnesium ratio is based on their percent saturation of the CEC. Some practitioners have proposed that there is an ideal calcium to magnesium ratio to provide proper nutrition for plants. There is, however, no published data to show the benefits of this methodology. Several research studies in Ohio have shown that optimal production can occur across a range of calcium to magnesium ratios. If the ratio of calcium to magnesium is 1:1 or less (less calcium than magnesium) and the soil calls for application of lime, calcitic (low magnesium, high calcium) lime should be applied. Most plants grow well across a wide range of calcium to magnesium ratios.

Magnesium to Potassium Ratio

To avoid potential grass tetany problems, the magnesium to potassium ratio should stay above 2 to 1. In other words, the percent magnesium saturation of the CEC should be twice that of the percent potassium saturation. As more potassium is taken up, less magnesium is absorbed resulting in a nutrient imbalance in the forage. This imbalance can be transferred to the grazing animal in the form of grass tetany.

Soluble Salts

The soluble salts test indicates the concentration of all fertilizer and non-fertilizer salts in the soil. Excessive salt levels, known as saline soil conditions, can be toxic to plants, especially germinating or young plants. Saline soil impairs the ability of the plant to extract soil water, leading to a drought-like symptom. Saline spots in the field are typically characterized by good tilth and excessive moisture retention. Severe brine solution spills cause excessive soluble salt concentrations. To reduce the salt concentration, the soil should be well drained and leached with high-quality water. Natural rainfall gradually reduces the soluble salt level in most well-drained Ohio soils. Table 3-11 provides a guide for interpreting soluble salt levels.

Table 3-11: Soil and Plant Conditions for Various Soluble Salt Concentrations.

Soil and Plant Condition	Soluble Salt Concentration (mmhos/cm)
Unfertilized, leached field soils	0.15
Well-fertilized soil for optimum plant growth	1-2
Growth of salt-sensitive crops affected	Greater than 2
Severe injury to plants	Greater than 3

Soil Health Assessment

Soil health and soil quality are areas of research that have been gaining traction over the past several years. The interest stems from the recognition by farmers, crop consultants, and scientists that managing soil function and processes for optimal agronomic production requires not only managing soil chemistry, but also soil physical structure and soil biological components. Even though a field could be within recommended ranges for nutrients, the soil physical structure or soil food web could be the primary constraint to production. Although there has been soil physical and biological methods around for decades, identifying and developing simple, rapid tests that can be implemented in a commercial soil testing laboratory framework remains a challenge. This is an active area of work across the North Central Region and in Ohio. As the field of soil health continues to develop, calibrating science-based actionable management decisions from these tests will remain a primary goal for soil testing laboratories and extension networks.

Plant Tissue Sampling and Analysis

To determine the nutritional status of field crops, producers may consider plant tissue testing. Plant analysis is not a substitute for soil testing, but rather a supplement to soil testing to determine the effectiveness of current nutrient management practices. Plant analysis can be used to diagnose suspected nutrient deficiencies or detect deficiencies before plant growth is limited.

Used in conjunction with other data and observations, a plant analysis report aids in evaluating the nutrient elements in the soil-plant system. It also provides a way to evaluate the effectiveness of fertilizers added to the soil. Plant analysis can also help determine response to fertilizer treatment by answering the question “Was the nutrient element supplied by the fertilizer sufficiently absorbed by the plant?” Plant analysis is especially useful for determining whether or not the soil is adequately supplying required micronutrients.

Each crop has its own sampling methodology, and sampling techniques for the major agronomic crops are shown in Table 3-12. When sampling young plants (seedlings) collect the above-ground portion of 10 to 20 plants. Plant samples can be analyzed for all major elements, which will impact the cost of analysis. The desired concentration of an element should occur within the sufficiency range for that nutrient. Table 3-13 lists the typical sufficiency ranges for corn, soybean, alfalfa, and small grains. Nutrient concentrations slightly lower than shown indicate a marginal condition, which may adversely affect plant growth. The limits for these ranges vary depending on crop, plant part, and stage of growth when sampled. These values relate specifically to a particular plant part sampled at a specific stage of growth. These values were selected after careful review of current literature and from the analytical results obtained from numerous samples collected from experiments conducted in Ohio.

Table 3-12: Plant Sampling from Older Plants (Prior to Pollination) of Corn, Sorghum, Soybeans, Small Grains and Alfalfa.

Crop	Sample Prior To or During	Plant Part	Number of Plants to Sample
Corn	Tasseling	Upper fully developed leaf	10
Corn	Initial silk	Ear leaf	10
Grain sorghum	Initial bloom	Upper fully developed leaf	10
Soybeans	Initial flowering	Upper fully developed leaf	15
Small grains or forage grasses	Initial bloom	Upper leaves	20
Alfalfa or forage legumes	Initial flowering	Top 6 inches	20

When sampling plants in an obviously stressed area, it may be beneficial to submit a “check tissue” sample which is from an adjacent area that is stress free. This helps further determine if a deficiency exists. The relative concentration of elements also helps determine sufficiency

Table 3-13: Marginal and Sufficient Nutrient Concentrations for Various Crops.

Nutrient Element	Corn Ear Leaf Sampled at Initial Silk During Initial Flowering		Soybean Upper Fully Developed Leaf Sampled During Initial Flowering		Alfalfa Top 6 Inch Sampled During Initial Flowering		Small Grains Upper Leaves Sampled During Initial Flowering Midseason		
	Marginal	Sufficient	Marginal	Sufficient	Marginal	Sufficient	Marginal	Sufficient	
	Percent								
Nitrogen (N)	2.44–2.89	2.90–3.50	3.99–4.24	4.25–5.50	2.99–3.75	3.76–5.50	2.75–3.24	2.59–4.00	
Phosphorus (P)	0.17–0.29	0.30–0.50	0.15–0.29	0.30–0.50	0.20–0.25	0.26–0.70	0.18–0.24	0.21–0.50	
Potassium (K)	1.24–1.90	1.91–2.50	1.24–2.00	2.01–2.50	1.74–2.00	2.01–3.50	1.50–1.99	1.51–3.00	
Calcium (Ca)	0.09–0.20	0.21–1.00	0.19–0.35	0.36–2.00	0.50–1.75	1.76–3.00	0.18–0.24	0.21–1.0	
Magnesium (Mg)	0.09–0.15	0.16–0.60	0.09–0.25	0.26–1.00	0.19–0.30	0.31–1.00	0.11–0.14	0.15–0.60	
Sulfur (S)	0.09–0.15	0.16–5.0	0.15–0.20	0.21–0.40	0.20–0.30	0.31–0.50	0.15–0.2	0.21–0.40	
	ppm								
Manganese (Mn)	14–19	20–150	14–20	21–100	19–30	31–100	15–19	16–200	
Iron (Fe)	9–20	21–250	29–50	51–350	19–30	31–250	7–10	11–300	
Boron (B)	1–3	4–25	9–20	21–55	19–30	31–80	2–5	6–40	
Copper (Cu)	2–5	6–20	4–9	10–30	2–10	11–30	3–5	6–50	
Zinc (Zn)	10–19	20–70	10–20	21–50	10–20	21–70	9–20	21–70	
Molybdenum (Mo)	—	—	0.4–0.9	1.0–5.0	0.4–0.9	1.0–5.0	—	—	

or deficiency and should be considered when interpreting plant analysis. For example, the ratio of potassium to magnesium, zinc to phosphorus, and manganese to iron assists in diagnosing suspected magnesium, iron, manganese and zinc deficiencies.

Optical Sensing of Leaf Chlorophyll and Nitrogen Status Using NDVI Sensors

Given the poor accuracy of nitrogen soil tests, scientists have begun to develop optical sensors to aid farmers in deciding whether or not their current crop is likely to benefit from a sidedress application of nitrogen. Optical sensors, such as the Trimble Greenseeker, can detect wavelengths of reflected light from the crop canopy and produce a normalized difference vegetation index (NDVI) value that is closely correlated with leaf chlorophyll (the molecule that gives the leaf its green color) and plant tissue nitrogen (Mullen et al., 2003; Varvel et al., 1997). Handheld NDVI sensors can be used to develop specific sidedress nitrogen rates for individual fields or for several smaller management zones within a field. Tractor-mounted NDVI sensors, when coupled with variable rate sprayers, offer the potential for “on-the-go” NDVI measurement and variable rate nitrogen application.

Since many factors other than nitrogen can affect the green color of your crop (e.g., water stress, K deficiency, micronutrient deficiency, herbicide damage, disease), optical sensors must be used in conjunction with a nitrogen-rich strip as a site-specific reference. To create nitrogen-rich strips, nitrogen should be applied at 1.5 times the normal nitrogen rate for your particular crop at or prior to planting. The fundamental concept is to measure NDVI values in a crop both with and without adequate nitrogen, and use these values to predict how much nitrogen is still needed to reach a crop’s yield potential.

In practice, if you can see the nitrogen-rich strip in your field at sidedress time, then you are probably running a bit short on nitrogen and you will need to sidedress. For corn, the optimal time to take NDVI measurements is at the eight to 10 leaf stage. For winter wheat, you can take measurements anytime in the March to April time frame just prior to topdressing.

To determine your nitrogen sidedress rate, collect NDVI data and then enter it to the Sensor-Based Nitrogen Rate Calculator developed by Oklahoma State University (nue.okstate.edu/SBNRC/mesonet.php). A specific option for corn in Ohio is available within the calculator and was de-

veloped by Ohio State Extension. The following steps for data collection are required:

1. Measure the NDVI of bare soil on the edge of the field.
Record this value as: $NDVI_{soil}$ _____
2. Measure NDVI in the section of your field that received the nitrogen-rich strip.
Record this value as: $NDVI_{ref}$ _____
3. Measure NDVI on a section of your field that did not receive a nitrogen-rich strip.
Record this value as: $NDVI_{fp}$ _____
4. These site-specific NDVI data can then be entered into the online calculator which will generate an approximate sidedress nitrogen rate for your crop.

Interpretation of Recommendations

For specific fertilizer recommendations for corn, soybeans, wheat, and alfalfa, see Extension Bulletin E-2567, *Tri-State Fertilizer Recommendations for Corn, Soybean, Wheat, and Alfalfa*, available at: agcrops.osu.edu/publications/tri-state-fertility-guide-corn-soybean-wheat-and-alfalfa.

Chapter 4

Corn Production

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Successful corn production requires an understanding of the various management practices and environmental conditions affecting crop performance. Planting date, seeding rates, hybrid selection, tillage, fertilization, and pest control all influence corn yield. A crop's response to a given cultural practice is often influenced by one or more other practices. The keys to developing a successful production system are to recognize and understand the types of interactions that occur among production factors, as well as various yield limiting factors, and to develop management systems that maximize the beneficial aspect of each interaction. In order to obtain higher yields and profits, knowledge of corn growth and development is essential.

How Climate Affects Corn Production

Temperature

Corn can survive brief exposures to adverse temperatures—low-end adverse temperatures being around 32 degrees Fahrenheit and high-end ones being around 112 degrees Fahrenheit. Growth decreases once temperatures dip to 41 degrees Fahrenheit or exceed 95 degrees Fahrenheit. Optimal temperatures for growth vary between day and night, as well as over the entire growing season. For example, optimal daytime temperatures range between 77 and 91 degrees Fahrenheit and optimal nighttime temperatures range between 62 and 74 degrees Fahrenheit. The optimal average temperatures for the entire crop growing season, however, range between 68 and 73 degrees Fahrenheit.

Even though corn seeds germinate and grow slowly at about 50 degrees Fahrenheit, the first spring planting dates usually begin when the average air temperatures reach 55 degrees Fahrenheit and soil temperature at seed depth is more favorable for seedling growth. Poor germination resulting from below normal temperatures is the greatest hazard of planting too early. The growing point of germinating seedlings remains below or near the soil surface, and usually is not vulnerable to freeze damage until plants reach the five- to six-leaf collar stage. By this time, corn is about 10-inches tall and the probability of freezing temperatures greatly decreases. The loss of leaves from frost generally does not seriously injure small plants, although such loss may delay plant development.

Temperatures less than 40 degrees Fahrenheit reduce photosynthesis, even if the only symptom is a slight loss of leaf color. Frost injury symptoms may appear on leaves even when nighttime temperatures do not fall below the mid-30s; radiational cooling can lower leaf temperatures to several degrees below air temperatures on a clear, calm night. If frost kills leaves but not stalks before physiological maturity (black layer formation) in the fall, sugars usually continue to move from the stalk into the ear. However, yields are generally lower, and harvest moisture may be high because of high grain moisture at the time of frost and slow drying rates following premature death.

High temperature stress during ear formation, reproduction, and grainfill can reduce yield, but temperatures less than 100 degrees Fahrenheit usually do not cause much injury if soil moisture is adequate. Under rain-fed conditions, corn usually begins to stress when air temperatures exceed 90 degrees Fahrenheit during the tasseling-silking (pollination) and grainfill stages. Corn yield may be reduced 1.5 bushels per acre for each day the temperature reaches 95 degrees Fahrenheit, or higher, during pollination and grainfill. Extended periods of hot, dry winds may cause tassel blasting and loss of pollen. Pollen shed usually occurs during cooler morning hours, however, and conditions severe enough to cause this problem are unusual in Ohio.

Precipitation

A corn crop in Ohio typically uses 20 to 22 inches of water during the growing season. Water requirements of corn vary according to the stage of development, as shown in Table 4-1. Corn reaches its peak water use during pollination, when plants are silking.

Excessive rainfall, resulting in flooding and ponding of soils, may cause serious injury to a corn crop depending on its stage of development. The major stress caused by flooding and ponding is a lack of oxygen needed for the proper function of the root system. When plants are very small (prior to six-leaf collar stage), they generally are killed after about five or six days of submersion. Death occurs more quickly (within two to four days) if the weather is hot, because warm temperatures speed up the biochemical processes that use oxygen, and warm water has less dissolved oxygen. Cool weather, on the other hand, may allow plants to live for more than a week under flooded conditions.

Table 4-1: Water Use Rates for Corn at Different Growth Stages.

Growth Stage	Water Use Rate, Inches/Day
Prior to 12-leaf stage	< 0.20
12-leaf	0.24
Early tassel	0.28
Silking	0.30
Blister kernel	0.26
Milk	0.24
Dent	0.20
Full dent	0.18

As soon as plants reach the six- to eight-leaf collar stage, and the plant's growing point is above the soil surface, plants can tolerate a week or more of standing water—not necessarily without harm. In older plants, total submersion may increase disease incidence, and plants will suffer from reduced root growth and function for some days after the water recedes. Tolerance of flooding generally increases with plant age, but reduced root function resulting from a lack of oxygen is probably more detrimental to yield before and during pollination than during rapid vegetative growth or grainfill.

Nutrient uptake is also reduced in soils saturated by excessive rainfall. Not only does poor aeration inhibit effective root development and function, but the anaerobic conditions associated with saturated soils promote denitrification. Frequent rainfall can also cause nitrate leaching.

For crop moisture to be adequate, available soil moisture must be more than sufficient to meet the atmospheric evaporative demand. On windy, hot, sunny days with low humidity, evaporation demand on a crop is high and a high amount of available soil moisture must be present if the crop is to avoid stress. Under cloudy skies, high humidity, and cooler temperatures, atmospheric evaporative demand is low and plants can get by with lower amounts of available soil moisture.

The soil must provide a corn crop with enough water to offset the amounts lost through transpiration. If these needs are not met, the plant will wilt. Table 4-2 shows the effect of drought on corn grain yield from four consecutive days of visible wilting. Through the late vegetative stage (the end of June in normal years), corn is fairly tolerant of dry soils. Mild drought during June may even be beneficial because roots generally grow downward strongly as surface soils dry, and the crop benefits from the greater amount of sunlight that accompanies dry weather. From the two weeks before through the two weeks following pollination, corn is very sensitive to drought, however, and dry soils during this period may cause serious yield losses.

Most of these losses result from pollination failure, and the most common cause is the failure of silks to emerge from the end of the ear. When this happens, the silks do not receive pollen; thus, the kernels are not fertilized and will not develop. Drought later in grainfill has a less serious effect on yield, though root function may decrease and kernels may abort or not fill completely.

Table 4-2: Effects of Drought on Corn Yield During Several Stages of Growth*.

Stage of Development	Percent Yield Reduction
Early vegetative	5 to 10
Tassel emergence	10 to 25
Silk emergence, pollen shedding	40 to 50
Blister	30 to 40
Dough	20 to 30

*After four consecutive days of visible leaf wilting.

Source: Claassen, M.M. and R.H. Shaw. 1970. Water deficit effects on corn. II. Grain components. *Agron. J.* 62:652-655.

Drought stress often leads to plant nutrient stress. The shallow depths where fertilizer is usually placed are dry under drought situations, which may limit nutrient uptake.

Corn Growth and Development

A key step in high yield corn production is monitoring fields and troubleshooting yield-limiting factors throughout the growing season. Corn growers who understand how the corn plant responds to various cultural practices and environmental conditions at different stages of development are able to use management practices more efficiently and, thus, obtain higher yields and profits. Knowledge of growth and development also helps in troubleshooting problems related to abnormal growth caused by pest problems or inappropriate cultural practices. A helpful resource with information for diagnosing problems related to pests and environmental stresses during the growing season is the *Corn, Soybean, Wheat and Alfalfa Guide*, Ohio State University Extension Bulletin 827.

Table 4-3 describes two of the most widely used staging systems for corn development. Extension agronomists use the Leaf Collar Method throughout the United States; crop insurance adjusters, however, use the Horizontal Leaf Method to assess hail and other weather-related plant damage. Table 4-4 shows a timeline relating corn growth and development to normal heat unit (growing degree day) accumulation during the growing season.

Table 4-3: Growth Staging Systems for Corn.

Leaf Collar Method

Start with first oval-shaped leaf as V1. Field defined as being at a given stage when at least 50 percent of plants show collars.

Horizontal Leaf Method

Growth staging system used by hail adjusters for hail damage assessment (Table 4-5).

1. Identify uppermost leaf that is 40 to 50 percent exposed and whose tip is below the horizontal.
2. Typically, a *horizontal leaf* growth stage will be one to two leaf stages greater than the collar method.

Field Corn Developmental Stages, Based on the Leaf Collar Method:

Vegetative Stages		Reproductive stages	
VE	Emergence	R1	Silking
V1	1-leaf collar	R2	Blister
V2	2-leaf collar	R3	Milk
V3	3-leaf collar	R4	Dough
V(n)	nth-node	R5	Dent
VT	Tasseling	R6	Physiological maturity

Table 4-4: A Timeline for Corn Growth and Development.

Growth Stage*	Approx. GDDs	Cum. GDDs**	Comments
- Planting	0	0	Seed planted
VE Emergence	100	100	Coleoptile emerges through soil surface; seminal roots established.
V3 3-leaf collar	246	346	Growing point below soil surface; nodal roots forming.
V6 6-leaf collar	246	592	Growing point at or above soil surface; primary ear shoot initiated; nodal roots dominant now; tassel initiated; # of kernel rows around ear determined V6-8.
V9 9-leaf collar	246	838	Rapid growth underway; brace roots may be present at soil surface.
V12 12-leaf collar	182	1020	Lower 3-4 leaves may not be present due to stalk expansion and subsequent decomposition.
V15 15-leaf collar	150	1170	Kernel # per row determined.
V18 18-leaf collar	150	1320	Silk elongation is most progressed on uppermost ear.
V19 19-leaf collar	50	1370	Tassel near full size.
VT Tasseling	50	1420	Last tassel branch visible; pollen may be shed on main branch of tassel before all branches of the tassel are fully extended.
R1 Silking	-	1420	One or more silks extending outside husk leaves; silks may be visible before tassel completely extended. A single plant can release ½ million or more pollen grains per day; silks receptive to pollen for about 10 days.
R2 Blister	266	1686	Occurs 10-14 days after R1; stress conditions, including drought can cause kernels to abort at R2-3.
R3 Milk	81	1767	Occurs 18-22 days after R1; “roasting ear” stage; kernel color changes from white/clear to orange/yellow.
R4 Dough	214	1981	Occurs 24-28 days after R1; less risk of kernel abortion from stress.
R5 Dent	343	2324	Occurs 35-42 days after R1; stress can reduce kernel weight but not kernel # per ear.
R5 Dent – ½ milk line			Occurs about 10 days after R5; 90% of total kernel dry matter accumulated.
R6 “Black Layer”	327	2650	Occurs 55-65 days after R1; physiological maturity—kernels have achieved their maximum dry weight and are safe from frost; kernel moisture averages 30% but can range from 25-40% grain moisture.

*Based on leaf collar method as defined by Abendroth, et al. (2011), *Corn Growth and Development*, PMR 1009 Iowa State Univ. Extension, Ames, IA.

**Approximate growing degree days (GDDs) between growth stages and cumulative GDDs since planting according to Nielsen, R.L. 2011. *Predicting Corn Grain Maturity Dates for Delayed Plantings*. Corny News Network, Purdue Extension. [online] kingcorn.org/news/timeless/RStagePrediction.html and Nielsen, R.L. 2016. *Grain Fill Stages in Corn*. Corny News Network, Purdue Extension. [online] kingcorn.org/news/timeless/GrainFill.html.

Table 4-5 lists estimated yield loss resulting from varying amounts of leaf area destruction for several stages of development. Although this table was developed to determine yield losses resulting from hail damage, it can also be used to help assess losses resulting from other defoliation injuries (such as wind, frost, insect feeding, herbicide damage, and foliar nitrogen “burn”). The most common damage from hail is loss of leaf area, although stalk breakage and bruising of the stalk and ear may also be severe. Note that the largest yield losses result from defoliation damage that occurs during the late vegetative stages and the reproductive stages (silking and tasseling). Defoliation at early growth stages does not affect yield the same way as it does at later growth stages because much of the plant’s total leaf area is not yet exposed. Extensive defoliation of plants in the 10-leaf growth stage (or V8, eight-leaf collar stage) does not result in a large yield loss because only 25 percent of the leaf area is exposed and the plant can easily recover from early damage. On the other hand, severe damage to plants during tasseling results in a large yield loss because, by that time, 100 percent of the leaf area has been exposed and cannot be replaced.

Table 4-5: Effect of Corn Leaf Area Loss at Various Growth Stages on Corn Yield.*

Growth stage**	Percent Leaf Area Destroyed					
	10	20	40	60	80	100
	Percent Yield Loss					
7 leaf (V5)	0	0	0	4	6	9
10 leaf (V8)	0	0	4	8	11	16
13 leaf (V11)	0	1	6	13	22	34
16 leaf (V14)	1	3	11	23	40	61
Tasseled (VT/R1)	3	7	21	42	68	100
Late milk (R2)	1	3	10	21	35	50
Dent (R4)	0	0	3	10	17	24

*Adapted from Corn Loss Instructions, NCIS publication No. 6102, Rev. 2013

**Based on horizontal leaf method for staging plant growth (V/R-stage is shown in parentheses – the horizontal leaf stage is approximately two-leaf stages greater than leaf collar method).

Early killing frost in the fall may damage immature corn and reduce yield. The effect of frost damage to corn depends on the severity of defoliation, stalk damage, and stage of growth (see Chapter 1, Figure 1-4, for the median fall frost dates). Tables 4-6 and 4-7 provide yield loss and moisture estimates resulting from premature plant death (defoliation) during grainfill.

Table 4-6: Yield Loss in Corn as a Result of Plant Defoliation at Three Kernel Development Stages.

Kernel Development Stage	Percent Grain Yield Reduction
Soft dough (R4)	34-36
Full dent (R5)	22-31
Late dent (late R5)	4-8

Source: Afuakwa, J.J., and R.K. Crookston. 1984. Using the kernel milklane to visually monitor grain maturity in maize. *Crop Science* 24: 687-691.

Table 4-7: Whole Plant and Kernel Moisture of Corn at Four Kernel Development Stages.

Kernel Development Stage	Kernel	Whole Plant
	Percent moisture	
Soft dough	62	>75
Full dent	55	70
Late dent	40	61
Physiological maturity (black layer*)	32	53

*Black layer—indicates end of kernel growth and maximum kernel dry weight (physiological maturity).

Source: Afuakwa, J.J., and R.K. Crookston. 1984. Using the kernel milklane to visually monitor grain maturity in maize. *Crop Science* 24: 687-691.

Hybrid Selection

Selecting a group of hybrids for planting is a key step in designing a successful corn production system. To stay competitive, growers must introduce new hybrids to their acreage on a regular basis. During the past 40 years, the genetics of corn hybrids has improved steadily, which has contributed to steady increases in grain yield potential ranging from 0.7 to 2.6 percent per year.

Growers should choose hybrids best suited to their farm operations. Corn acreage, soil type, tillage practices, desired harvest moisture, and pest problems determine the need for such traits as drydown rate, disease resistance, early plant vigor, plant height, etc. End uses of corn should also be considered (see the section on Specialty Corns). Will the corn be used for grain or silage? Will it be sold directly to the elevator as shelled grain or used on the farm? Capacity to harvest, dry, and store grain should also be considered. The most important factors for hybrid selection in Ohio are maturity, yield potential and stability, stalk quality and disease resistance.

Maturity

Growers should choose hybrids with maturity ranges appropriate for their geographic area or circumstances. Corn for grain should reach physiological maturity or “black layer” (maximum kernel dry weight) one to two weeks before the first killing frost in the fall. Use days to maturity and Growing Degree Day (GDD) ratings along with grain moisture data from performance trials to determine differences in hybrid maturity. Although yields of full-season hybrids often exceeded those of short-season hybrids in the past, early- to mid-maturing hybrids have been developed in recent years with yields comparable to those of full-season types. Late- to full-season hybrids do not always mature or dry down adequately before frost, which results in wet grain. When confronted with delayed planting or replanting decisions, growers may need to switch to early- to medium-maturity hybrids adapted to their area, but they should generally avoid short-season hybrids that are earlier than those normally used in their area. For more information on selecting hybrids for late planting, see the section on *Date of Planting*.

Days to Maturity Rating System

The most common maturity rating system is the days to maturity system. This system does not reflect actual calendar time between planting and maturity—a 106-day hybrid, for example, does not actually mature 106 days after planting. A days to maturity rating is based on relative differences within a group of hybrids for grain moisture at harvest. A one day maturity difference between two hybrids is typically equal to a ½ to ¾ percentage point difference in grain moisture. For example, a 106-day hybrid would be, on average, 3 to 4.5 points drier than a full season 112-day hybrid if they were planted the same day (6 days multiplied by 0.5 or 0.75).

The relationship between days to maturity and kernel moisture is usually dependable when comparing hybrid maturities within a single seed company. However, because there are no industry standards for the days to maturity rating system, grain moisture comparisons of similar hybrid maturities from different seed companies may vary considerably. Days to maturity ratings are satisfactory for pre-season hybrid maturity selection when length of the growing season is usually not an issue. For delayed planting or replanting hybrid selection needs, growers need more absolute descriptions of a hybrid’s growing season requirements to manage the risk of a killing fall frost to late-planted corn.

Growing Degree Day (GDD) Maturity Rating System

The GDD maturity rating system is based on heat units. It is more accurate in determining hybrid maturity than the days to maturity system because growth of the corn plant

is directly related to the accumulation of heat over time rather than the number of calendar days from planting. The GDD system has several advantages over the days to maturity system. The GDD system provides information for choosing hybrids that will mature reliably, given a location and planting date, allows the grower to follow the progress of the crop through the growing season, and aids in planning harvest schedules.

The GDD calculation method most commonly used for corn in the U.S. is the 86/50 cutoff method. GDD are calculated as the average daily temperature minus 50.

$$\text{GDD} = \frac{T_{\text{max}} + T_{\text{min}}}{2} - 50$$

If the maximum daily temperature (T_{max}) is greater than 86 degrees Fahrenheit, 86 is used to determine the daily average. Similarly, if the minimum daily temperature (T_{min}) is less than 50 degrees Fahrenheit, 50 is used to determine the daily average. The high cutoff temperature (86 degrees Fahrenheit) is used because growth rates of corn do not increase above 86 degrees Fahrenheit. Growth at the low temperature cutoff (50 degrees Fahrenheit) is already near zero, so it does not continue to slow as temperatures drop further. GDDs are calculated daily and summed over time to define thermal time for a given period of time. The cumulative GDDs associated with different vegetative and reproductive stages are shown in Table 4-4.

Each corn hybrid requires a certain number of accumulated GDDs to reach maturity. Most seed corn dealers have information on specific hybrids. Table 1-1 (see Chapter 1) lists average GDD accumulation for several Ohio locations from several dates in May to the 10 percent frost date at the particular location (late September). To monitor GDD accumulations during the growing season, the grower should follow the weekly report *Ohio Crop Weather* provided by the United States Department of Agriculture National Agricultural Statistics Service (NASS), available online at: www.nass.usda.gov/.

As with any system, the GDD system has several shortcomings. GDD ratings of hybrids with similar days to maturity ratings don’t always agree, especially if the hybrids are from different companies. Some seed companies start counting GDDs from the day of planting, while others begin from the day of emergence. When this occurs, similar maturity hybrids may vary by 100 to 150 GDDs—the average GDDs required for emergence. Some companies use entirely different mathematical methods to calculate GDD. Although most companies use the 86/50 cutoff method described above, others use different methods to calculate GDDs. Also, under certain delayed planting situations and stress conditions, GDD requirements for maturity may be reduced significantly (see the section on *Date of Planting*).

Yield Potential and Stability

Choose hybrids that have produced consistently high yields across a number of locations and/or years. The Ohio Corn Performance Tests (OCPT) indicate that hybrids of similar maturity vary in yield potential by as much as 40 bushels per acre or more. Choosing a hybrid because it possesses a particular trait, such as big ears, many kernel rows, deep kernels, prolificacy or upright leaves, does not ensure high yields; instead, look for stability in performance across environments.

Most of the hybrids marketed and planted in Ohio contain transgenic traits for herbicide and insect resistance. Planting herbicide-resistant hybrids allows growers to use herbicide formulations also used on soybeans. Hybrids with glyphosate and/or glufosinate ammonium resistance offer weed management options that generally involve fewer applications and use of more environmentally benign chemicals. Insect resistant hybrids contain a gene from bacteria that produces the insecticide known as *Bt*. Planting *Bt* corn hybrids may eliminate the need for soil insecticide treatments (rootworm) and post-emergent insecticide applications (corn borer), which are less effective and potentially harmful to nontarget beneficial insects. See the section on *Insect Control* in this chapter for more on the use of *Bt* resistance to minimize crop losses.

A major concern of growers is whether the yield potential of hybrids with fewer transgenic traits or no transgenic traits is less than that of stacked trait hybrids with multiple genes for above- and below-ground insect resistance. One explanation for this concern is that some seed companies are no longer introducing non-transgenic versions of certain hybrids or are releasing non-transgenic versions some years after the original hybrid has been introduced. So, when a new high yielding hybrid is introduced, it's often only available with stacked traits. As a consequence, some growers believe that in order to optimize yields with the newest genetics it's necessary to plant stacked trait corn hybrids with transgenic traits for above- and below-ground insect resistance. An assessment of corn hybrids in the OCPT without transgenic traits (non-GMO); with transgenic herbicide resistance only; with transgenic traits for above-ground insect resistance only; and with transgenic traits for above- and below-ground insect resistance indicated that non-transgenic hybrids are available that yield competitively with many transgenic corn hybrids in the absence of corn borer and rootworm pressure. Similarly, yields of hybrids with transgenic traits for above-ground insect resistance only were comparable to yields of hybrids with transgenic traits for above- and below-ground insect resistance. As to whether different insect and herbicide traits and combinations thereof affect hybrid performance (in the absence of insect pressure), OCPT data suggested that no set of traits performed consistently much better or much worse than other sets of traits and the numbers of traits was not highly correlated with yield performance among these sets.

Several major seed companies have recently introduced corn hybrids that specifically target enhanced drought tolerance. To date, these drought tolerant hybrids from DuPont Pioneer (Aqua Max) and Syngenta (Agrisure Artesian) contain native traits and those from Monsanto (Drought-Gard) a transgenic trait. In field studies conducted by Ohio State from 2012–2014, drought-tolerant hybrids from DuPont Pioneer and Syngenta were compared to conventional hybrids of similar relative maturity. Results suggested that in moderate- to lower-yielding environments in Ohio (below 185 bushels per acre average yield), the drought-tolerant hybrids can produce greater yields than their conventional counterparts under the same management conditions, but the yield may not be greater when conventional hybrids yield more than 185 bushels per acre. Drought-tolerant hybrids may offer a yield advantage in production environments at greater risk to water deficit with moderate- to low-yield potential.

Some investigators have reported that corn hybrids with different genetic backgrounds vary in their response to plant population and nitrogen fertilizer, and many seed corn companies characterize hybrids based on their response to plant population and nitrogen fertilizer. However, most university research indicates that differential response among hybrids for nitrogen and population is often inconsistent, strongly influenced by environmental conditions, and not a practical consideration when making nitrogen and seeding rate recommendations. Nitrogen and plant population response for different hybrids has also been found to vary by site and weather conditions.

Review the results of state, company and county performance trials before choosing hybrids. Because weather conditions are unpredictable, the most reliable way to select superior hybrids is to consider performance during the last year and the previous year over a wide range of locations and climatic conditions. When using university performance trials results, two years of data from several locations is usually adequate; test summaries for three or more years may exclude new hybrids with better performance potential. Moreover, most hybrids are not evaluated in the OCPT beyond two years.

On-farm strip tests are not reliable in hybrid selection because they cannot predict hybrid performance across a range of environmental conditions. However, on-farm hybrid tests can be useful in evaluating various traits, such as lodging, greensnap, drydown, harvestability (ease of shelling, ear retention, etc.), disease resistance and staygreen.

The Ohio State University conducts corn performance tests across Ohio. Test results are published each year in a bulletin titled Ohio Corn Performance Test, Agronomy Dept. Series 215, and is also available online at: oardc.ohio-state.edu/corntrials/. The bulletin summarizes hybrid tests conducted each year at 10 Ohio locations and includes yield information from the previous two years. The bulletin includes data on yields, grain moisture and standability of hybrids.

Stalk Quality and Lodging

Hybrids with poor stalk quality should be avoided for grain production even if they show outstanding yield potential. Hybrid stalk quality as measured by stalk lodging (stalk breakage below the ear) at harvest has improved greatly over the last 20 years. Nevertheless, this trait is particularly important in areas where stalk rots are perennial problems, or where field drying is anticipated—i.e., conditions that often lead to lodging. If growers have their own drying facilities and are prepared to harvest at relatively high moisture levels (above than 25 percent) or are producing corn for silage, then standability and fast drydown rates are less critical selection criteria.

Traits associated with improved hybrid standability include resistance to stalk rot and leaf blights, genetic stalk strength (a thick stalk rind), short plant height and ear placement, and high staygreen potential. Staygreen refers to a hybrid's potential to stay healthy late into the growing season, after reaching maturity, and should not be confused with late maturity. Resistance to European corn borer conferred by the *Bt* trait can also enhance stalk quality by limiting entry points in plant tissue through which fungal pathogens can invade the plant. However the *Bt* trait will do little to minimize stalk rot and lodging in a hybrid characterized by below-average stalk quality.

Another stalk-related problem, green snap or brittle snap has started to appear in recent years. Corn plants are more prone to snapping during the rapid elongation stage of growth when severe wind storms occur. According to studies in Iowa, Minnesota, and Nebraska, the V5 to V8 stages (corn approximately 10 to 24 inches in height) and the V12 stage through tasseling are the most vulnerable stages. Vulnerability to green snap damage varies among hybrids. However, all hybrids are at risk from wind injury when they are growing rapidly prior to tasseling. The use of growth regulator herbicides, such as 2,4-D or Banvel, has also been associated with stalk brittleness, especially if application is late or if application is made during hot, humid conditions occur. Once tassels begin shedding pollen, green snap problems generally disappear.

Disease Resistance and Tolerance

Hybrids should be selected for resistance or tolerance to stalk rots, foliar diseases and ear rots, particularly those that have occurred locally. Seed dealers should provide information on hybrid reactions to specific diseases in Ohio (Table 4-21). See the section on *Disease Management* for more on the use of hybrid resistance and tolerance to minimize crop losses.

Hybrid response to high population can be limited by stalk lodging, which often increases at higher plant density. Some hybrids that have shown positive yield response to higher populations cannot be grown at high plant densities because of the increased risk of lodging at harvest. Lodging reduces yields and slows the harvest operation. Therefore, it is essential that hybrids planted at high seed-

ing rates possess superior stalk quality for standability. Hybrids should also have resistance (or the best levels of tolerance available) to fungal leaf diseases (such as gray leaf spot and northern corn leaf blight), which contribute to stalk lodging problems and stalk rots (such as Anthracnose and Gibberella).

Grain Quality

The protein and oil composition of corn grain is a major factor affecting grain feeding value. Although the grain market does not include this factor in price determination, growers who feed livestock may use this information to reduce feed costs and optimize diets. Hybrid genetics significantly affect the protein and oil content of corn grain. For feed, protein content is of primary interest, whereas for processing uses, oil content is of interest. Corn grain is typically 8 percent protein and 3.6 percent oil (on a 15.5 percent moisture basis).

Although significant differences among hybrids for oil and protein are evident in under certain testing conditions, the Ohio Corn Performance Test has indicated that protein and oil levels vary considerably from test to test (Table 4-8). Some normal dent corn hybrids produced primarily for grain exhibit elevated protein and oil levels. Environmental conditions (temperatures, rainfall) and cultural practices (nitrogen fertility, plant population) can influence grain composition, especially grain protein. Additional information on hybrids developed for special grain composition characteristics is in the *Specialty Corns* section in this chapter.

Table 4-8: Average Protein and Oil Content of Corn Grain (at 15.5 Percent Grain Moisture), Ohio Corn Performance Test, 2001-2003.

Year	Region	Early Maturity Test		Full Season Test	
		Protein	Oil	Protein	Oil
		-----%-----		-----%-----	
2001	SW	7.5	3.3	7.4	3.5
	NW	8.5	3.7	8.5	3.9
	NE	8.9	3.8	8.4	3.8
2002	SW	8.5	4.0	8.5	4.1
	NW	8.9	4.3	9.1	4.4
	NE	8.1	3.9	8.4	4.1
2003	SW	8.5	3.8	8.4	3.8
	NW	8.0	3.7	8.0	3.8
	NE	8.3	3.6	7.9	3.7

Source: 2001-2003 OSU Corn Performance Test.

Date of Planting

The recommended time for planting corn in northern Ohio is April 15 to May 10 and in southern Ohio, April 10 to May

10. Approximately 100 to 150 GDDs (heat units) are required for corn to emerge. In central Ohio, this number of GDDs usually accumulates by the last week of April or the first week in May. Improved seed vigor and seed treatments allow corn seed to survive up to three weeks before emerging if soil conditions are not excessively wet. An early morning soil temperature of 50 degrees Fahrenheit at the ½- to 2-inch depth usually indicates that the soil is warm enough for planting. Corn germinates very slowly at soil temperatures below 50 degrees Fahrenheit. Short-term weather forecasts should be monitored to make the best decision on early planting. After April 25, planting when soil moisture conditions allow is usually safe. The latest practical date to plant corn ranges from about June 15 in northern Ohio to July 1 in southern Ohio. Plantings after these dates usually yield no more than 50 percent of normal yields.

Planting should begin before the optimum date, if soil conditions will allow the preparation of a good seedbed. Growers should have the equipment capability to plant more than half of their corn acres prior to the optimum planting date; this should allow planting all the corn acres prior to the calendar date when corn yields begin to quickly decline. Ohio corn producers usually cannot perform field operations during all days of their optimum planting date range due to spring rains and cool weather conditions that limit soil drying. On average, during the optimal corn planting time in Ohio, only one out of three days are available for effective fieldwork.

Table 4-9 shows the effect of planting date in Columbus. Yields decline approximately 1 to 1.5 bushels per day for planting delayed beyond the first week of May. Grain yield and test weight were increased by early plantings, whereas grain moisture was reduced, thereby allowing earlier harvest and reducing drying costs. Early planting generally produces shorter plants with better standability. Delayed planting increases the risk of frost damage to corn and may subject the crop to greater injury from various late insect and disease pest problems, such as European corn borer and gray leaf spot.

Table 4-9: Planting Date Affects Yield, Percent Grain Moisture and Test Weight of Corn Grain (Columbus, OH).

Planting Date (mo/day)	Percent of Maximum Yield	Percent Grain Moisture	Test Weight (lbs/bu)
4/23-29	100	20.8	55
4/30-5/7	99	23.7	55
5/8-14	92	24.9	55
5/22-27	87	28.2	54
5/28-6/4	79	35.0	51
6/23-25	52	40.0	49

In one out of four years, excessive rainfall in April and May forces farmers in Ohio to plant or replant up to half of their corn acreage as late as early to mid-June. Since 2005, evaluations of corn yield response to early and late planting dates (late April to mid-May versus early- to mid-June plantings dates) at OSU research farms in northwest (NW), northeast (WO), and southwest Ohio (SC), indicate that planting date effects on yield vary considerably

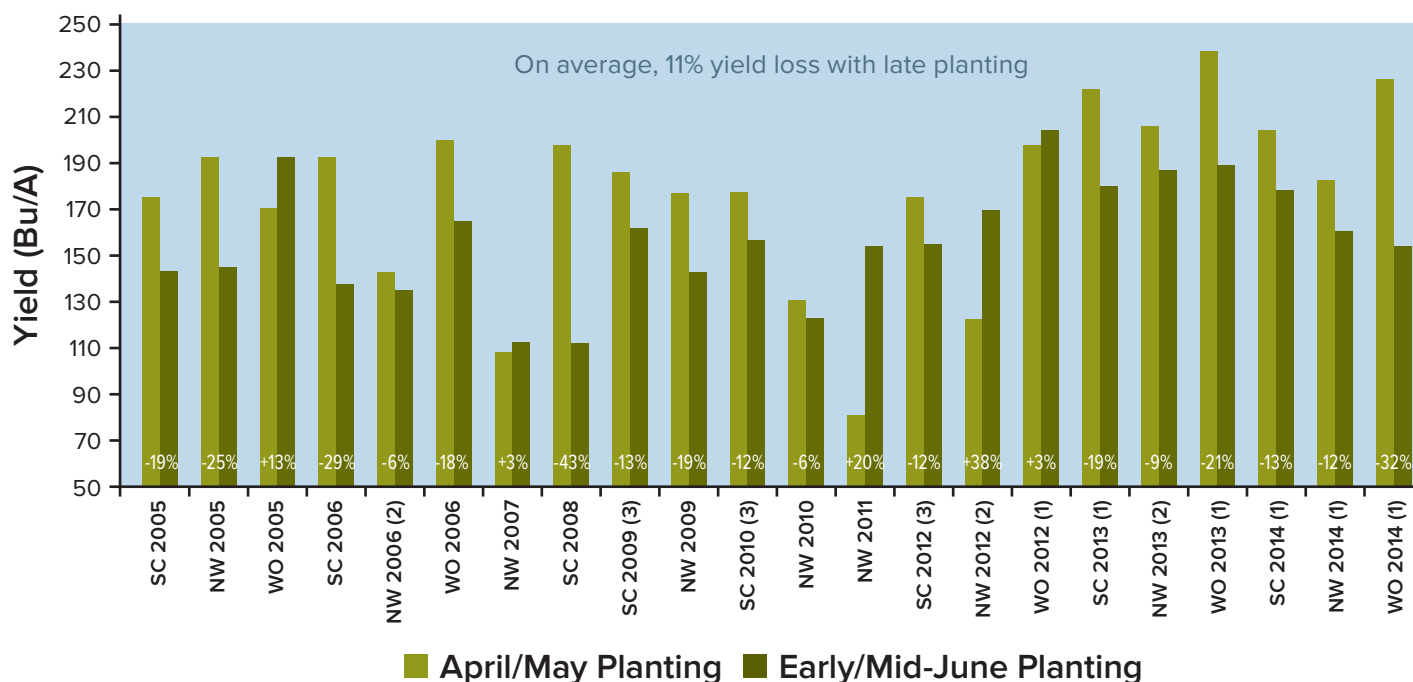


Figure 4-1. Grain yields of corn planted on "normal" Ohio planting dates in late April to mid-May vs. early to mid-June dates, OSU studies, 2005-2014.

across years and locations (Figure 4-1). The change in yield associated with the late planting dates ranged from -43 percent to +38 percent. Averaged across site years, yields decreased about 11 percent. For five of the 14 site years, yields of the later plantings were greater than or comparable to the early plantings which can be related to stressful early season growing conditions (excessively cold and wet) and unusually favorable late season growing conditions. The higher yields associated with June plantings occurred at the northern locations.

Studies have also been performed to determine if various management practices need to be adjusted to optimize yield when planting corn in early- to mid-June. These studies indicate that Ohio producers generally do not need to modify plant population for late plantings based solely on hybrid maturity. There are differences in yield response among hybrids for early mid-May and June planting dates but these differences were not strongly related to hybrid maturity. Results suggested that in some Ohio environments, plant populations should be reduced regardless of relative maturity to optimize yield. Although planting dates in early to mid-June usually results in lower yields, optimum nitrogen rates for late-planted corn were not consistently lower than early-planted corn. Significantly reducing nitrogen recommendations may place producers at risk of yield loss under certain environmental conditions.

Corn should be planted only when soils are dry enough to support traffic without causing soil compaction. The yield reductions resulting from *mudding the seed in* may be much greater than those resulting from a slight planting delay. No-till corn can be planted at the same time as conventional, if soil conditions permit. In reality, however, planting may need to be delayed several days to permit extra soil drying. Planting a full-season hybrid first, then alternately planting early-season and mid-season hybrids, allows the grower to take full advantage of maturity ranges and gives the late-season hybrids the benefit of maximum heat unit accumulation. When compared with short- to mid-season hybrids, full-season hybrids generally show greater yield reduction when planting is delayed. Planting early hybrids first, followed by mid-season, and finally the full-season hybrids spreads the pollination interval for all the corn acres over a longer time period and may be a good strategy for some drought-prone areas with longer growing seasons.

Planting hybrids of different maturities reduces damage from diseases and environmental stress at different growth stages (improving the odds of successful pollination) and spreads out harvest time and workload. Consider spreading hybrid maturity selections between early-, mid-, and full-season hybrids—for example, a 25-50-25 maturity planting, with 25 percent in early- to mid-season, 50 percent in mid- to full-season, and 25 percent in full-season. Planting a range of hybrid maturities is one of the simplest and most effective way to diversify and broaden hybrid genetic backgrounds.

When corn planting is delayed past the optimum dates or if a crop needs to be replanted, it may be necessary to switch hybrid maturities. In most delayed plantings situations, however, full-season hybrids still perform satisfactorily and reach physiological maturity (black layer formation) when planted as late as the last week of May. Hybrids planted in late May or early June mature at a faster thermal rate (require fewer heat units) than the same hybrid planted in late April or early May).

Ohio and Indiana research indicates that the required GDDs units from planting to kernel black layer decreases with delayed planting. For each day that planting was delayed after May 1, the reduction in GDD requirement was about 6.5 GDDs. A hybrid rated at 2,800 GDDs with normal planting dates (such as late April or early May) may require only 2,605 GDDs when planted on May 30. Therefore, a 30-day delay in planting may result in a hybrid maturing in 195 fewer GDDs (30 days multiplied by 6.5 GDDs per day).

Other factors concerning hybrid maturity need to be considered when planting is delayed. For plantings in late May or later, the drydown characteristics of hybrids should be considered. Although a full-season hybrid may still have some yield advantage over shorter season hybrids planted in late May, it could have significantly higher grain moisture at maturity than earlier maturing hybrids, there will be less calendar time for field drying, and drying costs will be higher. Later planting dates generally increase the possibility of damage from European corn borer (ECB) and Western bean cutworm (WBC) and warrants selection of *Bt* hybrids that control these lepidopteran pests if suitable maturities are available.

Seeding Depth

The appropriate planting depth varies with soil and weather conditions. For normal conditions, plant corn 1.5- to 2-inches deep to ensure adequate moisture uptake and seed-soil contact, provide frost protection and allow for adequate root development. Shallower planting often results in poor root development and should be avoided in all tillage systems. In April, when the soil is usually moist and evaporation rate is low, seed should be planted shallower—no deeper than 1.5 inches. As the season progresses and evaporation rates increase, deeper planting may be advisable. When soils are warm and dry, corn may be seeded more deeply—up to 2 inches on non-crusting soils.

When corn is planted 1.5- to 2-inches deep, the nodal roots develop about $\frac{1}{2}$ to $\frac{3}{4}$ inches below the soil surface. However at planting depths less than 1 inch, the nodal roots develop at or just below the soil surface. Excessively shallow planting can cause slow, uneven emergence due to soil moisture variation, and rootless corn (“floppy corn syndrome”) when hot, dry weather inhibits nodal root development. Shallow plantings can increase stress and result in less developed roots, smaller stalk diameters, smaller ears and reduced yields.

Some corn growers plant at depths less than 1.5 inches. The rationale for this shallow planting is that seed will emerge more rapidly due to warmer soil temperatures closer to the surface. This is an important consideration as corn growers across the Corn Belt are planting earlier so they can complete planting before yield potential begins to decrease after the first week of May. Particularly in soils that crust, speed of emergence is critical in order to establish plant stands before heavy rainfalls “seal” the soil surface. In recent OSU research evaluating varying planting depth, grain yields were about 14 percent greater for the 1.5-inch and 3-inch planting depths than the one-half-inch planting depth in 2011, and 40 percent greater in 2012. The lower yield of the shallow half-inch planting was associated with final stands that were 7,000 to 12,000 plants per acre less than those of the other two planting depths in 2011 and 2012.

Row Width

Since the early 1970s, average row spacing in Ohio decreased from about 35 inches to about 30 inches in 2015. This reduction in row spacing coincided with an increase in average plant population from approximately 18,000 plants per acre to nearly 30,000 plants per acre. Due to considerable interest in narrowing row spacing even further, many university and seed company studies have compared corn planted in narrow rows (row spacing 22 inches or less) and conventional 30-inch row spacing.

Although narrow row systems are often perceived as a proven method for increasing yield and profitability, studies on narrow-row corn production have produced mixed results. Some of the inconsistency may be related to latitude with narrow rows in the North Central Region of the U.S. exhibiting the largest yield increases (2 to 3 percent or more) over 30-inch rows. This advantage diminishes moving southward with little or no yield advantages for narrow rows in the central Corn Belt. Results of a Michigan State University study conducted in 1998-99 showed that corn grain yields increased by 2 percent and 4 percent when row width was narrowed from 30 inches to 22 inches and 15 inches, respectively. However, in university research in central Corn Belt states (Iowa, Illinois, and Ohio) the yield advantage of narrow rows over 30-inch row spacings has been smaller (usually less than 2 percent) and less consistent. When they occur, yield increases with narrow rows have been found to occur at both moderate and high plant populations and at high and moderate yield levels. University of Illinois research found no trend for higher or lower yielding sites to show more response to narrow rows. Hybrids varying in maturity and plant architecture have generally exhibited yield responses to narrow rows similar to those for 30-inch row spacing. Some companies have marketed hybrids for high populations and narrow rows but university trials have not shown that these hybrids have an advantage over high yielding hybrids in 30-inch rows.

Some growers are considering twin rows as another row spacing configuration that may offer some of the yield increases associated with narrow row corn. In the typical twin row system, two rows are placed 6 to 8 inches apart on 30-inch centers, although other twin row configurations are used. Twin rows make it possible to create narrow rows without changing the row configuration of other equipment, and to avoid costs associated with equipment conversion to a narrow row system. Staying on 30-inch centers allows growers to use the same corn header and tractor tire spacing used in 30-inch corn production. In recent university studies, results have generally indicated little or no advantage for twin row system compared to 30-inch row spacings.

Narrowing row spacing below 30 inches has usually proven advantageous in silage corn production. Studies at Pennsylvania State University indicate a 10 percent advantage for silage production using 15-inch or 20-inch rows compared to 30-inch rows.

Potential yield gains from narrow rows must be balanced against the investment for new equipment and higher input costs associated with narrowing row spacing. Key changes for narrowing rows include tractor and combine rims and tires, combine heads, and planter modifications. Greater interest in increasing equipment use efficiency by using the same planter or drill for soybean, sugar beet and corn may warrant adoption of narrow row systems for corn. Producers in northern regions that also grow soybeans and sugar beets in 22-inch rows often find it more efficient to use this same row spacing for corn.

Plant Populations and Seeding Rates

When corn is produced for grain in Ohio, recommended plant populations at harvest (or final stand) can range from 24,000 to 34,000+ plants per acre, depending on the hybrid and production environment. Yield response to plant population is influenced by several factors including environmental conditions, the hybrid, and the end use of the corn crop. To account for effects of the production environment, plant population adjustments should be made on a field-by-field basis using the average yield potential of a site over a three- to five-year period as a key criterion for determining the appropriate plant population. When determining the realistic yield potential for a site over a five-year period, it may be appropriate to ignore the highest and lowest yields, which may have occurred during years that were unusually favorable or unfavorable for corn performance.

Hybrids differ in their response to plant population with some exhibiting stalk lodging at the upper end of the plant population range. Seed companies specify a range in final stands for the various corn hybrids they market. Because of differences in genetic backgrounds for various traits, especially stalk quality, these seed company recommendations should be considered when adjusting seeding rates for specific hybrids.

Based on OSU studies, a plant population of 31,000 to 32,000 seeds per acre will optimize yields in most Ohio production environments. For fields with low yield potential, final stands of 24,000 to 26,000 seeds per acre will probably be sufficient. For fields with very productive soils and exceptionally high yield potential, final stands greater than 34,000+ seeds per acre may be necessary. Seeding rates can be cut to lower seed costs, but this approach typically costs more than it saves. In the absence of major environmental stresses, most research suggests that planting a hybrid at suboptimal seeding rates is more likely to cause yield loss than planting above recommended rates (unless lodging becomes more severe at higher population levels).

Plant populations recommended for corn silage are greater than those for grain. According to recent Pennsylvania State University research, optimum plant populations for silage are about 2,000 to 4,000 plants per acre greater for silage than for grain. Higher plant populations can increase silage yields but may reduce forage energy content.

If a grower plans to rely extensively on field drying that can delay harvest, there may be little benefit from using high plant populations much above 30,000 plants per acre. A recent OSU study evaluated effects of plant population (24,000 to 42,000 plants per acre) and harvest dates (early/mid October, November, and December) on the agronomic performance of four hybrids differing in maturity and stalk quality (Table 4-10). Although the hybrids exhibited similar yield potential when harvested early (early/mid October), differences in yield became evident with harvest delays, which could be attributed to differences in stalk quality. Yield differences among plant population were generally small on the first harvest date, but with harvest delays, major yield losses occurred at the higher plant populations, especially 42,000 plants per acre, due to increased stalk lodging. Grain moisture averaged about 24 percent on the first harvest date, 18 percent on the second harvest, and 17.5 percent on the third harvest date. After the first harvest in early/mid October, stalk lodging increased to as much as 80 percent for certain hybrids at high plant populations, resulting in yield losses of nearly 50 percent by mid-December.

Results from trials conducted at OSU and other universities indicate that higher seeding rates do not necessarily require higher nitrogen rates. In Ohio State University research, two different cropping rotations (corn after soybeans and corn after corn) and two seeding rates (30,000 and 40,000 seeds per acre) were evaluated across a range of nitrogen rates. In five out of eight site-years, seeding rate had no impact on fertilizer nitrogen response (the optimum nitrogen rate was similar regardless of seeding rate). When there were differences in optimum nitrogen rates, it was not because the higher seeding rate required more nitrogen. Only one out of the eight site-years (for corn after corn) revealed that the higher seeding rate required more nitrogen.

Table 4-10. Harvest Date and Plant Population Effects on Grain Yield, Moisture and Stalk Lodging.

Harvest Date	Harvest Population (plants/ac)			
	24,000	30,000	36,000	42,000
Yield, bu/ac				
Early/Mid Oct	191	194	197	198
Early/Mid Nov	187	194	193	188
Early/Mid Dec	172	174	167	161
Grain Moisture, %				
Early/Mid Oct	24.9	24.0	22.4	23.7
Early/Mid Nov	18.2	17.9	18.0	17.9
Early/Mid Dec	17.4	17.3	17.6	17.7
Stalk Lodging, %				
Early/Mid Oct	3	4	4	4
Early/Mid Nov	17	20	27	34
Early/Mid Dec	33	42	52	59

Final stands are always less than the number of seeds planted per acre. Cold, wet soil conditions, insects, diseases, cultivation, and other adversities will reduce germination and emergence. Generally, you can expect up to five to 10 percent fewer plants at harvest than seeds planted. To compensate for these losses, you need to plant more seed than the desired population at harvest.

To calculate your own planting rate, consider the following formula:

$$\text{Planting Rate} = \frac{\text{Desired Population per Acre}}{(\text{Germination} \times \text{Expected Survival})}$$

Germination is the percent seed germination shown on the seed tag (converted to decimal form). Expected survival is the percent of seedlings and plants that you expect to reach harvest maturity under normal conditions (converted to decimal form). If you are planting very early when the soil will likely remain cool for several days following planting, you may want to increase seeding rate by 5 percent. A similar approach should be followed when planting no-till, especially in heavy corn residues.

Example:

Target stand at harvest – 30,000 plants per acre
 Seed tag indicates 95% seed germination
 Assume 97% survival (3% plant mortality)
 Planting rate = 30,000 / (0.95 x 0.97) = 32556 seeds per acre

According to the formula, you should consider a planting rate of approximately 32,600 seeds per acre to achieve the desired final stand of 30,000 plants per acre.

Uneven plant spacing and emergence reduces yield potential. The impact of uneven emergence is usually greater than that of uneven spacing. Seed should be spaced as uniformly as possible within the row to ensure maximum yields and optimal crop performance—regardless of plant

population and planting date. Corn plants next to a gap in the row may produce a larger ear or additional ears (if the hybrid has a prolific tendency), compensating for missing plants. These plants, however, cannot make up for plants spaced so closely together in the row that they compete for sunlight, water, and nutrients. Crowding—especially when with uneven emergence—can result in barren plants or ears too small to be harvested (nubbins), as well as stalk lodging and ear disease problems. Although uniformity of stand cannot be measured easily, studies have indicated that reduced plant stands will yield better if plants are spaced uniformly than if there are large gaps in the row. As a general guideline, yields are reduced an additional 5 percent if there are gaps of 4 to 6 feet in the row and an additional 2 percent for gaps of 1 to 3 feet. Studies at Purdue University suggest that corn growers could improve grain yield from 4 to 12 bushels per acre if within-row spacing were improved to the best possible uniformity (depending on the unevenness of the initial spacing variability).

The most effective way to improve planter accuracy is to keep planting speed within the range specified in the planter’s manual. Following are additional considerations for improving seed placement uniformity:

- Match the seed grade with the planter plate.
- Check planters with finger pickups for wear on the back plate and brush (use a feeler gauge to check tension on the fingers, then tighten them correctly).
- Check for wear on double-disc openers and seed tubes.
- Make sure the sprocket settings on the planter transmission are correct.
- Check for worn chains, stiff chain links and improper tire

pressure.

- Make sure seed drop tubes are clean and clear of any obstructions.
- Clean seed tube sensors if a planter monitor is being used.
- Make sure coulters and disc openers are aligned.
- Match the air pressure to the weight of the seed being planted.

Uneven emergence affects crop performance because competition from larger, early emerging plants decreases the yield from smaller, later emerging plants. The primary causes of delayed seedling emergence in corn include shallow planting depths, poor seed to soil contact resulting from cloddy soils, inability of no-till coulters to slice cleanly through surface residues, worn disc openers, and maladjusted closing wheels. Other causes include soil moisture and temperature variability within the seed depth zone, soil crusting prior to emergence, occurrence of certain types of herbicide injury, and variable insect and/or soil-borne disease pressure.

Based on research at the University of Illinois and the University of Wisconsin, if the delay in emergence is less than two weeks, replanting increases yields less than 5 percent, regardless of the pattern of unevenness. However, if one-half or more of the plants in the stand emerge three weeks late or later, then replanting may increase yields up to 10 percent. To decide whether to replant in this situation, growers should compare the expected economic return of the increased yield with both their replanting costs and the risk of emergence problems with the replanted stand.

Use Tables 4-11 and 4-12 to determine the number of kernels dropped or the plant population per acre.

Table 4-11: Kernel Spacings Within the Row at Planting Rates (Kernels/ac) and Row Spacings.

Planting Rate/ac	Final Stand/ac (10% Loss)	Row Spacing (in.)							
		15	20	22	28	30	36	38	40
Inches Between Kernels									
15,000	13,500	27.9	20.9	17.6	14.9	13.9	11.6	11.0	10.5
16,000	14,400	26.1	19.6	16.5	14.0	13.1	10.9	10.3	9.8
17,000	15,300	24.6	18.4	15.5	13.2	12.3	10.2	9.7	9.2
18,000	16,200	23.2	17.4	14.7	12.4	11.6	9.7	9.2	8.7
19,000	17,100	22.0	16.5	13.9	11.8	11.0	9.2	8.7	8.2
20,000	18,000	20.9	15.7	13.2	11.2	10.5	8.7	8.3	7.8
22,000	19,800	19.0	14.3	12.0	10.2	9.5	7.9	7.5	7.1
24,000	21,600	17.4	13.1	11.0	9.3	8.7	7.2	6.9	6.5
26,000	23,400	16.1	12.1	10.1	8.6	8.1	6.7	6.4	6.0
28,000	25,200	14.9	11.2	9.4	8.0	7.5	6.2	5.9	5.6
30,000	27,000	13.9	10.4	8.8	7.5	7.0	5.8	5.5	5.2
32,000	28,800	13.1	9.8	8.5	7.0	6.6	5.4	5.2	4.9
34,000	30,600	12.3	9.2	7.8	6.6	6.1	5.1	4.8	4.6
36,000	32,400	11.6	8.7	7.3	6.2	5.8	4.8	4.6	4.4
40,000	36,000	10.4	7.9	7.1	5.6	5.2	4.4	4.1	3.9

Table 4-12: Length of Row Required for 1/1000 Acre at Various Row Widths.¹

Row Width (in.)	Length of Row for 1/1000 ac
15	34 ft. 8 in.
20	26 ft. 2 in.
28	18 ft. 8 in.
30	17 ft. 5 in.
36	14 ft. 6 in.
38	13 ft. 9 in.
40	13 ft. 1 in.
42	12 ft. 5 in.

¹Example: For 30-inch rows, count the number of kernels dropped or the number of plants in 17 feet, 5 inches and multiply by 1000. If there are 21 in the 17 feet, 5 inch row, the population is 21,000 per acre.

For twin rows, measure from the center of the twin rows to the center of the next set of twin rows to determine the effective row width. Count the plants in both of the twin rows on each side of that center. Example: If twin rows are planted 6 inches apart planted every 30 inches, the effective row spacing is 30 inches (There are rows 3 inches to each side of that 30 inch center). You need 17 feet, 5 inches of row in 30 inch rows. Measure off 17.5 feet of row and count the plants in both of the twin rows that are on each side of the 30 inch center.

Making Replant Decisions

Although it is not unusual that 5 to 10 percent of planted seeds fail to establish healthy plants, additional stand losses resulting from insects, frost, hail, flooding or poor seedbed conditions may call for a decision on whether or not to replant a field. The first rule in such a case is not to make a hasty decision. Corn plants can and often do out-grow leaf damage, especially when the growing point is protected beneath or at the soil surface (up until about the six-leaf collar stage). If new leaf growth appears within a few days after the injury, then the plant is likely to survive and produce normal yields.

When deciding whether to replant a field, assemble the following information: original planting date and plant stand, earliest possible replanting date and plant stand, and cost of seed and pest control for replanting. If the plant stand was not counted before damage occurred, providing that conditions for emergence were normal, estimate population by reducing the dropped seed rate by 10 percent. To estimate stand after injury, count the number of living plants in 1/1,000 of an acre (Table 4-12). Take counts as needed to get a good average—one count for every 2 to 3 acres.

Table 4-13 shows the effects of planting date and plant population on final grain yield. Grain yields for varying dates and populations are expressed as a percentage of the yield obtained at the optimum planting date and population.

When the necessary information on stands, planting, and replanting dates has been assembled, use Table 4-13 to locate the expected yield of the reduced plant stand by reading across from the original planting date to the plant stand after injury. Then, locate the expected replant yield by reading across from the expected replanting date to the stand that would be replanted. The difference between these numbers is the percentage yield increase (or decrease) to be expected from replanting.

Here’s how Table 4-13 might be used to arrive at a replant decision. Let’s assume that a farmer planted on May 9 at a seeding rate sufficient to attain a harvest population of 30,000 plants per acre. The farmer determined on May 28 that his stand was reduced to 15,000 plants per acre as a result of saturated soil conditions and ponding. According to Table 4-13, the expected yield for the existing stand would be 79 percent of the optimum. If the corn crop was planted the next day on May 29, and produced a full stand of 30,000 plants per acre, the expected yield would be 81 percent of the optimum. The difference expected from replanting is 81 minus 79, or 2 percentage points. At a yield level of 150 bushels per acre, this increase would amount to 3 bushels per acre, which would probably not justify replanting costs.

Keep in mind that replanting itself does not guarantee the expected harvest population. Corn replant decisions early in the growing season will be based mainly on plant stand and plant distribution. Later in the season as yields begin to decline rapidly because of delayed planting, calendar date assumes increased importance.

Table 4-13: University of Illinois Replant Chart Developed Under High Yielding Conditions (Adapted from Nafziger, 1995-96).

Planting Date	Plants per Acre at Harvest					
	10,000	15,000	20,000	25,000	30,000	35,000
% of Optimum Yield						
April 10	62	76	86	92	94	93
April 20	67	81	91	97	99	97
April 30	68	82	92	98	100	98
May 9	65	79	89	95	97	96
May 19	59	73	84	89	91	89
May 29	49	63	73	79	81	79

Source: Nafziger, E. D. 1994. Corn planting date and plant population. *J. Prod. Agric.* 7:59-62.

Fertility Recommendations

A good nutrient management program is one of the keys to high yield corn production. Instituting best management techniques to ensure adequate nutrient availability throughout the growing season can pay real dividends at the end of the year and minimize the adverse effects of nutrient runoff and leaching on the environment.

Nitrogen

Timing and Sources

Nitrogen fertilizer applications for corn production can be challenging to manage effectively. Fall application of nitrogen is not recommended, but if nitrogen is to be applied in the fall, make certain that soil temperatures are below 50 degrees Fahrenheit and that anhydrous ammonia is used. Do not apply nitrogen fertilizers that contain nitrate in the fall, the risk of loss is high due to leaching. Application of nitrogen in the spring is more efficient and less susceptible to loss. Nitrogen stabilizers may be used for early spring application, but the benefit of such compounds is inconsistent under certain growing conditions. Application of sidedress nitrogen is a good alternative to preplant applications of nitrogen. In-season applications move fertilization away from the busy planting period and are closer to actual crop uptake of nitrogen. Sidedressing also minimizes the risk of nitrogen loss especially on poorly drained, clay soils which are subject to denitrification and sandy soils which are susceptible to leaching. The main risk of in-season application is the possibility of delayed application due to wet conditions.

When selecting a nitrogen source remember that a pound of nitrogen is a pound of nitrogen, make selections based on risk and cost. For example, it would be risky to apply urea to the surface of no-till ground due to the potential loss of nitrogen by volatilization. Surface dribble banding of liquid nitrogen or subsurface injection are better alternatives. This is not to say that urea is not a good source of nitrogen, but in this instance there are better options. Always consider the cost of the material as well as the field environment that will be encountered to get the most efficient use of fertilizer nitrogen.

Rates

Current nitrogen recommendations for corn production are based on a simple economic model, the Maximum Return To Nitrogen (MRTN). In an area of variable grain prices and nitrogen fertilizer prices, this model strives to maximize farmer profitability, not maximize corn grain productivity. The MRTN takes into account a 'typical' yield response curve, the price of nitrogen fertilizer and the price of corn grain. A simple interface that allows users to generate nitrogen rate recommendations can be found at the following web address: cnrc.agron.iastate.edu/. The background and justification for this approach is laid out in this regional publication: extension.iastate.edu/Publications/PM2015.pdf.

Phosphorus and Potassium

Application Methods

Phosphorus and potassium are more straightforward than nitrogen when it comes to application methods. Phosphorus and potassium are not subject to the same loss mechanisms as nitrogen, thus application concerns are not as restrictive. The main loss mechanism for phosphorus is soil runoff. Utilization of conservation practices that minimize the risk of soil runoff to surface waters is adequate for good phosphorus management. Phosphorus and potassium can be applied either broadcast prior to planting or banded (near the row or over the row [pop-up]) as a starter when planting. If applying starter in a band 2 inches to the side and 2 inches below the seed, the total amount of salts applied (N + K₂O) should not exceed 100 pounds per acre. If starter is applied with the seed (not recommended due to potential salt problems), the total salts (N + K₂O) applied should not exceed 5 pounds per acre for low CEC soils or 8 pounds per acre for high CEC soils. The benefit of starter fertilizers increases when soil test levels and soil temperatures are low and when soil surface residues are high. Soils that have moderate to high levels of soil test phosphorus and potassium show little to no benefit from starter fertilizer.

Sources

Little difference exists between commonly used forms of phosphorus and potassium with regard to nutrient uptake. Ortho- and poly-phosphate formulations perform equally well, even though the crop takes up the ortho- form (poly forms convert to ortho forms rapidly). It should be mentioned that if dry formulations of phosphorus are to be applied in contact with the seed, monoammonium phosphate (MAP) is a somewhat safer form of phosphorus to apply than diammonium phosphate (DAP). DAP produces more ammonia (NH₃) which is toxic to germinating seeds. When banding MAP, DAP or ammonium polyphosphate (APP) do not exceed more than 40 pounds of nitrogen per acre. If soil test phosphorus and potassium are high on no-till soils, then only nitrogen should be applied as a starter, unless 40 to 60 pounds of nitrogen per acre has been applied preplant.

Rates

Soil test levels below the critical value are considered deficient and warrant application of fertilizer (Table 4-14). Current recommendations for phosphorus and potassium are presented in Tables 4-15 and 4-16. Buildup and maintenance recommendations are designed to increase soil test levels to the critical value or maintain current soil test levels. Considering it takes between 8 to 20 pounds of P₂O₅ and 5 to 10 pounds of K₂O (added or removed) to change the soil test level by one unit (depends largely upon soil texture), soil test levels above the critical value will be adequate for crop production for at least a few years (depending upon the soil test level).

Table 4-14: Critical Levels for Soil-Test Phosphorus and Potassium.

P ppm (lb/ac)	K at CEC			
	5	10	20	30
	-----ppm (lb/ac)-----			
15 (30) ¹	88 (175)	100 (200)	125 (250)	150 (300)

¹ Values in parentheses are pounds per acre.

Table 4-15: Phosphate (P₂O₅) Recommendations for Corn Using the Buildup and Maintenance Concept.

Soil test ppm (lb/ac)	Yield potential (bu/ac)				
	100	120	140	160	180
	-----lb P ₂ O ₅ per acre-----				
5 (10) ¹	85	95	100	110	115
10 (20)	60	70	75	85	90
15-30 (30-60) ²	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

¹ Values in parentheses are pounds per acre.

² Maintenance recommendations are given for this soil test range.

Table 4-16: Potassium (K₂O) Recommendations for Corn Using the Buildup and Maintenance Concept.

Soil test K ppm (lb/ac)	Yield Potential (bu/ac)				
	100	120	140	160	180
	-----lb K ₂ O per acre-----				
	-----10 meq/100 g-----				
	CEC				
25 (50)	160	165	170	175	180
50 (100)	120	125	135	140	145
75 (150)	85	90	95	100	105
100-130 (200-260)	45	50	60	65	70
140 (280)	25	25	30	30	35
150 (300)	0	0	0	0	0
	CEC				
	-----20 meq/100 g-----				
25 (50)	195	200	210	215	220
50 (100)	145	150	160	165	170
75 (150)	95	100	110	115	120
125-155 (250-310)	45	50	60	65	70
165 (330)	25	25	30	35	35
175 (350)	0	0	0	0	0
	CEC				
	-----30 meq/100 g-----				
25 (50)	235	240	245	250	255
50 (100)	170	175	185	190	195
75 (150)	110	115	120	125	130
150-180 (300-360)	45	50	60	65	70
190 (380)	25	25	30	30	35
200 (400)	0	0	0	0	0

Sulfur

Sulfur deficiencies are not common, but deficiencies are increasingly being reported, especially on sandier soils low in organic matter. Historically, sulfur was deposited in large quantities from atmospheric rainfall. However, emission standards on industrial activities have resulted in a sharp decrease in sulfur deposition from the atmosphere. As this trend continues, sulfur fertilization may become more important. Sulfur fertilization rates have not been established in Ohio. Corn grain removes a relatively low amount of sulfur: approximately 14 pounds of sulfur for 180 bushels per acre of corn. Accordingly, 20 to 40 pounds per acre of sulfur should be adequate for soils suspected of being deficient. Suitable sulfur fertilizers include: ammonium sulfate, ammonium thiosulfate and gypsum.

For comprehensive information on corn fertilization and soil fertility management, consult OSU Extension Bulletin E-2567, *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa*, available online at: agcrops.osu.edu/publications/tri-state-fertility-guide-corn-soybean-wheat-and-alfalfa and cnrc.agron.iastate.edu.

Crop Rotations

The corn-soybean rotation is by far the most common cropping sequence used in Ohio. This crop rotation offers several advantages over growing either crop continuously. Benefits to growing corn in rotation with soybeans include more weed control options, fewer difficult weed problems, less disease and insect buildup, and less nitrogen immobilization which requires less fertilizer use. Corn grown following corn typically leads to a 2 to 19 percent reduction in yields compared to corn grown following soybeans. Recent work in the North Central Region has suggested that reduced soil nitrogen availability from high corn residue is a primary driver of yield reductions in continuous corn. Table 4-17 shows the influence of crop rotation on corn yields from 2003-2013 at two long-term research plots in Ohio. Continuous corn is the lowest yielding rotation, the corn-soybean rotation yields in the middle and the corn-meadow rotation yields the highest. The rotation effect is large at Hoytville but small at Wooster, showing that soil type and site location influences nitrogen dynamics and availability. The yield advantage to growing corn following soybean is often much more pronounced when drought occurs during the growing season.

Table 4-17: Ten-Year Average (2003-2013) of Corn Grain Yield Grown in Varying Crop Rotations in the Long-Term Tillage Experiments in Ohio. The Chisel Tillage Treatment is Only Shown Here.

Crop rotation	Hoytville Silty Clay Loam	Wooster Silt Loam
	Corn Grain Yield (bu/ac)	
Continuous corn	144.8	183.2
Corn-soybean	160.5	183.7
Corn-meadow	175.2	202.0

Corn Pest Management

Weed Control

A number of factors need to be considered when developing weed control programs for corn, including soil type, weeds, weeds present, crop rotation and budget. No single control program effectively handles the various weed problems that arise under different environmental conditions. Weeds are the major pest control problem in corn production in Ohio. Specific chemical weed control recommendations can be found in the *Weed Control Guide*, Extension Bulletin 789, available at all County Extension offices and online at CFAES publications at: estore.osu-extension.org/.

Insect Control

Many insects will feed on corn throughout the growing season, but only a handful cause economic injury necessitating control measures. We have seen a recent shift of insect control to more preventative practices (e.g., transgenics), but if the pest pressure is not present, then the benefit derived from these treatments will not outweigh the cost of treatment. In general, corn insects are controlled by three tactics. First, transgenic corn will express proteins from the bacteria *Bacillus thuringiensis* (*Bt*) which will provide season long control, but is only active for certain pests (for a complete list see: msuent.com/assets/pdf/28BtTraitTable2016.pdf). *Bt* varieties can protect against above-ground pests, below-ground or both, depending on the variety. A refuge (a certain percentage of the field containing non-*Bt* corn) must still be planted; the percentage and placement (either a separate or integrated, i.e., refuge-in-the-bag) varies depending on the traits present. Second, seed can be coated with insecticidal seed treatments, which offers preventative control of secondary and minor pests. However these seed treatments are short lived (the activity window is about 30 days after planting) and have also been linked to a negative impact on honey bees and other pollinators, so it is important to use them judiciously. Finally, soil or foliar-applied insecticides can be used, although the need for foliar application of insecticides has become extremely rare because of *Bt* corn. Information on insecticides can be found here: [oardc.ohio-state.edu/ag/images/545_Final_2013\(3\).pdf](http://oardc.ohio-state.edu/ag/images/545_Final_2013(3).pdf).

The risk of injury from insects will vary largely depending on weather and region. Knowledge of the pests' biology, field history and scouting will help limit the damage from insects and slugs. Here, we provide a summary of the major pests of corn, damage symptoms and management recommendations.

FLEA BEETLE These tiny, black beetles with long jumping legs can sometimes cause injury after mild winters. While their feeding is usually not economic, they can vector pathogens that cause Stewart's wilt and leaf blight. Economic losses from the beetle or the pathogen are rare. Flea beetles can be controlled by insecticidal seed treatments or by foliar application (if > 3 percent of plants are wilted and dying and beetles are still active).

SEEDCORN MAGGOT The larvae of flies, these maggots will feed on corn seed or early emerging plants. The larvae are small, white and legless, resembling a grain of rice and can be found feeding on or near the young plant. Although rare, significant losses in plant stand can occur. Fields with the highest risk of seedcorn maggots have high organic matter (for example recent manure application), or green cover crops that are tilled under with corn planted five to 10 days later. Early-planted fields are also at higher risk. Adult maggots are attracted to the odor from decaying matter and lay eggs. Damage includes poor emergence, gaps in the row, or weak and stunted plants. Most insecticidal seed treatments (excluding imidacloprid) provide control, and soil-applied insecticides will also protect against damage. There are no thresholds or rescue treatments, and replanting may be needed in heavily damaged fields.

WIREWORM There are multiple species of wireworms, which are the larval form of adult click beetles. Wireworms are long and thin, and tan or brown. Damage from wireworm resembles seedcorn maggot; in fact, they can be found in the same fields. Fields with a history of turf or pasture are most at risk from wireworm. There are no thresholds or rescue treatments, but fields with a history of wireworms may need insecticidal seed treatments and soil insecticides which will control wireworms.

GRUBS There are multiple species of grubs in Ohio, all of which are fairly large, creamy white with orange heads. While most species are of minor importance, the Asiatic garden beetle is one that has caused significant damage in sandy soils, especially in northwest Ohio. Most grubs are controlled by insecticidal seed treatments or soil insecticides, and fields with a prior history of grub infestation may consider these options. Later planted corn tends to escape most of the damage, as the grubs feed less as the season progresses.

BLACK CUTWORM Adults migrate from southern regions and will tend to oviposit in fields with a heavy presence of broadleaf weeds such as chickweed and purple deadnettle. After egg hatch, black cutworm larvae will feed on emerging corn. Smaller larvae will cause pinhole-like

damage, while larger larvae can cut the plants at the base. If cut plants are observed, and corn is still below V6 stage, additional cutting may occur; for every fresh cut, an additional three to four plants could have damage. Only soil insecticides will control black cutworm as a preventative treatment—insecticidal seed treatments have little effect. However, it is difficult to predict the timing and location of when adults arrive and oviposit, which sometimes limits effectiveness of preventative treatments. Rescue treatments are very effective against cutworm, as is proper weed control that limits emergence of spring weeds. A few varieties with *Bt* will also provide control of black cutworm.

TRUE ARMYWORM Like black cutworm, armyworm adults fly from southern regions, but tend to lay eggs in grassy fields, such as wheat or rye cover crops. Once the wheat matures, or the cover crop is killed, larvae march like an army to feed on corn. The striped larvae tend to skeletonize corn, eating away the leaf edges but leaving the midrib. Soil insecticides and some seed treatments will control armyworm, as *Bt* varieties carrying the *Vip3A* genes (*Vip-tera*). Rescue treatments are effective, if 25 percent of the stand shows feeding injury.

SLUGS No-till fields covered in residue in combination with cool and wet springs favor slug conditions. Where slug populations are known to be a problem, use of row cleaners may reduce early stand losses. However, if slugs continue to be a problem on a yearly basis, implementation of minimum tillage will tend to reduce the overall problem. There are no thresholds for slug treatment, although the level of defoliation combined with corn growth stage will provide indications to treat. Slugs tend to feed only on leaves and not the growing point of corn, which makes damage less serious than it is on soybean. Slugs can be controlled by the use of slug bait; examples include metaldehyde and iron phosphate.

EUROPEAN CORN BORER Once the most common and important insect pest in Ohio, European corn borer numbers have declined significantly due to the use of *Bt* corn. There are two generations per year: the first generation attacks whorl stage corn, while the second generation attacks ears. If corn does not include above ground *Bt* traits, foliar applications may be needed if 75 percent of stand in V-stage corn shows evidence of damage. Controlling second generation is more difficult, and depends on the presence of eggs or early larvae. Late planted corn is at higher risk for second generation infestation.

WESTERN CORN ROOTWORM This beetle has replaced European corn borer as the most important insect pest of corn. The major damage is caused by the larvae, which emerge in the soil around mid-June and feed on developing corn roots. Significant lodging can occur if roots are not protected, decreasing yield. Rootworms can be controlled by *Bt* varieties, soil insecticides, and insecticidal seed treatments; however the latter do not perform well under high rootworm pressure. Furthermore, in the Western Corn Belt, rootworms are now resistant to a few

Bt varieties, but this has not been found in Ohio. Continuous corn fields are at the highest risk for both high rootworm populations and *Bt* resistance, since adults tend to mate and lay eggs in corn fields. In recent history, a variant of rootworms would disperse into soybean fields and lay eggs, putting first year corn at risk; however the occurrence of this variant has not been seen in Ohio since 2009. Rootworm populations also tend to be higher in western Ohio. There are no rescue treatments available for larvae feeding, but digging and inspecting roots can provide some indication of risk the next year, if growing continuous corn. Continuous corn fields with a history of rootworm pressure may consider using *Bt* varieties, or a soil insecticide at planting. It is not recommended to use both, as this is not economical and places unnecessary selection pressure on rootworms. Rootworm adults may also feed on foliage or silks. In rare occasions, this can impact pollination and kernel set. Thresholds are set at five adult beetles per silk mass (25 total silk masses), and if silks are not brown and clipped to one-half inch length from the husk. Most clipping occurs at the edge of the field, so inspecting of entire field is necessary.

WESTERN BEAN CUTWORM First found in Ohio in 2006, this is a significant ear pest of corn (note: it does not feed on soybean). There is one generation per year, and adults emerge in mid to late June. Adult flight continues until the end of August, but peak flight is usually the third or fourth week of July. Females will lay eggs on the upper surface of the one to three top corn leaves. They prefer pre-tassel corn, so late-planted corn is always at a higher risk of infestation, especially if tasseling has not occurred by peak flight. After hatch, larvae will feed on pollen, but then enter the ear through silk or by chewing holes in the husk. Foliar applications are very effective against Western bean cutworm, and thresholds are set at 5 to 8 percent of 100 plants with egg masses or larvae. However, applications must be made before larvae enter the ear, so proper egg scouting is important. *Bt* varieties with Cry1F or Viptera (Vip3A) are labeled for control. However, Cry1F has been shown to not provide control in certain areas such that we do not recommend this gene for control. The highest distribution of Western bean cutworm is in the northern third of Ohio, specifically the northwest and northeast corners.

Disease Management

Major corn diseases in Ohio include leaf blights, stalk rots, ear rots and kernel rots (Table 4-18). Although some diseases can be controlled by a single practice, such as planting a resistant hybrid, most diseases require a combination of practices to ensure that economic damage is kept to a minimum. Once a disease has been identified, its management depends on understanding its cause(s), the factors that favor disease development, which plant parts are affected, as well as when and how the disease organisms are spread. The following is a summary of management practices to prevent yield losses in corn from diseases in Ohio.

1. Plant high-quality seed, treated with a fungicide seed treatment, in a well-prepared seedbed. Plant seed 1.5- to 2-inches deep at rates recommended by the seed company to ensure proper plant populations. When populations are excessively high, the stress caused by plant-to-plant competition may increase stalk rot and lodging.
2. Plant high-yielding hybrids with resistance to leaf blight, particularly northern corn leaf blight and gray leaf spot, ear rots, particularly *Gibberella* and *Fusarium* ear rots, and stalk rots. Several hybrids with high levels of resistance to these diseases are available. Review the level of resistance available in hybrids offered by your seed dealer before ordering seed for planting.
3. Balanced fertility is the key to vigorous, well-developed plants. High rates of nitrogen, especially when excessive in relation to potassium, favor the development of stalk rot and some leaf diseases. Use recommended levels of nitrogen, phosphorus, and potassium based on soil tests.
4. Crop rotation and destroying corn residues by tillage reduces the number of disease organisms surviving in the field. However, reduced tillage should be practiced to conserve energy and to protect soil from loss through erosion. When corn is planted after corn, especially under reduced tillage production, these disease management practices are lost. Other disease management practices, such as growing highly resistant hybrids and applying a fungicide, become essential to compensate for not having tillage and crop rotation as management options.
5. Improve soil drainage in poorly drained soils. This reduces water stress and reduces losses from seedling blights, root and stalk rots.
6. Control insects and weeds in and around fields. Insects such as rootworm, ear worm and stalk borer create wounds that serve as entry points for fungi causing stalk and ear rots. The corn flea beetle serves as the vector of Stewart's leaf blight bacterium. Some weeds act as reservoirs for corn pathogens. In southern Ohio, eradicate Johnsongrass to eliminate the reservoir for corn viruses and their insect vectors.
7. Fungicide application may be justified in commercial corn production fields only if susceptible hybrids are grown and conditions are favorable for disease development. Popcorn and inbreds grown for seed production are generally more susceptible to leaf diseases than dent corn and should be scouted for leaf diseases regularly. Fungicides are most effective against foliar diseases when applied at tassel or silking (VT or R1); the most consistent yield responses are achieved when applications are made at VT/R1; and the highest yield responses are usually seen when fungicides are applied under disease-favorable conditions/situations.

- Early, pre-tassel applications or applications made in the absence of disease (when the hybrid is resistant or conditions are not favorable for disease development) often do not result in yield responses that are high enough to offset fungicide application cost.
8. Survey fields in the fall prior to harvest to determine the incidence of stalk rot. A rapid and easy technique to determine the incidence of stalk rot is the squeeze method. Grasp the base of the stalk above the brace roots and squeeze the stalk between the thumb and first two fingers. Stalks with significant rot will crush easily. Those fields with the greatest percentage of rotted stalks should be harvested first to avoid losses resulting from lodged corn.
 9. Proper adjustment and operation of the combine or picker reduces harvesting losses in the field with stalk-rotted, lodged corn. Some equipment companies have attachments for the combine header to help pick up lodged corn.
 10. Survey fields just prior to harvest for ear rots, particularly if in-season conditions were favorable for *Gibberella* ear rot development (cool, wet weather during the two to three weeks after R1). Harvest affected fields separately, at the correct moisture, and adjust the combine to minimize damage to the grain. Send samples for mycotoxin analysis, and dry and store grain at 13 to 14 percent moisture to minimize further mold growth and toxin contamination in storage.
 11. For long-term storage, dry shelled corn to 13 to 14 percent. Ear corn to be cribbed should be dried to 20 percent moisture. Maintain cool and dry storage conditions to prevent storage molds from developing. For more information on recognizing and managing corn diseases, and on mycotoxins associated with moldy grain, visit ohioline.osu.edu/findafactsheet, where you can download disease fact sheets.

Harvesting

Harvest date should be determined by crop maturity, not by the calendar. Plan to harvest fields with potential lodging or harvest loss problems (such as stalk rot or deer damage) first. All field shelled corn with more than 15 percent moisture must be dried for safe storage. The ideal kernel moisture level at which to harvest for dry grain storage is 25 percent. Corn normally dries approximately 0.75 to 1 percent per day during favorable drying weather (sunny and breezy) during the early, warmer part of the harvest season—from mid-September through mid-October in central Ohio. By late October to early to mid-November, field dry-down rates usually drop to probably no more than 0.5 percent per day. By mid- to late November the rate drops to 0.25 percent per day, and after Thanksgiving, drying rates are negligible (Table 4-10).

Table 4-18: Major Diseases Affecting Corn in Ohio.

Leaf Blights

Gray leaf spot
Northern corn leaf blight
Anthracnose
Southern corn leaf blight
Northern corn leaf spot
Eyespot
Common rust

Seedling Diseases

Pythium seed rot and seedling blight
Fusarium seed rot and seedling blight
Bipolaris seedling blight

Ear and Kernel Rots

Gibberella ear rot
Fusarium kernel rot
Diplodia ear rot

Stalk Rots

Gibberella stalk rot
Anthracnose stalk rot
Fusarium stalk rot
Diplodia stalk rot

Virus Diseases

Maize dwarf mosaic
Maize chlorotic dwarf

Miscellaneous

Common smut
Crazy top

Dry-down rates can also be estimated in terms of GDDs. Generally it takes 20 to 30 GDDs to lower grain moisture each point from 30 percent down to 20 percent. In September, accumulation of GDDs averages 10 to 15 per day. In October, the accumulation drops to 5 to 10 GDDs per day. These estimates are based on generalizations, however, and some hybrids may vary considerably from this pattern of dry-down.

Monitoring harvest losses is an important part of the harvesting process. Ear corn losses from in front of the combine (preharvest losses) should be subtracted from the total harvest loss estimate. The loss of one normal-sized ear per 100 feet of row translates into a loss of more than 1 bushel per acre. An average harvest loss of two kernels per square foot is about 1 bushel per acre. Keep in mind that most harvest losses occur at the gathering unit. An Ohio State University study found that approximately 80 percent of the total machine loss is caused by corn never getting into the combine.

Drought-induced stalk lodging and insect problems reduce the yield potential of many corn fields if harvesting is delayed much beyond maturity. Ear drop damage may be high in some years as a result of extensive European corn borer damage to hybrids without ECB *Bt* resistance. Estimates of harvest losses based on long-term average data at Purdue University indicate that losses increase by 1 to 2 percent for each week of harvest delay. Yield losses associated with harvest delays are magnified at high plant populations (Table 4-10) and hybrid susceptibility to stalk rots. Ear damage by corn borers, Western bean cutworm and other insects may also increase the potential for grain quality problems caused by ear molds.

Shelled grain weights can be adjusted using a grain shrink table (Table 4-19). Shrink represents both the moisture loss and a 0.5 percent dry matter loss encountered during drying and grain handling. To estimate the amount a given wet weight of corn will lose during the drying process, multiply the wet weight by the shrink factor from the table. For example, assume that 1 ton (2000 pounds) of shelled grain at 25 percent moisture will be dried to 15.5 percent moisture. Drying and handling losses are 2000 pounds multiplied by 0.1174, or 235 pounds. This results in 2000 pounds minus 235 pounds, or 1765 pounds of grain at 15.5 percent moisture. Monitor debris and cracked corn in the grain as harvesting progresses. Debris and cracked corn lower grain quality and increase the potential for spoilage of stored corn.

Test Weight and Shelled Corn Grades

Test weight of corn determines the weight of a bushel volume (1.244 cubic feet) of grain. Test weights determined on dry (15.5 percent moisture) corn indicate whether the grain crop reached full maturity. Low test weights indicate immaturity. If bushel test weight of mature corn is determined at harvest when grain moistures are greater than 15.5 percent, the test weights will be biased downward. In other words, as corn grain dries, test weight increases. Differences in test weight influence USDA grading of shelled corn (Table 4-20). The adjustments in test weights do not apply if grain contains more than 10 percent broken kernels, was damaged by drought or disease, was harvested when immature or was dried at air temperatures of 180 degrees Fahrenheit or higher.

Table 4-19: Shelled-Grain Shrinkage.

Percent Grain Moisture	Percent Shrinkage When Grain is Dried To:*					
	13.0%	13.5%	14.0%	14.5%	15.0%	15.5%
13.0	0	0	0	0	0	0
13.5	1.07	0	0	0	0	0
14.5	2.22	1.66	1.08	0	0	0
15.0	2.80	2.23	1.66	1.09	0	0
15.5	3.37	2.81	2.24	1.67	1.09	0
16.0	3.95	3.39	2.83	2.25	1.68	1.09
16.5	4.52	3.97	3.41	2.84	2.26	1.68
17.0	5.10	4.55	3.99	3.42	2.85	2.28
17.5	5.67	5.12	4.57	4.01	3.44	2.87
18.0	6.25	5.70	5.15	4.59	4.03	3.46
18.5	6.82	6.28	5.73	5.18	4.62	4.05
19.0	7.40	6.86	6.31	5.76	5.21	4.64
19.5	7.97	7.44	6.90	6.35	5.79	5.23
20.0	8.55	8.01	7.48	6.93	6.38	5.83
20.5	9.12	8.59	8.06	7.52	6.97	6.42
21.0	9.70	9.17	8.64	8.10	7.56	7.01
21.5	10.27	9.75	9.22	8.69	8.15	7.60
22.0	10.84	10.33	9.80	9.27	8.74	8.19
22.5	11.42	10.90	10.38	9.86	9.32	8.78
23.0	11.99	11.48	10.97	10.44	9.91	9.38
23.5	12.57	12.06	11.55	11.03	10.50	9.97
24.0	13.14	12.64	12.13	11.61	11.09	10.56
24.5	13.72	13.22	12.71	12.20	11.68	11.15
25.0	14.29	13.79	13.29	12.78	12.26	11.74
25.5	14.87	14.37	13.87	13.37	12.85	12.33
26.0	15.44	14.95	14.45	13.95	13.44	12.93
26.5	16.02	15.53	15.03	14.54	14.03	13.52
27.0	16.59	16.11	15.62	15.12	14.62	14.11
27.5	17.17	16.68	16.20	15.70	15.21	14.70
28.0	17.74	17.26	16.78	16.29	15.79	15.29
28.5	18.32	17.84	17.36	16.87	16.38	15.88
29.0	18.89	18.42	17.94	17.46	16.97	16.48
29.5	19.47	19.00	18.52	18.04	17.56	17.07
30.0	20.04	19.58	19.10	18.63	18.15	17.66
30.5	20.61	20.15	19.69	19.21	18.74	18.25

*All percentages include actual moisture loss plus 0.5 percent for dry matter loss. The shrinkage percentage may be applied to pounds, bushels, tons and all other units of quantity.

Table 4-20: USDA Grades and Grade Requirements for Shelled Dent or Flint Corn.

Grade	Minimum Test Weight per Bushel (lbs.)	Maximum Limits of:		
		Damaged Kernels Heat Damaged Kernels (%)	Total (%)	Broken Corn and Foreign Material (%)
U.S. No. 1	56.0	0.1	3.0	2.0
U.S. No. 2	54.0	0.2	5.0	3.0
U.S. No. 3	52.0	0.5	7.0	4.0
U.S. No. 4	49.0	1.0	10.0	5.0
U.S. No. 5	46.0	3.0	15.0	7.0

U.S. Sample grade is corn that:

- (a) Does not meet the requirements for U.S. Grade Numbers 1, 2, 3, 4, or 5; or;
- (b) Contains stones with an aggregate weight in excess of 0.1% of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 2 or more castor beans (*Ricinus communis* L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 8 or more cocklebur seeds (*Xanthium* spp.), or similar seeds singly or in combination, or animal filth in excess of 0.2% in 1,000 grams; or
- (c) Has a musty, sour, or commercially objectionable foreign odor; or
- (d) Is heating or otherwise of distinctly low quality.

Source: USDA-GIPSA.

Ear Corn

Ear corn can be cribbed safely when the grain moisture is 21 percent or less. However, with cold weather and narrow (4 foot), well-ventilated cribs, corn may be stored when grain moisture is several percentage points higher. Use Table 4-21 to convert ear corn yields to shelled corn equivalents. For example, 4 tons (8,000 pounds) of ear corn at 21 percent grain moisture is equivalent to 8000 divided by 77.7 or 103 bushels of shelled corn.

Table 4-21: Weight of Corn (Shelled and Ear) to Equal 56 Pounds (1 Bu Shelled Corn) at 15.5 Percent Moisture.

Percent Grain Moisture	Weight (lb)	
	Shelled	Ear
11.0	53.17	66.04
11.5	53.47	66.50
12.0	53.77	66.97
12.5	54.08	67.46
13.0	54.39	67.97
13.5	54.71	68.49
14.0	55.02	69.02
14.5	55.35	69.57
15.0	55.67	70.13
15.5	56.00	70.70
16.0	56.33	71.28

Percent Grain Moisture	Weight (lb)	
	Shelled	Ear
16.5	56.67	71.87
17.0	57.01	72.47
17.5	57.36	73.09
18.0	57.71	73.71
18.5	58.06	74.34
19.0	58.42	74.98
19.5	58.78	75.62
20.0	59.15	76.28
20.5	59.52	76.94
21.0	59.90	77.60
21.5	60.28	78.27
22.0	60.67	78.94
22.5	61.06	79.62
23.0	61.45	80.31
23.5	61.86	80.99
24.0	62.26	81.68
24.5	62.68	82.37
25.0	63.09	83.06
25.5	63.52	83.75
26.0	63.95	84.44
26.5	64.38	85.14
27.0	64.82	85.83
27.5	65.27	86.53
28.0	65.72	87.22
28.5	66.18	87.91
29.0	66.65	88.61
29.5	67.12	89.30
30.0	67.60	90.00
30.5	68.09	90.69
31.0	68.58	91.39
31.5	69.08	92.08
32.0	69.59	92.78
32.5	70.10	93.48
33.0	70.63	94.18

Corn Silage

Corn harvested for silage yields one-third more feed nutrients per acre than corn harvested for grain. Corn in the full dent stage produces 50 percent more feed than in the milk stage and 100 percent more feed than in the silking stage. Corn harvested in the milk or silking stage results in poorer quality silage because of its high moisture content.

One of the most important steps in producing quality corn silage is to harvest at the proper moisture. The storage structure determines the proper moisture level at which to harvest.

Desired moisture levels for different structures are as follows:

Sealed airtight silos – 55 to 60 percent

Bag silos – 60 to 70 percent

Upright silos – 62 to 68 percent

Trench silos – 65 to 70 percent

Ideally moisture levels in the silage should be monitored at harvest to prevent harvesting the crop outside the desired range. If moisture testing is not feasible, then estimate the crop moisture by the stage of crop development.

Kernel milk line can serve as an indicator of whole plant moisture levels. As kernels start to dent, a separation between kernel starch and milk can be seen. The firm starch is deposited in the crown (outer) area of the kernel, and the milk occupies the basal area of the kernel. This appears as a whitish line separating the two areas. As the crop matures, this kernel milk line moves down the kernel, and the whole plant moisture declines. When this line reaches the midpoint of the kernel, 90 percent of the final kernel dry weight has been achieved and silage yields reach a maximum. At this point, the stover part of the plant has good digestibility, and the moisture is usually in the desired range for storage in airtight silos.

A higher moisture level and a slightly earlier harvest is recommended for bunker silos (full dent to one-quarter milk line) and upright conventional silos (one-quarter to one-third milk line). Harvest time can be predicted by monitoring the progression of the milk line. When the milk line reaches the base of the kernel, a black layer forms and the crop is physiologically mature.

Silage harvest should not be delayed beyond the black layer point because the silage gets too dry, the kernels tend to harden, and the digestibility of the stover declines rapidly. The desired chopping length for corn silage is 5/8 to 3/4 inch. If silage is harvested when the crop moisture is lower than desired, consider chopping finer than normal to promote good packing and to minimize air pockets in the silage. For more information on producing silage, consult North Central Regional (NCR) publication 574, *Corn Silage Production: Management and Feeding*.

Specialty Corns

The type of corn most widely planted in Ohio and across the U.S. is yellow dent. High grain and silage yield potential, high feed value, and availability of adapted superior hybrids account for the widespread use of yellow dents. Yellow dents have the highest content of carotene (vitamin A) of the cereal grains. Other types of corn include flint, pop, waxy and sweet. Most specialty corns have unique kernel characteristics that determine its use and how it is grown.

Because most specialty corn hybrids (including white dent, waxy, high oil, and popcorn) are grown under contract, it is advisable to identify a market before planting. Also, some specialty corn processors specify certain hybrids and cultural practices they want growers to use. Contracts for growing specialty hybrids usually offer a premium over the yellow dent price to compensate for the lower yield potential and the special handling required to ensure high grain quality. More information on specialty corns for identity preserved (IP) grain production is available online at: oardc.ohio-state.edu/hocorn/. Some of the specialty corns grown in Ohio and the U.S. in recent years include:

WHITE CORN White corn types are equal to yellow types in carbohydrate content but are deficient in vitamin A. White types are grown primarily for direct human consumption for use in Mexican-style and other corn-based foods including tortillas, corn flakes, corn meal, grits and hominy. Yields of white hybrids are generally not competitive with yellow dent yields. White corn has been among the most widely grown specialty corns but accounts for less than 1 percent of U.S. corn production.

WAXY CORN The carbohydrate or starch granules of regular dent corn consist of approximately 75 percent amylopectin and 25 percent amylose. Waxy corn has nearly 100 percent amylopectin. Waxy corn was initially recognized as a valuable source of industrial starch. The stability and clarity of amylopectin starch make it highly suitable as a food thickener. Waxy corn has also been considered as a potential animal feed. Feeding trials with waxy corn hybrids have occasionally shown a benefit, but they have not been consistent. Changes in feed efficiency and production have been insignificant, but usually in favor of the waxy corn hybrids. Yields of waxy corns are generally lower than those of yellow dent corn.

HIGH-LYSINE CORN The quantity of two essential amino acids in yellow dent corn, lysine and tryptophan, is below nutritional requirements for humans and nonruminant (single stomached) animals, such as pigs and chickens. High-lysine corn corrects this deficiency and may offer advantages in feeding rations. Adapted high-lysine corn hybrids are limited in number and have generally been lower in grain yield than normal dent varieties. The softer kernels of some high-lysine corn hybrids are more vulnerable to breakage at harvest, which has led to a higher incidence of kernel or ear rot.

HIGH-OIL CORN High-oil corn (HOC) contains 50 to 100 percent more oil than normal yellow dent corn, which averages about 4 percent oil on a dry weight basis. High-oil corn has been promoted as a livestock feed because it has greater energy value than normal yellow dent corn and can replace more expensive dietary sources of fats and proteins. Feeding trials with HOC indicate that it has improved feed efficiency and results in increased rate of

gain over conventional corn. However yields of HOC are lower than conventional hybrids. In the late 1990s, HOC acreage increased to more than one million acres. Since then, HOC acreage has dropped sharply. A major factor contributing to this decline is the availability of cheaper sources of oils and fats which compete with HOC as an energy source in livestock feed rations.

These specialty corns must be grown in isolation from yellow dents to prevent cross-pollination and maintain purity standards required by the end user. Separation distances recommended by seed companies range from 60 to 300 feet depending on the specialty corn being grown. These distances can often be adjusted if harvested grain is separated by varying numbers of border rows from the rest of the field.

POPCORN Popcorns are essentially small-kerneled flint corns and are among the most primitive of the surviving races of corn. Kernels contain a hard endosperm with only a small portion of soft starch. Popcorns are generally either pearl or rice types. Pearls have smooth, rounded crowns, and rices are pointed. Heating the kernel turns the moisture inside the soft starch in the center into steam that explodes the kernel inside out. The greater the expansion, the higher the quality. Hybrids differ as to kernel quality, which also includes flavor, tenderness, absence of hulls, color, and shape. Popcorn hybrids usually yield less than half of normal dent hybrids. To achieve maximum quality, minimize mechanical damage and dry with low heat to a moisture of 13.5 percent. Overdrying and kernel damage result in reduced popping volume. Handling and quality are extremely important aspects of popcorn production. From an agronomic standpoint, popcorn must be planted to mature before frost, and herbicide programs must be labeled for popcorn. Fertility programs for popcorn and conventional yellow dent corn can vary, e.g., pay close attention to potassium fertility to guard against poor stalk quality and lodging. Most popcorn in the U.S. is grown under contract for processors and companies. Growers producing popcorn commercially generally follow cultural practices, plant popcorn hybrids, etc., specified by these companies. The isolation requirements for popcorn are not as critical as they are for other specialty corns because some popcorn hybrids are dent-sterile and cannot be pollinated by conventional dent corn hybrids.

Several seed companies have evaluated their existing conventional grain hybrids to determine which are best suited for ethanol production using the wet milling and dry-grind ethanol production methods. Most of the current ethanol output is produced using the dry-grind corn process, whereas wet milling plants (corn refineries) account for the remainder. The dry-grind method produces more gallons of ethanol per bushel of corn grain. Hybrids with high levels of extractable starch are best suited for ethanol production using the wet milling procedure. Such hybrids have been characterized as high extractable starch (HES) hybrids. Hybrids best suited for the dry-grind procedure generally contain high total fermentables and have been

characterized as highly fermentable (HTF – high total fermentables) corn hybrids. Hybrids with HTF may not necessarily include the HES trait, nor is either trait necessarily correlated with total starch content. Some hybrids naturally release a higher percentage of the kernel's starch in the wet milling process. The HES trait is related to the extractability of starch from the kernel. Total fermentables are the sum of all starch and simple sugars that can be utilized by yeast cells used in the fermentation process to produce ethanol. Many hybrids with HES or HTF have high grain yield potential and are widely adapted to Corn Belt growing conditions. Unlike most specialty corn traits, HES and HTF do not require rigorous IP protocols to ensure their expression.

ENOGEN® CORN Enogen® corn is a special type of corn developed and introduced by Syngenta for ethanol production. It contains a transgene from a bacteria that produces alpha amylase, an enzyme that breaks down corn starch into sugar. Presently alpha amylase enzyme is added to corn in a liquid form during the ethanol production process. Corn hybrids with the Enogen trait technology (i.e., Enogen corn) express alpha amylase enzyme directly in the corn kernel, eliminating the need for liquid alpha amylase in dry grind ethanol production. To prevent contamination of commodity grain by Enogen grain, Syngenta has established a stewardship program. Management practices that farmers under contract are required to follow include planting buffers of non-Enogen corn around fields planted to Enogen corn, storing the Enogen grain in separate bins, and cleaning planters and combines between uses.

Isolation Requirements for Identity Preserved (IP) Non-GMO Corn Production

Managing pollen drift is an important consideration in the production of specialty corns and non-GMO (non-transgenic) corn as IP grain crops. Corn is a cross-pollinating crop in which most pollination results from pollen dispersed by wind and gravity. Although most of a corn field's pollen is deposited within a short distance of the field, with a 15-mph wind pollen may travel as far as ½ mile in a couple of minutes. Pollen from corn containing transgenes—genetically modified organism (GMOs), such as *Bt* corn—may contaminate (by cross-pollination) nearby non-GMO corn.

The European Union guidelines require that foods, including grains, containing more than 0.9 percent biotech material (GMOs) are labeled as genetically engineered. Ohio producers of IP non-GMO corn, such as organic farmers, need to minimize pollen contamination by GMO corn if they are to obtain premiums. This can be challenging since most of the corn planted in Ohio is GMO corn. Growers can follow several planting practices to minimize GMO pollen contamination, including use of isolation and border rows, planting dates and/or hybrid maturity.

Several state seed certification agencies that offer IP grain programs for corn require that non-GMO IP corn be planted at a distance of at least 660 feet from any GMO corn. This isolation distance requirement may be reduced by removing varying numbers of non-GMO border rows, the number of which is to be determined by the acreage of the non-GMO IP corn field. These isolation and border-row requirements are designed to produce corn grain that is not more than 0.5 percent contaminated with GMOs.

In recent years the demand for organic corn has increased sharply. Although organically produced corn hybrid seed is available for planting, some organic corn growers prefer to grow open-pollinated varieties. Open-pollinated varieties are perceived as more nutritional and less likely to have been contaminated by transgenic traits. Because of their superior agronomic performance, hybrids account for nearly all the corn produced in the U.S. In comparisons

of open-pollinated varieties with hybrids in the Ohio Corn Performance Test, hybrid yields averaged 60 percent greater than those of the open-pollinated varieties. Stalk lodging was higher in the open pollinated varieties (29 percent versus 8 percent).

Several seed companies producing non-GMO corn seed for organic growers have been marketing hybrids that contain the PuraMaize™ gene system, also known as the Ga1-s isolating mechanism. This is a naturally occurring gene in corn that impedes pollen originating from a plant that does not have the Ga1-s gene from being able to pollinate a plant that does have the Ga1-s gene. As a pollen recognition system, corn plants that contain the PuraMaize gene system will quickly accept pollen from other PuraMaize plants and essentially block pollen from foreign plants, such as GMO corn, allowing the pollen from PuraMaize plants to fertilize the developing kernels.

Chapter 5

Soybean Production

By Dr. Laura Lindsey, Dr. Kelley Tilmon, Dr. Andy Michel and Dr. Anne Dorrance



NOTE: Material in this chapter related to pesticides may not be valid after 2017. Please contact the County Extension office or the Agronomy Team website, agcrops.osu.edu, for current information.

The major objective of a crop production system is the interception, fixation, and storage of sunlight energy. There are many components of a system that will accomplish that objective. The most important are early planting, narrow rows, productive varieties that resist disease, the control of weeds, insects, and diseases that rob energy from the system, and providing soil nutrients in adequate amounts. Other inputs to the system must not limit energy fixation or slow the process. Following is a discussion of the effects, interactions and relationships of various inputs of an efficient soybean production system.

Variety Selection

Most soybean varieties have genetic yield potentials well over 100 bushels per acre. A variety's adaptability to the environment and production system where it will be used sets the yield potential of the production system. The quality of the weather during the growing season and the stresses from weeds, diseases, and insects determine what the crop yield will be. A variety's performance in a previously conducted yield trial is a measure of its performance in that particular environment and production system, and does not assure satisfactory performance under a different set of conditions. When a group of varieties is tested for yield over a range of environments, their rank order commonly changes, which indicates that some varieties are better adapted to a specific environment than others. Therefore, it is best to select varieties with characteristics that will help them perform well in the cultural system and environment to be used rather than on their yield record alone. For example, if excessive growth and lodging are problems, then select varieties that are medium to short in height with good standability. If the field has a history of *Phytophthora*, then select a variety with a resistance gene plus a high partial resistance rating to address that problem. The selection of medium or small seed when using a grain drill will improve metering and stand uniformity. Alternatively, select the varieties that performed best at a test site that is similar to the field for which a variety is being selected, or select a variety that has performed well over several test sites and years that vary widely in yield potential. Maturity information should

be used to select varieties that mature at different times to allow for timely harvest. Generally, each 10-day delay of planting in May delays maturity three to four days in the fall. For best yields in wide rows, select full-season varieties with a bushy growth habit. Growth habit is not important in narrow rows. Fitting the variety to the environment is superior to selecting a variety and hoping the environment and weather will fit it.

Variety Performance Trials

The purpose of the Ohio Soybean Performance Trials is to provide an unbiased evaluation of variety characteristics and performance to facilitate the selection of varieties appropriate for particular production sites and systems. Field trials are conducted at six locations representing the diverse production regions of Ohio. Data are collected on yield, lodging, seed size, plant height, and grain quality (oil, protein, and fiber content). The data for approximately 200 entries are published each December as a supplement in Ohio's Country Journal, *Ohio Soybean Performance Trials*. Details of testing and evaluation procedures are included in the supplement, which is also available, free of charge from county Extension offices and on the internet at: u.osu.edu/perf.

Disease Control

EARLY SEASON AND SEED-BORNE DISEASES *Phytophthora* root and stem rot is the most serious soybean disease in Ohio and is present everywhere soybeans are grown. Damage to the crop by *Phytophthora* is most prevalent in fields with poor drainage, high number of years with soybeans, and reduced tillage systems. Varieties are susceptible at all stages of growth. Saturated soil with a temperature above 60 degrees Fahrenheit provides the ideal conditions for infection. Susceptible varieties should not be grown in poorly drained soils or on soils known to have a history of the disease. Seed of varieties with good partial resistance should be treated with a fungicide that aids in the control of *Phytophthora* damping off. Varieties with *Rps* genes should also be treated to control *Phytophthora* damping off because these *Rps* genes are not effective in every field nor across the whole field. Planting early, well before soil temperatures reach 60 degrees Fahrenheit, often allows varieties with high levels of partial resistance to escape early infection if the soil does not become saturated.

Pythium and *Rhizoctonia* root rots are also common in Ohio and most varieties are susceptible. Damage to plant stands is greatest on poorly drained soils and during seasons of high rainfall.

Phomopsis seed rot can be severe when rainfall occurs intermittently during grain drydown and harvest. The longer soybeans are in the field after ripening, the greater the incidence of seed rot. Harvesting soon after the soybeans mature (15 to 20 percent moisture) decreases the amount of seed damage. Using varieties with a range of maturities allows for a more timely harvest of each field. Many varieties are resistant to *Phomopsis* seed rot; if *Phomopsis* develops in a variety, look for a different variety for future years. Crop rotation and tillage are excellent management tools for this seed rot pathogen as it survives on old crop residue.

Phomopsis seed rot can reduce overall germination in certain seed lots and *Phytophthora*, *Pythium* and *Rhizoctonia* can kill seeds and seedlings after they are planted. One of the management tools for these seed and soil-borne plant pathogens is to use fungicide seed treatments. No one fungicide is highly effective for all pathogens. Choosing a mix of several compounds will provide broad spectrum control. Seed treatments are best used on fields with poor drainage, a history of stand establishment problems, and reduced tillage systems.

MID-SEASON TO LATE-SEASON SOYBEAN DISEASES

Soybean cyst nematode (SCN) exists in production fields throughout Ohio. In some fields, the population of SCN is currently quite high (>10,000 eggs per cup of soil). Populations of SCN may take eight to 10 years from introduction to reach damaging levels throughout a field. In a variety test in west central Ohio on a fertile, dark-colored soil, varieties resistant to SCN yielded over 50 bushels per acre, whereas those susceptible to SCN yielded from 24 to 39 bushels per acre. Although these studies were conducted in problem fields, the estimated yield loss from SCN in other Midwestern states is 8 to 12 percent.

In the vast majority of fields in Ohio, SCN causes no above-ground symptoms. The only difference that growers will see is that yields may be 5 to 10 bushels less than fields with similar yield potential. In more severe situations, where SCN populations are high, injury is easily confused with other crop production problems, such as nutrient deficiencies, injury from herbicides, soil compaction or other diseases. The first field symptoms are usually detected in circular to oval patches of stunted, yellowed plants. Symptoms are most evident in late July or August when plants are under drought stress or in fields with low fertility. When populations of nematodes are high, the symptoms may even occur under normal to optimal growing conditions. Affected areas of a field may increase in size each year in the direction of tillage. In these affected areas, SCN females can often be found feeding on the roots.

Soybean cyst nematode is best managed with crop rotation, rotating non-host crops such as wheat, corn, alfalfa or

red clover and rotating sources of SCN resistance. Never plant a SCN resistant variety without checking your SCN population levels first. When a non-host crop is planted, SCN populations will decline by as much as 50 percent annually. Soybean cyst nematode resistance is measured by a reduction in the number of females that feed on roots, but a few females will reproduce. Thus, over time, populations will adapt to these sources of resistance and reproduce in increasing numbers.

To determine what your SCN levels are, soil samples should be collected. Each field should be divided into sections not exceeding 10 acres and each section sampled by taking 15 to 20 subsamples in a zigzag pattern. This level of sampling is necessary to obtain relatively accurate counts of the nematode population and to make meaningful recommendations for control. The soil samples should be moist, but not wet, packaged in double plastic bags, and protected from becoming too warm. Mail samples to: C. Wayne Ellett Plant and Pest Diagnostic Clinic, The Ohio State University, 8995 E. Main Street, Bldg. 23, Reynoldsburg, Ohio 43068. The telephone number for the clinic is: 614-292-5006. A short video showing how to properly sample for SCN can be found here: [youtube.com/watch?v=FQgg-UPQdcs&feature=youtu.be](https://www.youtube.com/watch?v=FQgg-UPQdcs&feature=youtu.be).

Phytophthora stem rot will continue to infect plants throughout the growing season. This late season phase of the disease can only be found in fields where heavy rains or saturated soils have occurred, varieties with ineffective *Rps* genes and low levels of partial resistance. If the *Rps* genes are effective against the *P. sojae* population, then no disease will develop; however if they are no longer effective, the stem rot will develop. We have found from a number of years and locations that varieties with high levels of partial resistance rarely develop stem rot. One reminder that not all seed companies use the same scoring system.

Sclerotinia stem rot is present throughout most of Ohio and may be severe (50 percent of plants in a field infected) when wet weather occurs prior to and during flowering. Varieties with resistance to *Sclerotinia* have fewer numbers of plants infected but all are susceptible to some degree. Stem symptoms first appear as water-soaked lesions followed by cottony growth and eventually, black irregular-shaped sclerotia which resemble mouse droppings. Wide rows (30 inches) aid in control by permitting air to move through the canopy to dry plant leaves and the soil surface but also reduce yield due to less sunlight fixation. Reduction in plant populations (160,000 to 180,000) and planting in 15-inch rows can reduce overall incidence of *Sclerotinia* stem rot without negatively impacting yields.

Brown stem rot can severely reduce yield. This fungus enters the plants through the roots and slowly colonizes the stem and the xylem, where it interferes with water transport. The disease symptoms develop after flowering and are identified by an internal browning of the stem in August. Foliar symptoms are rarely seen in Ohio, but the

leaves of infected plants may suddenly wilt and dry 20 to 30 days before maturity and drop from the plant. Crop rotation is an excellent control for this disease.

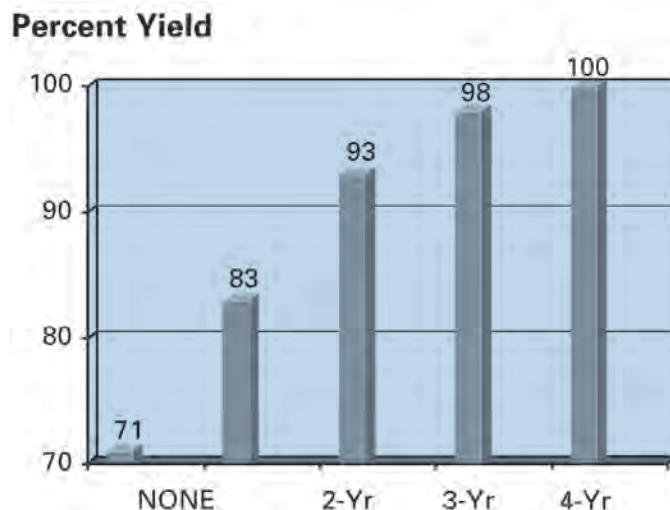
Sudden Death Syndrome (SDS) is another late season disease that always appears to be associated with soybean cyst nematode and areas of the field with very poor drainage. Symptoms are very similar to brown stem rot in that brown spots develop in the leaves between the veins, surrounded by a bright yellow chlorosis. In SDS, the roots are very degraded along with the crown. One of the key diagnostic tools is the color of the pith, which remains white and healthy with SDS and is brown and decayed with brown stem rot. This fungus survives in soil for long periods of time, so to prevent rapid build-up of the pathogen, crop rotation and improving soil drainage are key.

Crop Rotation

Crop rotation is the most effective pest control practice available to crop producers. The sequence of crops grown in a field affects the productivity of each crop. Research from most Midwest states indicate that a soybean crop following a crop other than soybeans will usually yield about 10 percent more grain, on average, than when soybeans follow soybeans. Many of the crop disease and insect problems currently experienced in Ohio are due to short crop rotations or no crop rotation. If all our crops were produced in a four-year crop rotation, yield loss to disease and insects would be near zero rather than at the 8 to 12 percent we currently experience. The effect of crop rotation on yield has been thoroughly investigated by most land-grant universities. Researchers at the University of Wisconsin conducted a crop rotation study with corn and soybean. Averaged across 29 years by location environments, corn and soybeans in their corn-soybean rotation resulted in 13 percent and 11 percent greater yield than the respective monoculture. Kansas State University conducted a 20-year crop rotation study in which the soybean yields were 20 percent greater when rotated with wheat or grain sorghum than without rotation. Results of a Canadian crop rotation study show that soybean yields from a wheat-corn-corn-soybean rotation were 7.1 percent higher than in a corn-corn-soybean rotation. Results of a 10-year crop rotation study conducted in northern Ohio indicated that continuous corn yielded only 89 percent as much as corn in a corn-oats-hay rotation, and corn in a corn-soybean rotation yielded 94 percent of the corn-oat-hay rotation.

Economics often dictate crop sequence, but where choices are available, soybeans should follow crops other than soybeans. Corn or other grass crops can make good use of the nitrogen left by legume crops. The effect of the length of a crop rotation on yield can be seen in Figure 5-1.

Figure 5-1. Effect of length of crop rotation on percent crop yield.



Tillage

Tillage disrupts soil aggregates, and repeated disruption destroys soil structure. It also causes a long-term decline in soil organic matter, which further destabilizes soil structure. Tillage disrupts the continuity of large soil pores and restricts the movement of water through the soil profile, creating soil drainage problems. Repeated use of tillage tools operating at the same depth, or when the soil is too wet, results in the formation of compacted zones which restrict both water movement and root development.

Secondary tillage operations performed to prepare fine seedbeds usually cause the formation of impermeable crusts on light-colored silt loam soils such as Blount and Crosby. These crusts reduce seedling emergence, air exchange and water intake, all of which reduce yields. When thick crusts form, disrupting them by rotary hoeing or cultivation often improves yield, particularly in dry years.

Tillage is one of the largest out-of-pocket expenses used for crop production and often does not generate enough yield to make the tillage profitable. While no-till can reduce production costs and increase profits, it also creates problems that producers must solve with proper management of the other inputs and production practices. Some of these problems are colder, wetter soil at planting, more root rot disease, slower emergence and growth, dealing with crop residues and the diseases they contain, etc. There are times when tillage is warranted, and will likely be profitable. Here is a partial listing of some of the situations when tillage may be needed:

1. Use tillage when inadequate soil drainage leads to serious yield loss due to root rot diseases, poor stand establishment or late planting.
2. Use tillage to bury crop residue and thus reduce pathogen and insect survival that can infect a following crop.

- Use tillage as a prelude to land leveling, rock removal, and for the incorporation of soil amendments such as lime or very high rates of fertilizer.
- Use tillage to mitigate compacted soil layers or zones that interfere with water movement into and through the soil which may delay planting, harvesting and other field operations.

The cost to perform various tillage operations and the yield increases needed to pay for those operations can be found in Table 5-1.

Table 5-1: Cost of Various Tillage Operations and the Yield Increases of Corn, Soybean and Wheat Required to Pay the Cost.

Operation*	Typical cost (\$/ac)	Yield increase (bu/ac) required to pay for tillage**		
		Corn	Soybean	Wheat
Chisel Plow	17.80	4.7	2.0	3.9
Disk Chisel	17.85	4.7	2.0	3.9
Field Cultivator	13.55	3.6	1.5	2.9
Land Leveling	13.50	3.6	1.5	2.9
Moldboard Plow	21.25	5.6	2.4	4.6
Strip Tillage	17.25	4.5	1.9	3.8
Sub-Soiling	19.85	5.2	2.2	4.3
V-Ripping	20.45	5.4	2.3	4.4

*Cost of tillage operations from Ohio Farm Custom Rates 2016 available at: aede.osu.edu/about-us/publications/ohio-farm-custom-rates-2016

**Based on corn, soybean and wheat prices of \$3.80, \$8.85 and \$4.60 per bushel, respectively.

Producing Soybeans Without Tillage

Growing soybeans in Ohio without tillage has become both practical and profitable, and often reduces or eliminates some tillage related problems. Time savings accrued by eliminating tillage can be invested in earlier and more careful planting or the planting of more acres. Maintenance of crop residue on the soil surface reduces soil crusting, which can lead to better and more uniform seedling emergence; improved yields on some soils; and reduced needs for rotary hoeing, cultivating and replanting. In addition, no-till systems do not bury weed seeds, reducing the germination potentials of some species, particularly “large seeded” broadleaf weeds. Finally, use of no-till systems can prolong the life of surface drainage improvements, particularly on flatter fields.

When planting no-till soybeans, growers should pay attention to soil drainage; planting procedures; crop rotation options; and disease, insect, and weed control. While the improper management of any of these factors will reduce

yields in tillage systems, their effects can be much more adverse with no tillage. The following problems are created by removing tillage from the crop production system and important adjustments must be made to offset those negative effects:

1. Cooler soil temperatures slow germination, emergence and early growth.

Because the soil is warmer at the surface than at the 1.5-inch planting depth, the solution is to plant shallow (1 inch), but in moist soil. The warmer soil temperatures at shallow depth will enable seeds to germinate and emerge earlier and, in effect, produce a closed leaf canopy and get to the reproductive stage sooner. The use of narrow rows (7.5 inches) will compensate for the slower early growth associated with no-till production. Good seed to soil contact and the use of high quality seed treated with the appropriate fungicides promotes the rapid emergence of a healthy crop. Slower planting speed will allow the planting tool to space seed more uniformly in the row and at a more uniform depth so that seeding rates can be reduced, thus lowering production costs.

2. Root rot diseases are much more severe due to a wetter and cooler soil environment.

Two actions can increase plant stands and improve root health:

Select varieties with high levels of Phytophthora partial resistance that will give a good level of protection against all strains of Phytophthora, and then treat the seed to protect the seedling from Phytophthora and Pythium root rot until the partial resistance mechanism takes effect just after emergence.

Another strategy is to use soybean varieties that have one or more Rps resistance gene(s) for control of Phytophthora root rot. Other broad spectrum fungicides will control other diseases that damage the root system and lower stand counts. No-till is not advised for poorly drained fields, and do not plant when the soil is too wet for shallow tillage. Tillage or planting operations on a wet soil compacts the soil particles which inhibits the proper development of root systems and thus reduces yield. For additional information on controlling soybean diseases see: agcrops.osu.edu.

3. Heavy crop residue and more dense soil can interfere with proper seeder function and lead to poor distribution, poor placement of seed and lack of adequate depth control.

Spreading crop residue evenly when harvesting will help keep the field surface uniformly covered with residue and at uniform moisture so the entire field is ready to plant at the same time. Due to its fineness, wheat residue keeps the soil colder and wetter than other residues because it provides nearly 100 percent cover

and its light color reflects sunlight. Remove wheat straw when possible and partially incorporate the stubble with a disk to promote its degradation.

Try not to plant on old corn rows since old corn roots interfere with depth control and seed placement. Maintain a down pressure of at least 200 pounds on each row opener to penetrate hard soil areas and use a good depth control mechanism to maintain the proper seeding depth in soft soil. A residue cutting coulter will prevent hair pinning of residue into the seed furrow which interferes with seed placement, and it will also loosen some soil that the furrow closers can use to cover seed and improve seed-to-soil contact.

Rhizobium Inoculation

Twenty-seven soybean inoculation trials were conducted between 2013 and 2014 in fields with a history of soybean production. Across the 27 trials (10 locations and six inoculant products), the average yield increase due to inoculant was 1.5 bushels per acre. Due to the relatively small yield increase associated with inoculant, we can only report the 1.5 bushel per acre yield increase at a 70 percent confidence level. The cost of inoculating an acre of soybeans is \$4 to \$5, depending on the product and rate used. If soybeans are worth \$9 per bushel, the per acre profit for inoculating soybeans would be about \$13 to \$14 per acre.

When loading a drill or planter using an auger, liquid or dry inoculation materials should be added to the seed as it enters the auger for thorough application. When loading a planter or drill from bags, fill the seed box to a depth of 3 inches and scatter an appropriate amount of inoculum over the seed and mix thoroughly. Continue to add seed in 6-inch layers, treating each until the box is filled. With some dry materials, it may be necessary to moisten seed slightly to increase adherence. A few small specks of inoculum on each seed is adequate. At the recommended use rate, there will be more than 500,000 bacterial cells on each seed. Excessive amounts of inoculum on seed can reduce seed metering by up to 35 percent. Seeding equipment should be calibrated using the treated seed to be planted. Some seeding rate monitors allow a continuous check of seeding rates so adjustments can be made to the seeding rate if and when necessary.

When soybeans are planted in a field for the first time, it is not uncommon for even the most ideal inoculation procedures to be less than adequate for producing enough nitrogen for a good crop. When the nodules are insufficient to supply adequate nitrogen, it will be necessary to supply some nitrogen to the crop. In this event, one application of 75 pounds actual nitrogen as urea can increase yields by 8 to 12 bushels per acre. This supplemental nitrogen should not be applied until flowering, which is usually late June and July depending on variety maturity, date of planting, and the weather. To assure the establishment of a reliable inoculation for future years, it is advisable to grow soy-

beans in a new field two successive years and to inoculate the seed thoroughly both years.

For satisfactory nitrogen fixation in eastern Ohio where soils tend to be more acid, the pH in the plow layer should be above 6.5, and the percent base saturation of calcium and magnesium should be greater than 40 and 10 percent, respectively. On fields where the lime requirement is very high, a shallow incorporation (2 to 4 inches) of 2 to 4 tons of dolomitic limestone will aid in the establishment of bacterial colonies on the root system. Dolomitic limestone should be used whenever magnesium levels are lower than 10 percent base saturation.

Planting Date

The date of planting has more effect on soybean grain yield than any other production practice. The results of a two-year planting date study conducted in Clark County, Ohio are shown in Figure 5-2. Yield loss resulting from delayed planting ranges from ¼ bushel to more than 1 bushel per acre per day, depending on the row width, date of planting, and plant type. In southern Ohio, soybeans should be planted any time after April 15 when soil conditions are suitable. In northern Ohio, planting should begin the last few days of April if soil conditions are satisfactory. Soybeans should not be planted until soil temperatures reach 50 degrees Fahrenheit and moisture is present at the planting depth of 1 to 1.5 inches. Planting too early (before field conditions are adequate) comes with a risk. Factors such as damping-off and pressure from bean leaf beetles are concerns to keep in mind, as well as the possibility of a late-spring frost.

Regardless of planting date, row width or plant type, the soybean crop should develop a closed canopy (row middles filled in) prior to flowering or by the end of June, whichever comes first. Generally, when planting in early May, rows must be less than 15 inches apart to form a canopy by late June (Table 5-2). An early canopy results in high yields because more sunlight is intercepted and converted into yield than when row middles do not fill in until late in the growing season. Assuming a half bushel per acre per day yield loss with delayed planting, a 10-day delay in planting 300 acres would decrease total production by 1,500 bushels, which is worth \$13,275 (at a price of \$8.85 per bushel).

Figure 5-2. Effect of planting date on soybean grain yield in Clark County, Ohio.

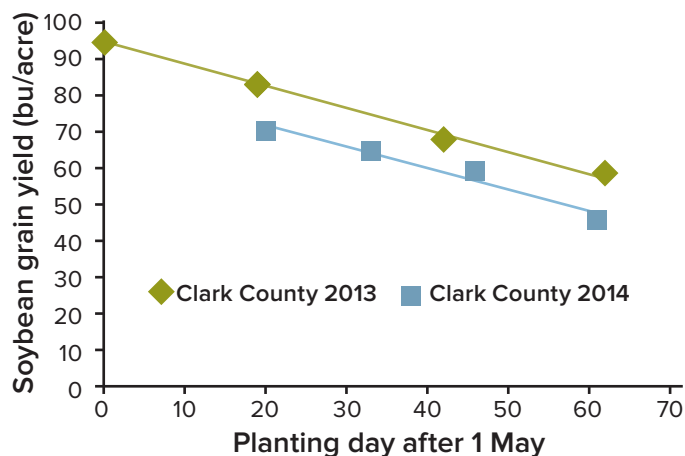


Table 5-2: Effect of Row Spacing on the Number of Days and (Date) to Complete Canopy Formation*.

Row Spacing (inch)	Date of Planting					
	Before May 5		May 6-15		May 16-25	
7	35	(6/5)	30	(6/10)	25	(6/15)
10	40	(6/10)	35	(6/15)	30	(6/20)
15	50	(6/20)	45	(6/25)	40	(6/30)
20	60	(6/30)	55	(7/5)	50	(7/10)
30	75	(7/15)	70	(7/20)	65	(7/25)

Adequate, vigorous stands are sometimes more difficult to obtain with early planting. Seed treatments, good seed-soil contact, and reduced seeding depths, however, aid in establishing vigorous stands. Herbicide programs must provide weed control for a longer time until the crop is large enough to suppress weed growth through competition. Narrow rows provide the needed competition for weeds sooner than wide rows.

Late Planting

Late planting reduces the cultural practice options for row spacing, seeding rate, and variety maturity. The row spacing for June planting should be no greater than 7.5 inches. Appropriate seeding rates for the first half of June are about 200,000 to 225,000 seeds per acre. For the last half of June, 225,000 to 250,000 seeds per acre is recommended, and in early July, the recommendation is 250,000 to 275,000 seeds per acre.

Relative maturity (RM) has little effect on yield for plantings made during the first three weeks of May, but the effect can be large for late plantings. During the first half of June, a four-day delay in planting delays physiological maturity about one day. In the last half of June it takes a five-day planting delay to delay physiological maturity one day. As planting is delayed, yield potential goes down and there is concern about whether late maturing varieties will mature

before frost. When planting late, the rule of thumb is to plant the latest maturing variety that will reach physiological maturity before the first killing frost. The reason for using late maturing varieties for late planting is to allow the plants to grow vegetatively as long as possible to produce nodes where pods can form before vegetative growth is slowed due to flowering and pod formation. More nodes equates to more pods and more yield. Late-maturing varieties are needed that will mature before getting frosted, but since the first frost date is unknown, we use a narrow range of maturity that will not be damaged by frost occurring at the normal time.

The recommended relative maturity ranges in Table 5-3 assume normal weather and frost dates, so varieties with those relative maturities should mature before frost and produce maximum possible yields when planted on the dates indicated. Varieties with an earlier relative maturity will mature earlier but will produce reduced yields.

Table 5-3: Recommended Relative Maturity Ranges For Soybean Varieties Planted in June and July in Northern, Central and Southern Ohio.

	Planting Date	Suitable Relative Maturity	Yield Potential (bu/ac)
Northern Ohio	June 1-15	3.2-3.8	20-45
	June 15-30	3.1-3.5	15-35
	July 1-10	3.0-3.3	10-25
Central Ohio	June 1-15	3.4-4.0	25-48
	June 15-30	3.3-3.7	20-40
	July 1-10	3.2-3.5	15-33
Southern Ohio	June 1-15	3.6-4.2	30-50
	June 15-30	3.5-3.9	25-45
	July 1-10	3.4-3.7	20-40

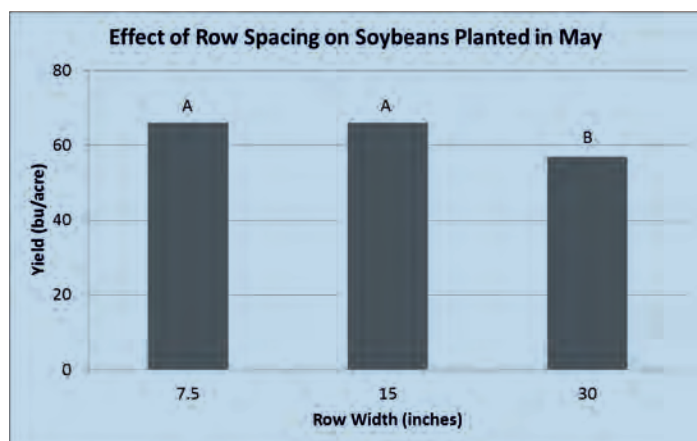
Row Spacing

In Ohio, most soybeans are planted in narrow rows (7.5- to 15-inch). Soybeans grown in narrow rows produce more grain because they capture more sunlight energy, which drives photosynthesis. Within limits, as sunlight interception increases, so does yield. Researchers have learned that the peak demand for the products of photosynthesis occurs during the reproductive stage. Therefore, the row width should be narrow enough for the soybean canopy to completely cover the interrow space by the time the soybeans begin to flower (June 20 to July 10). The row widths that will accomplish that goal will vary with soil type, planting date, weather conditions and, in some cases, variety. The later in the growing season soybeans are planted, the greater the yield increase due to narrow rows. The response to narrow rows is also greater for short varieties and when growing conditions cause plants to grow slowly or be short. Planting systems using precision seed

metering to achieve uniform seed spacing within the row plus uniform depth of seed placement usually produce higher yields than planting systems with less uniform seed spacing and variable depth of planting.

The effect of row spacing on the yield for soybeans planted in May can be seen in Figure 5-3. Soybeans planted in 7.5- to 15-inch row widths yielded similarly while soybeans planted in 30-inch row widths yielded 14 percent less. The yield reduction associated with 30-inch row widths would be magnified when planting in June or July.

Figure 5-3. Effect of row spacing on yield for soybeans planted in May.



Plant Population

The effect of plant population on yield is very small over the normal range of seeding rates and for any particular set of conditions. For a crop planted before May 20 in narrow rows, final populations of 100,000 to 120,000 plants per acre are generally adequate for maximum yield. Final populations for mid-June plantings should be in the range of 130,000 to 150,000 plants per acre. Final populations for early July plantings (double crop) should be greater than 180,000 plants per acre. Final population is a function of seeding rate, quality of the planting operation, and seed germination percentage and depends on such things as soil moisture conditions, seed-soil contact, disease pressure, fungicide seed treatments, etc. Final harvest stands are typically 60 to 80 percent of the seeding rate when high quality seed is used and there are few impediments to stand establishment. Some seed is dead when planted, other seeds may not have the vigor needed to emerge and grow rapidly, some will be lost to disease and insects prior to emergence, some emerged plants will be killed by disease and some will not grow fast enough to compete adequately for sunlight and thus perish during the growing season.

Replanting

Sometimes, plant stands are reduced by disease, herbicide injury, hail, insects and flooding. If crop insurance covers the damage, consult the insurance agent before taking action. When all plants of a field are lost, it is realistic to replant if adequate growing season remains for the crop to mature. Areas of fields may be replanted while leaving the remainder of the field as is, and areas of inadequate stands can be thickened by interplanting additional seed. If the stand loss is random or erratic throughout the field, a stand count should be taken to determine the number of plants remaining. For dark soils, do not interplant more seed unless the number of plants per foot of row is less than 45 percent of the recommended seeding rate for the date on which replanting could be accomplished (see Table 5-4). For light-colored soils, do not interplant unless the number of plants per foot of row is less than 60 percent of the recommended seeding rate for the date on which replanting could be accomplished.

For example: A stand count reveals that for most of the field there are about 1.5 plants per foot of 7.5-inch row. The date is June 10 and a replanting can be made on June 15 when the recommended seeding rate for 7.5-inch wide rows is 2.8 seeds per foot of row. If the soil in the field is dark in color and good vegetative growth is anticipated, then replanting would likely not be profitable. However, for a field with light-colored soil or where plants will likely be small, interplanting may be warranted and the interplant rate should be 1.65 seeds per foot of row. That replant rate is the difference in the current stand and the recommended seeding rate for the date on which the interseeding could take place, plus about 10 percent to compensate for the plants killed while interplanting. For example:

The recommended seeding rate for June 15 is 2.8 seeds per foot of 7.5-foot row.

There are currently 1.5 plants per foot of row.

$2.8 \text{ seeds per foot} - 1.5 \text{ plants per foot} = 1.3 \text{ plants per foot of row needed.}$

$1.3 \text{ seeds per foot} \times 110\% = 1.43 \text{ seeds per foot of row or about } 100,000 \text{ seeds per acre or } 40 \text{ pounds of seed if there were } 2500 \text{ seeds per pound.}$

If low plant populations are due to root rot diseases, the guidelines for replanting also include planting a variety with disease resistance genes or partial resistance plus the use of a fungicide seed treatment.

Table 5-4: Suggested Seeding Rates for Combinations of Planting Date, Relative Maturity and Row Spacing.

Relative Maturity	Planting Date	Seeds Per Foot of Row*		Seeds (1,000 per acre*)	
		7.5 inch	15 inch	7.5 inch	15 inch
2.1-2.5	Before 5/20	2.8	5.6	195	195
	5/21-6/05	3.0	6.0	209	209
	6/06-6/20	3.3	---	230	---
2.6-3.0	Before 5/20	2.6	5.0	181	174
	5/21-6/05	2.8	5.4	195	188
	6/06-6/20	3.0	5.6	209	195
	After 6/20	3.3	---	230	---
3.1-3.5	Before 5/20	2.4	4.2	167	146
	5/21-6/05	2.6	4.5	181	157
	6/06-6/20	2.8	4.9	195	171
	After 6/20	3.1	5.4	216	188
	Double Crop	3.5	---	255	---
3.6-4.1	Before 5/20	2.3	4.1	160	140
	5/21-6/05	2.5	4.4	173	151
	6/06-6/20	2.7	4.8	188	164
	After 6/20	3.0	5.3	207	180
	Double Crop	3.4	---	245	---

*For good growth environments these seeding rates can be reduced to 75 percent of the table values, and for poor growth environments they should be increased by 30 percent of the table values.

Planting Depth

One inch to 1.5 inches is the ideal planting depth where tillage is used. Where tillage is used, the soil should be free of large clods to insure good seed-soil contact and good seed coverage. Shallow planting (¾ to 1 inch) in late April promotes more rapid emergence than deeper planting. However, be aware of the increased exposure to herbicides, which may damage young seedlings. In late April, soil temperatures at 1-inch depth are 3 to 8

degrees warmer than at 2-inch depth. After May 15, the air temperatures are higher and the probability of crusting increases. It is a poor practice to plant deeper than 1 to 1.5 inches because a crust may form above the seed and reduce emergence. It takes the combined pressure of many plants to break through the crust. In the process, many of the hypocotyls are broken, and the seedlings do not emerge. When planted at a 1-inch depth, the seed is more likely to be inside the crust layer. As the seed swells in the germination process, the soil crust is broken and a higher percentage of plants emerge. On some crusting silt loam soils, deep planting results in 25 to 50 percent mortality during emergence. Where soil crusting is a problem, no-till planting and crop residue are preferred. Adequate crop residue prevents the formation of soil crust and aids in stand establishment. Three-fourths- to 1-inch seeding depth is ideal for no-till seeding.

Fertilization Recommendations

For optimal yields on mineral soils with subsoil pH greater than 6.0 (generally western Ohio), the pH range should be maintained between 6.0 and 6.8. On mineral soils with subsoil pH less than 6.0 (generally Eastern Ohio), the range should be higher (6.5 to 6.8). Lime should be added to soybean fields when pH levels drop below the optimal range. A soil test will be necessary to calculate lime requirements based on buffer pH or lime test index (buffer pH multiplied by 10). Lime may be applied anytime for recommendations of 2 tons or less. Fall applications will allow time for lime to raise the soil pH before spring planting. Split applications will be required for recommendations larger than 4 tons per acre: half before plowing and half after plowing. Regardless of the recommendation, no more than 8 tons of lime should be applied in one season. Lime application rates for no-till fields should be one half of recommendations given for a tilled field sampled to an 8-inch depth.

Nitrogen (N)

Soybeans, like other legumes, have the ability to form a symbiotic relationship with nitrogen-fixing bacteria. In Ohio, even under high-yielding conditions (>70 bushels per acre), farmers seldom see a positive economic return and little benefit in yield have been obtained by adding nitrogen to well nodulated soybeans. Soybeans adjust to early-applied nitrogen by fixing less nitrogen from the atmosphere. Applications after flowering have not shown a consistent or predictable yield advantage.

Soybeans also do not respond to starter nitrogen (most soils have the ability to provide adequate nitrogen until the *Bradyrhizobia* bacteria infects roots and forms nodules). Bacterial infection occurs soon after emergence and nitrogen fixation begins as early as growth stage V2 (second trifoliolate leaf).

Yield-limiting deficiencies of nitrogen are uncommon in soybeans. Deficiencies may occur temporarily during

extended cool and/or wet soil conditions after planting. These short-term situations should not lower yields and nitrogen fixation will quickly resume with warmer temperatures and drier soils. Deficiencies seldom occur later in the growing season. However, disease—such as soybean cyst nematode, or extended hot and dry weather may limit the ability of plants to absorb nutrients and produce symptoms that resemble nitrogen deficiency.

Nitrogen fertilizer may be necessary the first time soybeans are planted in a field, even when seed inoculation is used. If the crop does not have a dark green color by early July, 75 pounds of nitrogen per acre should be applied as urea. To ensure a reliable source of inoculation in new fields, soybeans should be grown for two years and the seed inoculated each year.

Phosphorus (P)

Soybeans require relatively large amounts of phosphorus. It is not unusual for a 60 bushel per acre crop to contain 48 pounds of phosphate (P₂O₅) in the grain. Although phosphorus is taken up throughout the growing season, the period of greatest demand occurs during pod development and early seed fill (growth stages R3 – R5). Deficient plants seldom exhibit specific leaf symptoms. Generally, phosphorus deficient plants will be stunted, a symptom easily confused with disease and environmental stress symptoms. Plant and soil tests are the most reliable methods to insure against phosphorus deficiency. Soil-test phosphorus levels should be maintained between 15 and 30 parts per million (based on a Bray P extraction) or 21 and 43 parts per million (based on a Mehlich 3 extraction). Phosphate recommendations are based on the yield potential of the field and the corresponding phosphorus levels from a recent soil test (Table 5-5). If soil-test phosphorus is above the critical level of 15 ppm Bray P (21 ppm Mehlich P), no yield response is expected with additional fertilizer application. In an Ohio study conducted in 2014 and 2015 at four locations, there was no yield benefit when 100 pounds of phosphate per acre was applied to soybean when soil-test phosphorus levels were within the recommended critical level (Figure 5-4).

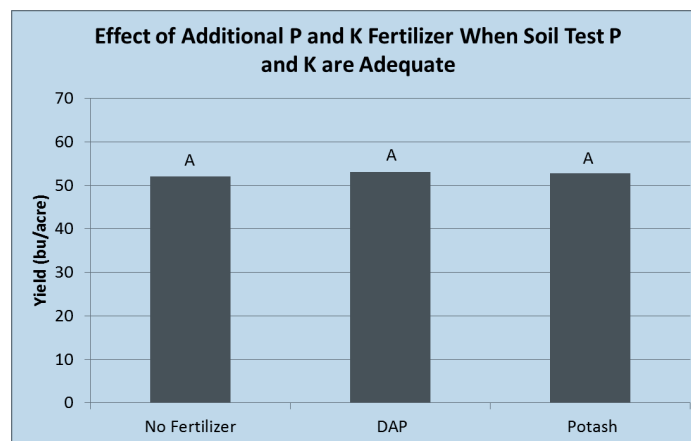
Table 5-5: Phosphorus (P₂O₅) Recommendations for Soybeans.

Soil test (Bray P) ppm (lb/ac)	Yield Potential (bu/ac)				
	30	40	50	60	70
	lb P ₂ O ₅ /acre				
5 (10)*	75	80	90	100	105
10 (20)	50	55	65	75	80
15-30 (30-60)**	25	30	40	50	55
35 (70)	10	15	25	25	30
40 (80)	0	0	0	0	0

*Values in parentheses are pounds per acre.

**Maintenance recommendations given for this soil test range.

Figure 5-4: Effect of additional phosphorus (P) and potassium (K) fertilizer when soil-test phosphorus and potassium are adequate according to state guidelines.



Potassium (K)

Soybeans require large amounts of potassium. It is essential for vigorous growth, yet never becomes a part of protein molecules and other organic compounds. Potassium is not involved extensively in biological activities in the soil. Most of the total plant potassium will be in the seed at maturity (1.4 pounds per bushel). Deficiencies are not common but are easy to recognize by yellow leaf margins.

Soil Cation Exchange Capacity (CEC) affects potassium availability so the critical level increases as the CEC increases. The critical level for soybeans (ppm) is 75 + (2.5 x CEC). For soils low in potassium, recommendations are designed to provide more potash than crop removal, so that soils will build up above the critical level in four years. Potash should be applied annually until soil-test potassium is above the critical level. Once above the critical level, recommendations are made to replace soil potassium removed by the crop. These recommendations are slightly above the critical level to account for soil sampling or analytical variation. Depending on the CEC, the range to maintain soil-test potassium levels for optimum soybean production is between 100 and 180 ppm. Potash recommendations are given in Table 5-6. These recommendations are dependent upon a field's yield potential, CEC, and soil-test level. If soil-test potassium is above the critical level, no yield response is expected with additional fertilizer application. In an Ohio study conducted in 2014 and 2015 at four locations, there was no yield benefit when 100 pounds potash was applied to soybean when soil-test potassium levels were above the recommended critical level (Figure 5-4).

Table 5-6: Potash (K₂O) Recommendations for Soybeans at Various Yield Potentials, Cation Exchange Capacities (CECs) and Soil-Test Levels.

Yield Potential	bu/ ac	30	40	50	60	70
Soil-Test K		---lb K ₂ O per acre---				
ppm (lb/ac)	CEC	--- 5 meq/100g---				
25 (50) ¹		140	155	170	180	195
50 (100)		110	125	135	150	165
75 (150)		80	90	105	120	135
88-118 (175-235) ²		60	75	90	105	120
130 (260)		25	30	35	40	45
140 (280)		0	0	0	0	0
	CEC	---10 meq/100g---				
25 (50)		175	190	205	215	230
50 (100)		135	150	165	180	195
75 (150)		100	115	130	140	155
100-130 (200-260) ²		60	75	90	105	120
140 (280)		30	40	45	50	60
150 (300)		0	0	0	0	0
	CEC	---20 meq/100g---				
50 (100)		210	225	240	255	270
75 (150)		160	175	190	205	220
100 (200)		110	125	140	155	170
125-155 (250-310) ²		60	75	90	105	120
165 (330)		30	40	45	50	60
175 (350)		0	0	0	0	0
	CEC	---30 meq/100g---				
75 (150)		250	265	280	290	300
100 (200)		185	200	215	230	245
125 (250)		125	140	155	165	180
150-180 (300-360) ²		60	75	90	105	120
190 (380)		30	40	45	50	60
200 (400)		0	0	0	0	0

¹ Values in parentheses are pounds per acre.

² Maintenance recommendations given for this soil test range.

Calcium (Ca) and Magnesium (Mg)

Soybeans require a minimum exchangeable soil test level of 200 and 50 ppm (400 and 100 pounds per acre) of calcium and magnesium, respectively. In most cases, these requirements are automatically met when soils are maintained at the proper soil pH. Soybeans will grow well over a wide range of calcium to magnesium ratios and should

not need additional calcium as long as the proper pH is maintained and soil calcium levels are higher than magnesium. Soils naturally low in magnesium (Eastern, extreme southern, and sandy soils of northwestern Ohio) should be limed with dolomitic limestone. Dolomitic lime is an economical source of magnesium and still contains generous amounts of calcium.

Sulfur (S)

Soybeans use large amounts of sulfur. A crop yielding 60 bushels per acre contains about 25 pounds of sulfur, 15 pounds of which is in the grain. Soils with more than 1 percent organic matter usually supply adequate sulfur for high yields. Deficiencies generally occur during cool, wet weather on sandy soils and/or soils low in organic matter. Soil tests are not reliable in predicting crop response to sulfur. A continuing plant analysis program is the best guide to confirm the need for additional sulfur. If a need for sulfur is identified, several suitable materials, such as gypsum, potassium sulfate or potassium sulfate magnesia will correct the deficiency.

Manganese (Mn)

Even though manganese deficiency in soybeans is not a widespread problem, its occurrence is more common than the other micronutrient deficiencies. Deficiencies are most likely to occur in glacial lakebed, glacial outwash, peat and muck soils. Soil pH is the most important factor affecting manganese availability (becomes less soluble at higher pH levels), but other factors such organic matter, soil type, and weather may magnify the problem. On silt loams and clayey soils, it seldom occurs below pH 6.8. It may occur on sandy soils that are high in organic matter with a pH as low as 6.2. Muck and peat soils occasionally are deficient at a pH as low as 5.8. Pale yellow to nearly white leaves with distinct green veins (interveinal chlorosis) is the most visual symptom of manganese deficiency. Deficiency symptoms will first appear on younger leaves. In severe cases, the plants will become stunted.

Manganese may be banded for wide row soybeans, but narrow rows require foliar applications. Generally, when the plants have two or three trifoliolate leaves (growth stages V2 or V3), a foliar application of 4 to 8 pounds of manganese sulfate will usually correct minor deficiencies. Multiple applications may be needed when both the surface and subsoil have high pH values.

Manganese fertilizers should probably not be mixed with herbicides such as glyphosate to prevent the loss of weed control. Producers should examine the herbicide label to confirm that the product selected will not interfere with the activity of the herbicide. Spraying at the optimal time for weed control and using the manganese chelate product, EDTA, may lower the potential for antagonism between fertilizer and herbicide.

Insect Control

Insect pests in soybean are sporadic but can be yield-limiting when their populations do build. It is difficult to predict when and where insects may become a problem in soybean, so regular scouting is important. Timely foliar insecticide applications at the recommended thresholds are usually effective for protecting yield from insect damage. For products labeled for soybean insects, see Ohio State University Extension Bulletin 545, *Control of Insect Pests of Field Crops* and Table 5-7. Insecticidal seed treatments have not been shown to be cost-effective for most forms of insect management and are only recommended under particular circumstances, such as fields transitioning to soybean production from pasture or CRP use. For more information see the multi-state extension fact sheet *The Effectiveness of Neonicotinoid Seed Treatments in Soybean*.

SOYBEAN APHIDS Soybean aphids are small (1/16 inch) pear-shaped insects ranging in color from pale to bright green or yellow-green. Aphids can have up to 12 generations per year, and can occur in both winged and wingless forms depending on conditions. They are often found in clumped colonies on the undersides of leaves. Early in the season they are most likely on new vegetation, and later in the season they are found lower in the canopy. Though the first colonists to soybean usually arrive in June (from buckthorn shrubs, where they spend the winter), populations usually do not start to build until mid-July or reach economic levels until August. Soybean aphids have piercing-sucking mouthparts and feed on plant fluids, so plant damage is not obvious until it is well-advanced, at which time plants may be stunted and covered with black sooty mold that grows on the aphid feeding waste. To avoid economic loss, populations should be managed before plant damage is apparent. Scout for soybean aphids starting at least 100 feet from the field's edge. Examine 20 to 30 plants in widespread (not clumped) locations by walking a W pattern across the field. Count the number of aphids per plant and average the results. Before the R5 growth stage, treatment is recommended if numbers exceed an average of 250 aphids per plant with more than 80 percent of plants infested. After the R5 growth stage, an economic return on a spray is unlikely.

BEAN LEAF BEETLE The bean leaf beetle (BLB) is a small beetle that varies in color from golden brown to green, generally having four black spots on the wing covers, and always having a black triangle centrally behind the head and thorax. Larvae develop below ground and can be found feeding on soybean nodules, though this feeding is not economically relevant. The BLB overwinters in the adult stage and resumes activity in the spring. It can be found feeding on soybean foliage soon after soybean emergence. Bean leaf beetles pass through two generations in Ohio with the first generation of BLB appearing in early summer and the second generation appearing around late August or early September. The time of peak occurrence of BLB adults per generation may differ from

field to field depending on the date of planting because the time of initial egg laying in a field depends on the time of initial emergence of the crop, which attracts the overwintering beetles to the site. If a soybean field is late-planted relative to other fields in the area, the first generation may not become established in the field and the probability of early season BLB damage is minimal. However, if planted late and missing the first generation, the likelihood of the field staying green in September enhances the chance of having a higher second BLB generation, where they may cause significant pod-feeding injury. A secondary concern with BLB is its ability to vector bean pod mottle virus (BPMV), which is a concern for seed quality.

Early-season foliar feeding is seldom economic. Foliar injury from the next generation will again appear in early July and continue until fall as a succession of first and second generation BLB adults emerge and feed on the crop. When pod set occurs, BLB adults will begin to feed more on the succulent pods, a more likely source of yield loss. Prior to pod formation, decisions to apply an insecticide rescue treatment are based primarily on the observed defoliation from all leaf-feeding insects combined. Rescue treatment is justified when defoliation exceeds 40 percent prior to bloom, 15 percent from bloom to pod-fill, and 25 percent after pod-fill to plant yellowing. Pod injury due to adult BLB feeding may be detected following pod set. Evaluation of pod injury should be based on inspection of all pods on 10 randomly selected plants. On each plant sampled, count the number of total pods and the number of pods exhibiting pod injury, and then determine the percent pod injury based on the 10 plants inspected. It is important to estimate percent pod injury on inspection of the entire plant. Treatment is justified if the percent pod injury is reaching 10 to 15 percent, and BLB adults are still present and still active.

TWO-SPOTTED SPIDER MITE Two-spotted spider mites are arachnids (related to spiders), not insects, but are scouted and managed in the same way. They tend to be more of a problem under hot, dry conditions—typically later in the summer, though economic infestations can occur earlier under the right conditions. Spider mites are very small (< 0.002 inch) and difficult to spot, so the easiest way to scout for them is to look for telltale signs of their injury—yellow spotting or stippling on the upper side of leaves. This damage usually begins in the lower canopy and progresses upward as the mite population increases. Heavily infested leaves may also have light webbing similar to spider webs. Vegetation can be tapped over a black sheet of paper (black construction paper works well, often better than white paper); dislodged mites will resemble fine grains of sand or motes of dust. Spider mite infestations often begin at field borders and progress inwards. There are no number-based thresholds available for mites, in part because counting them is not practical in a scouting context. Populations can increase rapidly so scouting every four to five days is recommended during drought conditions. Walk a broad pattern in the field and examine

at least two plants in each of 20 locations. Use the following scale developed by the University of Minnesota to evaluate spider mite damage in soybean, with treatment recommended at level 3:

0. No spider mites or injury observed.
1. Minor stippling on lower leaves, no premature yellowing observed.
2. Stippling common on lower leaves, small areas on scattered plants with yellowing.
3. Heavy stippling on lower leaves, with some stippling progressing into middle canopy. Mites present in middle canopy with scattered colonies in upper canopy. Lower leaf yellowing common and some lower leaf loss. (Spray Threshold)
4. Lower leaf yellowing readily apparent, leaf drop common. Stippling, webbing, and mites common in middle canopy. Mites and minor stippling present in upper canopy. (Economic Loss)
5. Lower leaf loss common, yellowing or browning moving up plant into middle canopy, stippling and distortion of upper leaves common. Mites present in high levels in middle and lower canopy.

There are relatively few products available for the treatment of two-spotted spider mites and some pyrethroid insecticides may actually “flare” spider mite populations, making them worse. Common choices for spider mite control in soybeans are products containing chlorpyrifos,

dimethoate, bifenthrin though other miticides exist. It is important to re-scout five days after treatment as many products will not kill mite eggs, which will hatch to form a new generation of mites.

STINK BUGS A number of stink bug species may be found in Ohio soybeans, including green, brown, red-shouldered and brown marmorated stink bugs. These are relatively large, shield-shaped insects that often appear at field edges first. Stink bugs have piercing-sucking mouthparts which they insert into developing soybean pods, feeding on the developing seeds. This damage can be subtle from the outside, but results in shriveled or aborted seeds which decreased yield but also reduces seed quality (a particular concern for seed or food-grade beans). Adults will lay egg masses in soybean starting in mid-July and the immatures (nymphs), and later the adults, will feed on pods. Sample for stink bugs with a sweep net by taking five sets of 10 sweeps at different parts of the field. Count all stink bug species and life stages together. Treatment is recommended at an average of four stink bugs per 10 sweeps for grain soybeans, and two per 10 sweep for food grade or seed soybeans. Brown marmorated stink bugs are difficult to capture in a sweep net, however, so if this particular species is present visually scan vegetation for them and treat at one to two per row-foot.

A number of insect species feed directly on soybean leaves and are sporadic pests or occur in low numbers. But collectively, their feeding may add up. These insects include Japanese beetles, grasshoppers, green cloverworms and various other caterpillars. A general defoliation

Table 5-7: Insecticides Labeled for the Control of Soybean Insects.

Chemical	BLB	MBB	JB	GCW	PLH	GH	SA	SM	PHL	
Ambush**	●	●	●	●	●				60	<i>Bt</i> - <i>Bacillus thuringiensis</i> BLB = Bean leaf beetle MBB = Mexican bean beetle JB = Japanese beetle GCW = Green cloverworm PLH = Potato leafhopper GH = Grasshoppers SA = Soybean aphid SM = Spider mites PHL = Preharvest limitation, waiting period required (in days) prior to harvest or foraging. * Use is restricted to certified applicators only. † These compounds are highly toxic to bees exposed to direct treatment or residues on blooming crops or weeds. Do not apply these products or allow them to drift to blooming crops or weeds if bees are visiting the treatment area.
Asana**	●	●	●	●	●	●	●		21	
<i>Bt</i> (several names)				●					0	
Dimethoate†	●	●			●	●		●	21	
Dimilin*		●				●			21	
Furadan**		●				●	●		21	
Lannate**	●	●		●					14	
Larvin†	●	●		●					28	
Lorsban†	●	●		●		●	●	●	28	
Malathion†		●		●					7	
Mustang**	●	●	●	●	●	●	●		21	
PennCap-M**	●	●	●	●	●	●	●		20	
Pounce**	●	●		●	●				60	
Scout**	●			●		●			21	
Sevin†	●	●	●	●	●	●			21	
Tracer†				●					28	
Warrior**	●	●	●	●	●	●	●	●	45	

threshold can be collectively used for leaf-feeding insects, with treatment recommended at 40 percent defoliation prior to bloom and 15 percent from bloom to pod-fill. These percentages refer to whole-plant defoliation, not just a few leaves.

Weed Control

Specific chemical weed control recommendations can be found in the Weed Control Guide, Extension Bulletin 789, available at all County Extension offices and online at CFAES publications at: estore.osu-extension.org/.

Chapter 6

Small Grain Production

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NOTE: Material in this chapter related to pesticides may not be valid after 2017. Please contact the County Extension office or the Agronomy Team website, agcrops.osu.edu, for current information.

The major objective of a small grain production system is the interception, fixation, and storage of sunlight energy. The most important components of such a system are variety selection, timely planting, disease control and adequate fertilization. The effects, interactions and relationships of various inputs to small grain production systems are discussed here.

Wheat Production

Ohio is a leading state in the production of soft red winter wheat and enjoys an outstanding reputation for the quality of its crop. Flour made from soft red winter wheat is superior for making cakes, crackers, cookies and all sorts of pastries. Any contamination from hard red wheat or soft white wheat in marketing channels reduces its market value and the quality of flour made from it.

Attempting to produce ultra-high yields by using extra inputs is not always profitable for most Ohio wheat producers. That is because the climate of Ohio limits maximum wheat productivity. Most years, Ohio's weather is too wet in May and June, resulting in diseases and yield loss. June and July are usually too hot and kill the crop well before it has time to reach its maximum yield potential. When we have one of those rare dry springs with low disease levels followed by a cool June, the yields of some fields have reached 120 bushels per acre or more. Because those good growing seasons are rare, we should manage for the more normal weather. It is the weather that usually prevents us from taking advantage of high management inputs such as high seeding rates and extra nitrogen.

The most prudent production system is one of defensive management: planting after the fly-safe date to dodge diseases, holding seeding and nitrogen rates down to reduce disease and production cost, using resistant varieties, applying fungicides only when warranted (weather conditions are favorable and varieties are susceptible), etc. This management system will not produce the maximum possible yield in those really good years, but it will be the most profitable system for all those other years (the norm) when the weather is not ideal for maximum yields.

High yields and low production cost are necessary for wheat to be a viable economic partner in the crop-rotation sequence. Increased profitability will only come from improved management. The guidelines presented here will help minimize the factors limiting wheat yields and also lower production costs. Additional specific information on wheat can be obtained at Ohio State University Extension offices or on the internet at: agcrops.osu.edu/specialization-areas/wheat.

Variety Selection

The Ohio Wheat Performance Test is conducted annually to measure yield and other agronomic characteristics important to producers. Information on wheat variety performance can be obtained in the annual *Ohio Wheat Performance Test*, Ohio State University Horticulture and Crop Science Department Series 228, available at County Extension offices or on the internet at: oardc.ohio-state.edu/wheattrials/.

The yield potential of currently available varieties is generally in excess of 150 bushels per acre. This yield is not approached, however, primarily because of a short grain fill period caused by high air temperatures in late June and early July which kill the crop. Select wheat varieties with high yield potential, high test weight, good winter hardiness, good straw strength and disease resistance. Information on variety performance should be obtained from multiple sources such as seed companies and university performance trials where multiple sites and years of testing are presented. Always plant more than one variety each year to reduce the risk of disease losses and to spread out harvest dates. Select varieties with resistance to *Fusarium* head blight (head scab), wheat spindle streak mosaic, powdery mildew, leaf rust, and *Stagonospora* leaf and glume blotch. However, since no variety is resistant to every disease, always select varieties with resistance to the diseases most prevalent in your area of the state. Avoid varieties that are highly susceptible to head scab. Information on reaction of varieties to various diseases can be obtained from seed company dealers and the annual Ohio wheat performance test report (oardc.ohio-state.edu/wheattrials/).

High-Quality Seed and Seed Treatment

Purchase only high-quality seed that has been thoroughly cleaned to remove shriveled kernels and that has a germination of 90 percent or better. All seed should be treated with a seed-treatment fungicide to control seed-borne diseases such as loose smut, common bunt, *Fusarium* scab, and *Stagonospora glume blotch*. However, since no single active ingredient will provide adequate protection against all of these diseases, use a seed treatment that consists of a mixture of active ingredients. Avoid planting wheat seeds with more than 30 to 40 percent scabby kernels. However, if you do have to plant scabby wheat, cleaning, germ test, and fungicide seed treatment are absolutely necessary. Cleaning will get rid of light, scabby materials, and this will naturally increase the test weight of the lot. If you can increase the test weight to about 56 pounds per bushel after cleaning and your germination rate is above 80 percent, then you will have decent quality seed. Gravity table would be your best option for cleaning. In addition to cleaning and treating, seeds should be stored under cool, dry conditions until planting to prevent mold development. Blending of scabby wheat with healthy wheat is another good option to increase the overall quality of the lot. Increasing the seeding rate will also be helpful, but you should determine percent germination first—this will help you to adjust your seeding rate accordingly.

Crop Rotation

Plant wheat following soybeans. A three-year rotation of corn-soybean-wheat appears to be optimum for sustained yield of all three crops. Crop rotation is the most effective method to reduce pathogen populations that affect the three crops in the sequence. The purpose is to provide enough time away from the host plant for pathogens to die out before that crop is planted again. Wheat should never follow wheat or spelt in the rotation sequence.

Soil-borne diseases, such as take-all and *Cephalosporium* stripe, can cause complete crop failure in non-rotated fields. Foliar diseases, like powdery mildew and *Stagonospora glume blotch*, may also become more of a problem. Wheat should not follow corn in the rotation because the same fungus that causes *Gibberella* ear and stalk rot in corn also causes *Fusarium* head scab in the wheat. Planting wheat into corn residues greatly increases the risk of a severe outbreak of head scab in the wheat crop. Wheat also serves as an excellent rotation crop for corn and soybeans, allowing populations of pathogens (like soybean cyst nematode and *Sclerotinia*) to decline before host crops are again planted in the field.

Land Selection and Preparation

Wheat grows well in a range of soil types; however, well-drained soils with medium to fine texture produce the highest yields in Ohio. Adequate drainage is essential; thus, tiling poorly drained fields is important. Plan the crop-rotation sequence far enough in advance to plant early-maturing soybean varieties in fields to be planted to wheat in the fall. This will permit planting of wheat at the optimum time for maximum winter survival and yield potential. Drilled, medium-season soybean varieties, planted early yield as well as full-season varieties.

Planting no-till wheat into soybean stubble has been very successful in reducing erosion and almost totally eliminates spring heaving and also reduces production costs. Soybean residues should be evenly spread across the field during harvest to ensure uniform seeding depth (1.5 inches). Do not plant into soils that are too wet and monitor planting depth when the soil is hard and dry.

Planting Date

Avoid planting wheat prior to the *fly-safe date* because of the possibility of early establishment of foliar fungal diseases and severe damage by barley yellow dwarf virus and Hessian fly (Figure 6-1). The best time for seeding is a 10-day period starting the day after the fly-safe date. Long-term average yields are highest from seedings made during that time (Figure 6-2). Seeding during that time usually produces ample growth for winter survival, and reduces the likelihood of fall disease establishment and attack by potentially damaging insects. Occasionally, when freezing weather is delayed until late November or early December, wheat seeded more than three weeks after the fly-safe date is equal in yield to that seeded during normal planting time. Because of reduced fall growth, late seeded wheat is less winter hardy and more susceptible to spring heaving.

Figure 6-1. Hessian fly-safe dates for planting wheat for Ohio counties.

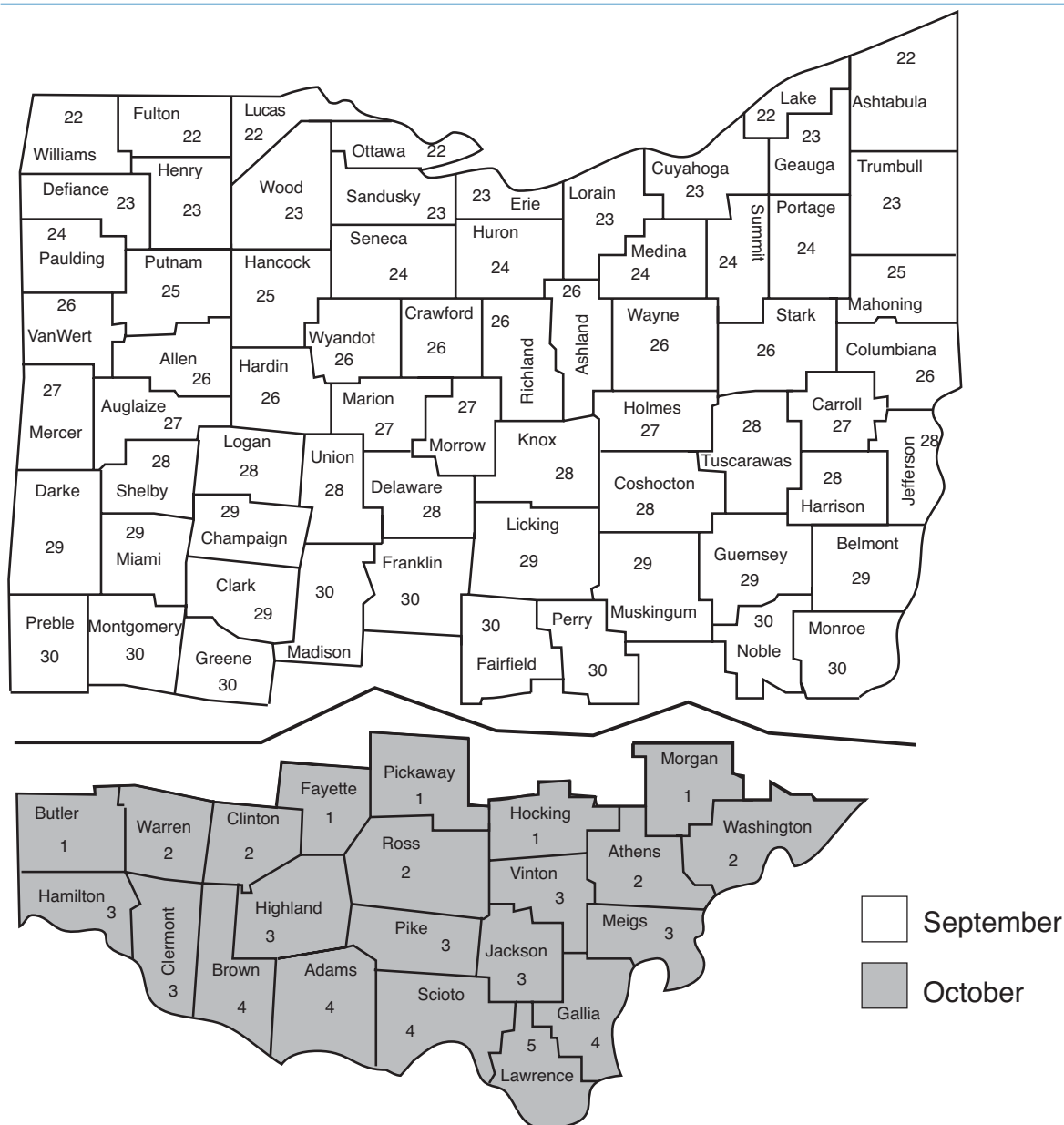
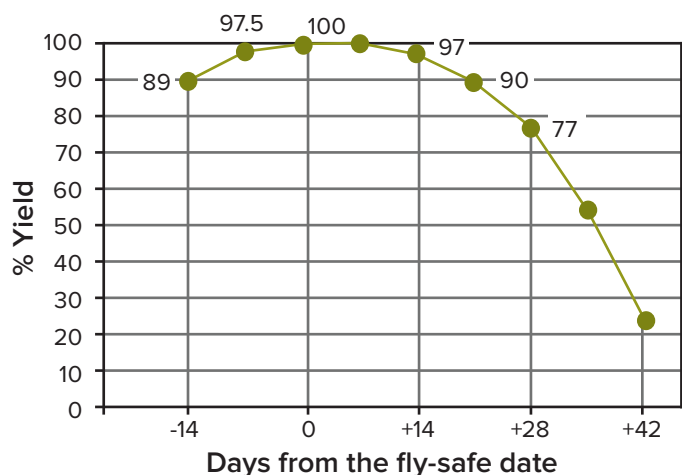


Figure 6-2. Effect of planting date on wheat.



Seeding Practices

When planting at the proper time and into soil that is not too wet, seed should be planted 1.5-inches deep. Row width should be 6 to 8 inches. Planting by bushels per acre is very inaccurate due to variability in seed size from year to year and from one variety to another. Low seeding rates result in inadequate stands and winter injury, while excessively high rates increase lodging and disease severity.

Do not plant weak-strawed varieties prone to lodging. Calibrate the drill each year for each variety and seed lot planted. The optimum seeding rate is 1.2 to 1.6 million seeds per acre (18 to 24 seeds per foot in 7.5-inch row width) when planting during the two weeks following the fly-safe date. During the third and fourth week after the fly-safe date, plant 1.6 to 2 million seeds per acre (24 to 30 seeds per foot of row). Do not plant faster than the speed

at which the drill was calibrated. The number of seeds per pound and germination rates are critical factors that need to be known before a proper seeding rate can be determined and the drill calibrated. This information should be listed on the bag of seed. The information in Tables 6-1 and 6-2 can be used to calibrate grain drills accurately.

Table 6-1: Pounds of Seed Needed to Plant From 1.6 to 2 Million Seeds Per Acre With Seed of Varying Size.

Seeds Per Pound	Millions of Seed Per Acre				
	1.2	1.4	1.6	1.8	2.0
10,000	120	140	160	180	200
11,000	109	127	145	164	182
12,000	100	116	133	150	167
13,000	92	108	123	138	154
14,000	85	100	114	129	143
15,000	80	93	107	120	133
16,000	75	88	100	113	125
17,000	71	82	94	106	118
18,000	66	77	89	100	111

Table 6-2: Seeds Per Foot of Row for Different Row Spacings and Target Seeding Rates.

Desired Seeding Rate	Row Spacing in Inches*			
	7	7.5	8	10
Million seed/ac	-----Seeds/foot of row-----			
1.2	16.0	17.2	18.4	23.0
1.4	18.7	20.0	21.4	26.8
1.6	21.4	23.0	24.5	30.6*
1.8	24.1	25.8	27.5	34.4*
2.0	26.8	28.7	30.6*	38.3*

*At 15-inch row width, 25 seeds per foot of row is recommended.

Producing Wheat in 15-Inch Rows

Growers are interested in wide-row wheat production due to reductions in equipment inventory (lack of grain drill) and to allow intercropping of soybean into wheat. Wheat row spacing work conducted during the 2012-2013 and 2013-2014 growing seasons indicated that wheat grown in 15-inch rows produced yields that were 1 to 11 percent lower than wheat grown in 7.5-inch row spacing (Table 6-4). In both years and locations the plots were planted within 10 days after the fly-safe date at the rate of 25 seeds per foot of row for both row spacings (1.7 and 0.85 million seeds per acre for 7.5-inch and 15-inch row spacings, respectively). Nitrogen (30 pounds per acre) was applied at planting each year to stimulate fall growth, tillering and improve winter hardiness. Because the seeding rate per foot of row for wheat is the same for all row widths the seed cost for 15-inch rows is half that for 7.5-inch rows. When wheat seed cost \$0.03 per 1000 seeds and wheat grain is worth \$4.70 per bushel, the lower yield from wide rows is almost offset by the reduced seed cost.

When producing wheat in wide rows, consider the following management tips:

1. Choose a variety that is high yielding and resistant to major diseases such as powdery mildew, leaf rust, Septoria and *Stagonospora* blotches, and head scab. See oardc.osu.edu/wheattrials/ for the *Ohio Wheat Performance Test Wide Row Evaluation*.
2. Plant wheat as soon as possible after the Hessian fly-safe date.
3. A seeding rate of 25 to 29 seeds per foot of row (0.85 to 1 million seeds per acre) is recommended. In on-farm research trials conducted in Fulton County, there was no yield increase when wheat was seeded at 29 seeds per foot of row (1 million seeds per acre) compared to 43 seeds per foot of row (1.5 million seeds per acre).
4. Spring herbicide application is very important to maximize yield.
5. Changing row spacing will change the microclimate within the wheat canopy, and this could affect disease development. Scout fields for foliar diseases and use the scab forecasting system (wheatcab.psu.edu) to determine whether disease risk is high enough to warrant a fungicide application.

Table 6-3: Effect of Wheat Row Spacing and Variety on Wheat Grain Yield.

Year	County	Variety	Yield in 7.5-Inch Rows	Yield in 15-Inch Rows	Yield Reduction of Wheat Grown in Wide Rows
---bu/ac---					
2012-2013	Wayne	A	86	82	5%
		B	85	81	5%
		C	84	72	11%
		D	81	80	1%
2013-2014	Wayne	A	114	112	2%
		B	106	104	2%
		C	110	111	1%
		D	103	104	1%
2012-2013	Wood	A	60	59	2%
		B	61	60	2%
		C	61	56	8%
		D	44	41	7%
2013-2014	Wood	A	98	99	-1%
		B	100	94	6%
		C	98	95	3%
		D	90	88	2%
AVERAGE			86	84	2%

Lodging Control

Lodging is a serious deterrent to high yields. Some cultural practices that tend to increase grain yield also increase the likelihood of lodging. Using recommended seeding rates (18 to 24 seed per foot of 7.5-inch row), applying proper rates of nitrogen, and selecting lodging-resistant varieties prevents lodging in high-yield environments where yields of 100 bushels per acre are anticipated. When lodging occurs, the severity of foliar disease increases, resulting in reduced grain yield and quality. Additional effects of lodging are reduced straw quality and slowed harvest. The prevention of lodging increases dividends through a combination of reduced input costs and improved grain and straw quality.

Fertilization

A successful soil fertility program for wheat requires knowledge of a field's yield potential and a recent soil test. The soil test will provide current levels of phosphorus and potassium in the soil and the soil pH. Soil pH will assist in determining the need for micronutrients and other soil amendments most importantly lime. When the proper soil pH is maintained, adequate levels of micronutrients and secondary nutrients should be released by the soil organic

matter. The proper soil pH for western Ohio (subsoils derived from limestone) should be above 6.0 and below 7.0, and above 6.5 and below 7.0 for eastern Ohio (subsoils derived from shale and sandstone). The lime test index or buffer pH on the soil test should be used for lime recommendations. These recommendations are for mineral soils with adequate drainage containing 1 to 5 percent organic matter. Organic soils (organic matter > 20 percent) and sandy soils (CEC < 6) will require different recommendations.

The Ohio State University currently uses the Extension Bulletin E-2567, *Tri-State Fertilizer Recommendations for Corn, Soybean, Wheat, and Alfalfa* (agcrops.osu.edu/publications/tri-state-fertility-guide-corn-soybean-wheat-and-alfalfa) for nitrogen, phosphorus and potassium recommendations. The following discussion of these nutrients have been adapted from this publication.

Nitrogen (N)

Nitrogen rates are based on yield potential and not on soil analysis. Total nitrogen recommendations are given in Table 1 or may be calculated by the following equation:

$$40 + [1.75 \times (\text{yield potential} - 50)]$$

For the corresponding rate, part of it should be applied in the fall and the rest after green-up. Generally, 20 to 30 pounds of fall applied nitrogen should be adequate for early fall and spring growth. Spring recommendations should be the total nitrogen required less the amount applied in the fall. No credits are given for previous crops. For example, a wheat crop with a 90-bushel-per-acre yield goal would require 110 pounds nitrogen per acre (Table 6-5). If the grower applied 20 pounds in the fall, the remaining 90 pounds should be applied in the spring.

Table 6-5: Nitrogen Recommendations for Wheat.

Yield Potential (bu/ac)	Nitrogen Rate (lb/ac)
60	60
70	75
80	90
90	110
100	130

Yields are generally not affected when the initial spring nitrogen is applied between green-up and Feekes GS (Growth Stage) 6 (early stem elongation). Nitrogen losses may be severe on applications prior to green-up and may cause significant yield reductions, regardless of nitrogen source. Significant yield losses may also occur if initial spring applications are delayed until after Feekes GS 6.

Split Applications and Nitrogen Source. Split application may improve nitrogen efficiency; however, in most years, yield gains from a split application have not been large enough to offset the application cost of a second trip

across a field. A split spring application program may be a benefit in poorly drained fields that are prone to nitrogen loss, and also in years that the potential for nitrogen loss is great. Years that have a potential for nitrogen loss generally have a warmer than normal winter followed by a warm and wet April. Delaying initial nitrogen application until closer to Feekes GS 6 would have the same effect as a split application without sacrificing yields. In a split application program, the larger proportion of the nitrogen should be in the second application by Feekes GS 6.

Nitrogen Source. Nitrogen source is not a concern unless conditions are conducive for nitrogen loss. In general, urea-ammonium nitrate solutions have the greatest potential for loss, then urea, and ammonium sulfate the least. Risk for nitrogen loss potential is the greatest for early applications and decreases as plants approach Feekes GS 6. Fields prone to wet conditions would also be susceptible to nitrogen loss. If nitrogen loss is not a concern, economics and application equipment should determine nitrogen source.

Nitrogen Summary. Initial spring application should be applied between green-up and Feekes GS 6. Waiting until Feekes GS 6 may increase yields slightly but the small gain is offset by the risk of an extended wet period at elongation time. If these wet conditions delay application until late stem elongation or later, a yield decrease may occur. Nitrogen source should be dependent upon the risk of nitrogen loss conditions and cost.

Phosphorus (P)

Phosphorus should be applied before planting when the soil-test level is below 50 ppm. Recommendations are determined by yield goal and soil-test level (Table 6-5). Phosphorus and fall-applied nitrogen are often applied as diammonium phosphate (DAP) or monoammonium phosphate (MAP).

Table 6-5: Phosphorus Recommendations for Wheat at Various Yield Potentials and Soil-Test Levels.

Yield Potential (bu/ac)	Soil-Test P (Bray) in ppm				
	15	20	25-40	45	50
	-----lb P ₂ O ₅ /acre-----				
60	90	65	40	20	0
70	95	70	45	20	0
80	100	75	50	25	0
90	105	80	55	30	0
100	115	90	65	30	0

Potassium (K)

Potassium recommendations are based upon yield goal, soil CEC and the soil-test level (Tables 6-6 and 6-7). Soils with larger CEC values have a greater chance of potassium becoming unavailable to the crop, and require more potash than low CEC soils. Table 6-6 recommendations only account for grain removal of potassium by the crop. Recommendations should be greater in fields where the straw may be baled and removed (Table 6-7).

Table 6-6: Potash Recommendations for Wheat at Various Yield Potentials, CECs and Soil-Test Levels—Only Grain Removed (no straw removal).

Yield Potential (bu/ac)	Soil CEC	Soil-Test K (ppm)						
		25	50	75	100	125	150	175
60		lb K ₂ O/acre						
	10	155	115	80	40	40	0	0
	15	195	150	110	65	40	25	0
	20	240	190	140	90	40	40	0
80		lb K ₂ O/acre						
	10	160	125	85	50	50	0	0
	15	205	160	115	70	50	30	0
	20	250	200	150	100	50	50	0
100		lb K ₂ O/acre						
	10	170	130	95	55	55	0	0
	15	210	165	125	80	55	35	0
	20	260	205	155	105	55	55	0

Table 6-7: Potash Recommendations for Wheat at Various Yield Potentials, CEC and Soil Test Levels—Both Grain and Straw Removed.

Yield Potential (bu/ac)	Soil CEC	Soil-Test K (ppm)						
		25	50	75	100	125	150	175
60		lb K ₂ O/acre						
	10	210	170	135	100	100	0	0
	15	250	205	160	120	100	60	0
	20	300	250	200	150	100	100	0
80		lb K ₂ O/acre						
	10	235	200	160	120	120	0	0
	15	275	230	190	145	120	80	0
	20	320	270	220	170	120	120	0
100		lb K ₂ O/acre						
	10	260	225	185	150	150	0	0
	15	300	260	215	170	150	95	0
	20	350	300	250	200	150	150	0

Sulfur (S)

Sandy soils and soils low in organic matter often respond to sulfur fertilizer. Medium- to fine-textured soils with adequate organic matter generally have not produced larger yields with supplemental sulfur. Current research has shown no yield increase on these soils. However, atmospheric depositions have decreased over past decades as sulfur emissions from manufacturing processes have diminished, which may cause these soils to be deficient in the future. Sulfur rates have not been established as a result of soils generally not being deficient; however, 20 to 40 pounds per acre of sulfur mixed with topdress nitrogen should be adequate for soils suspected of being deficient. Suitable sulfur fertilizers include: ammonium sulfate, ammonium thiosulfate and gypsum.

Manganese (Mn)

Manganese (Mn) deficiency has rarely been seen in Ohio wheat fields. Generally, the whole field is not deficient, and the deficiency is found in pockets and small areas of a given field. Deficient soils have generally occurred where soil pH is above 7.0. Deficient plants will have reduced tillers, appear weak and thin, and have leaves with interveinal chlorosis or white specks and blotches. Foliar applications of 4 pounds per acre of manganese (generally manganese sulfate) is often the best practice for mineral soils with a history of manganese deficiency, which may be added to spring applications of urea-ammonium nitrate.

Nutrient Value of Wheat Straw

The nutrient value of wheat straw is influenced by several factors including weather, variety, and cultural practices. Thus, the most accurate value requires sending a straw sample to an analytical laboratory. However, *book value* can be used to estimate the nutrient value of wheat straw (Table 6-8).

Table 6-8: Nutrient Value of Wheat Straw Collected from Field Trials Located in Wooster, Ohio During the 2012-2013 Growing Season.

Nutrient	Wheat Straw (lb/ton)
N	14-18
P ₂ O ₅	3-4
K ₂ O	20-23

The nitrogen in wheat straw will not immediately be available for plant uptake. The nitrogen will need to be converted by microorganisms to ammonium and nitrate (a process called *mineralization*). Once the nitrogen in the ammonium and/or nitrate form, it is available for plant uptake. The rate at which mineralization occurs depends on the amount of carbon and nitrogen in the straw (C:N ratio). The USDA reports a C:N ratio of 80:1 for wheat straw, which means there are 80 units of carbon for every unit of nitrogen. Mineralization rapidly occurs when the C:N ratio is ≤ 20:1. At a C:N ratio of 80:1, mineralization will be much slower. (For comparison, corn stover is reported to have a C:N ratio of 57:1.) Rate of mineralization is also influenced by soil moisture and temperature. Since mineralization is a microbial-driven process, mineralization will be slowed (halted) in the winter when temperatures are cold. Thus, no nitrogen credit is given for wheat straw since it is not known when the nitrogen will mineralize and become available to the following crop.

Disease Management

Disease is one of the major factors limiting wheat yield and quality in Ohio and other Midwestern states. Yield losses as high as 30 to 50 percent are not uncommon in fields planted with susceptible varieties under disease-favorable conditions. Effective disease management requires knowledge and understanding of how—and under what conditions—each disease develops, at what growth stage the crop is most susceptible, and how the disease causing organism survives and spreads. In Ohio, the most frequently occurring and damaging diseases are caused by fungi that survive in crop residue left in the field from one growing season to another, and the greatest losses occur when flag leaves and spikes are damaged before grain-fill is complete. Producers should fine tune their disease management strategies for those diseases that are most prevalent in their area of the state and are most

capable of causing substantial yield and quality losses. Correct diagnosis is critical for effective disease management, and producers with little experience identifying diseases should seek help from competent sources, such as plant pathology extension state specialists, Ohio State University Extension or an agricultural consulting service.

A comprehensive wheat disease-management program consists of the following practices:

1. Planting disease-resistant varieties is the most effective and economical means for controlling diseases. Select resistant varieties based on research conducted by universities and seed companies. Varieties are available with moderate to high levels of resistance to leaf rust, powdery mildew, and wheat Spindle Streak mosaic virus, and moderate levels of resistance to *Stagonospora* leaf and glume blotch, and *Fusarium* head scab. When varieties have high resistance to a disease, they effectively limit losses in yield. However, resistance to leaf rust and powdery mildew may fail due to the development of new races of the pathogens. When selecting varieties, give priority to head scab resistance. Although this disease does not occur every year, it is by far the most important and damaging disease of wheat in Ohio. Most of the other important diseases can be effectively controlled (80 to 90 percent) with a single, well-timed fungicide application, but the best fungicides only provide about 50 percent control of head scab and vomitoxin when applied to a susceptible variety. Therefore, fungicides have to be used in combination with the most scab resistant variety in order to achieve the best results in terms of scab and vomitoxin reduction. While no variety is equally resistant to every disease, high-yielding varieties with moderate resistance to head scab and one or more of the other diseases are available (oardc.ohio-state.edu/wheat-trials/). So, in addition to scab, select varieties with resistance to the disease most common in your part of the state. Powdery mildew is most common throughout Ohio, except in the northwestern part of the state. *Stagonospora* glume blotch is most severe in central, west central, northwest and southern Ohio. Leaf rust has the greatest potential for damage in southern Ohio. Monitoring wheat diseases aids a producer in selecting varieties with resistance to the common diseases of his or her region.
2. Plant well-cleaned, disease-free seed, treated with a fungicide that controls seedling blights, bunt, and loose smut. Seed treatments will also provide protection against foliar diseases such as *Stagonospora* leaf blotch and reduce stand establishment problems due to head scab, when scabby seeds are planted.
3. Plant in a well-prepared seedbed, after the fly-safe date.
4. Rotate crops; never plant wheat where the previous crop was corn, wheat or spelt. A two- to three-year rotation from wheat prevents most pathogens from surviving in fields. Planting wheat after other small grain crops, such as barley, may also increase the risk of some diseases.
5. Plow under residues from heavily diseased fields, especially those affected by head scab, *Stagonospora*, *Cephalosporium* stripe or take-all. Plowing enhances decomposition of residue and death of the disease-causing fungi.
6. Use a well-balanced fertility program based on a soil test. Apply sufficient amounts of phosphorus, nitrogen, and potassium in the fall for vigorous root and seedling growth. Spring topdress with nitrogen at the rate recommended to achieve the yield goal. Excessive nitrogen increases the severity of foliar diseases such as leaf rust, powdery mildew and lodging.
7. Control grass weeds. Destroying volunteer wheat, quack grass and other grass weeds in and around potential wheat fields reduces the amount of inoculum available to infect the crop. Weeds and volunteer wheat may also serve as hosts (or overwintering reservoir) for several viruses that affect wheat and the insects that transmit them.
8. Apply fungicide. The upper two leaves and the glumes of the heads contribute most of the sugars to grain fill. Thus, it is important to keep these upper plant parts free of disease to minimize yield loss. A well-timed foliar fungicide application is able to effectively control most foliar fungal diseases such as powdery mildew, leaf rust, *Septoria*, and *Stagonospora nodorum* leaf and glume blotch, and suppress head scab and vomitoxin, but such an application is not always warranted. For instance, applications made in the absence of diseases (for plant health), at green-up or at half-rates do

not provide consistent yield gains and are not always cost-effective in Ohio. The economic benefit of using a fungicide depends on grain price, application cost, and variety susceptibility. In Ohio, at any given grain price, the chance of obtaining a yield response high enough to offset fungicide application cost is highest for applications made at flag-leaf emergence (Feekes GS 8) or boot stage (Feekes GS 10), and lowest when applications are made at green-up (Feekes GS 4-5).

For foliar diseases, fungicides are often most warranted and beneficial when susceptible and moderately susceptible varieties are planted. Scout fields from flag-leaf emergence through flowering, and make your fungicide application decision based on disease threshold and risk. Disease thresholds are 1 percent of leaf area affected on the leaf below the flag leaf between Feekes 8 and 10, and 1 percent of leaf area affected on the flag leaf between head emergence and flowering (Feekes 10.1-10.5.1). When these disease thresholds are reached, a fungicide should be applied as soon as possible to protect leaf tissue before more becomes infected. One percent leaf area affected roughly translates to five to 10 leaf rust pustules, two to three powdery mildew pustules, or one to two *Stagonospora nodorum* blotches.

For head scab, disease thresholds cannot be used as a guide for making a fungicide application. Applications have to be made at flowering, or at the very latest, four to six days after flowering. This is 14 to 21 days before actual head scab symptoms are observed. Therefore, the head scab forecasting system (wheatscab.psu.edu) should be used as a guide for making a fungicide application for scab and vomitoxin control. Information on how to use and interpret the forecasting system can be found in fact sheet PLPTH-CER-03, *Fusarium Head Blight Forecasting System* at: ohioline.osu.edu/factsheet/plpath-cer-03/.

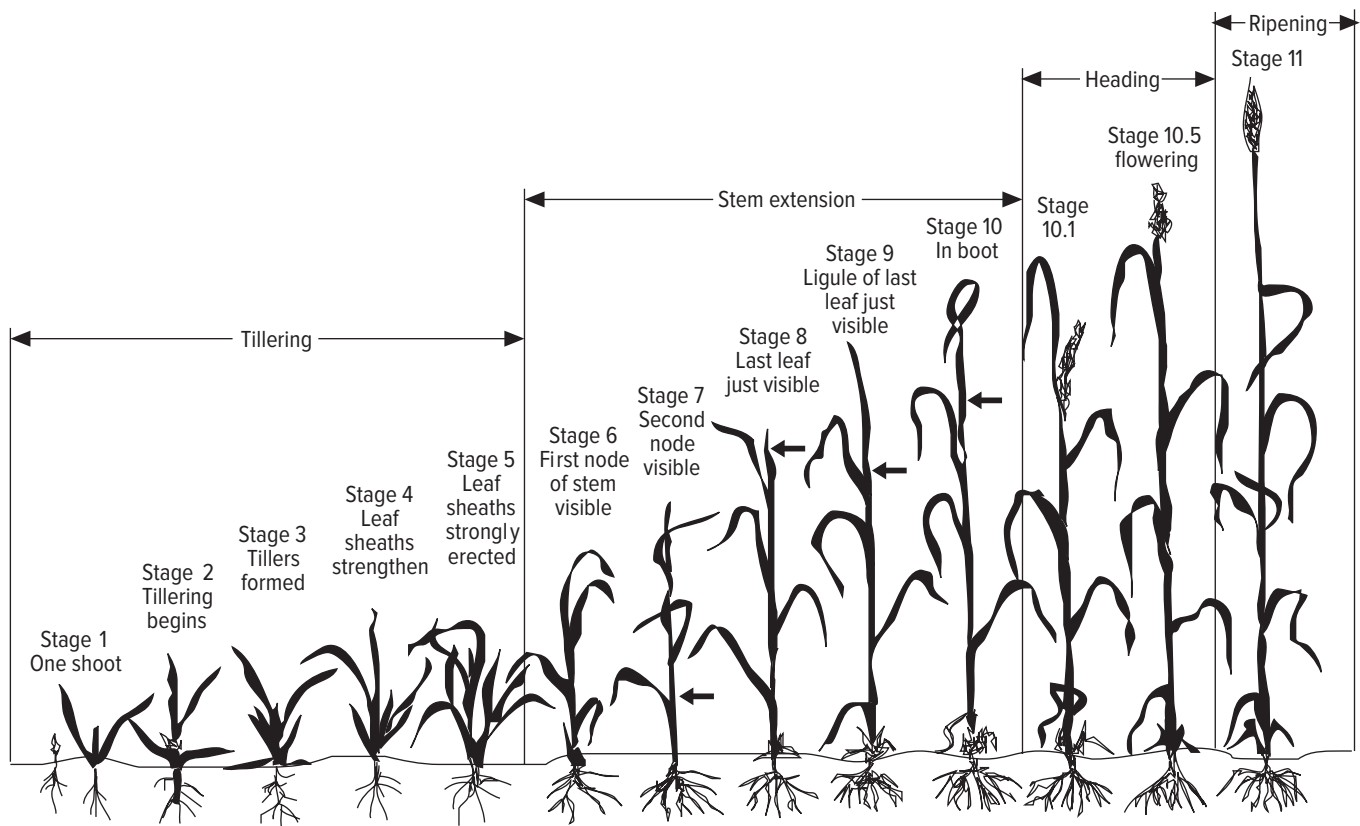
Growers should become familiar with symptoms of the common diseases affecting wheat in Ohio. Correct diagnosis and scouting are important steps in identifying the yield-limiting diseases on your farm. Scouting fields for disease is particularly important when growing moderately susceptible and susceptible varieties to determine the need for fungicide applications. This involves checking the level of disease on 30 to 50 individual tillers randomly selected throughout the field. Fields should be scouted for powdery mildew at flag-leaf emergence and boot stage (Feekes GS 8 and 10, respectively, see Figure 6-3) and scout for *Stagonospora* leaf blotch and leaf rust at boot stage and full-head emergence.

Help in diagnosis can be obtained from plant pathology extension state specialists, the C. Wayne Ellett Plant and Pest Diagnostic Clinic (ppdc.osu.edu/), OSU Extension, or other crop consultants. OSU Extension fact sheets with descriptions and pictures of the common diseases in the state are available on Ohioline at: ohioline.osu.edu. Symptoms and appropriate control measures for several important wheat diseases are provided in Table 6-9.

Table 6-9: Wheat Diseases and Disorders Common in Ohio.

Disease or Disorder	Symptoms	Environment	Control
Head scab	Spikelets of head turn straw colored; glume edges with orange-pink spore masses; kernels shriveled white to pink in color.	Warm, wet, humid weather during flowering and early grain-fill.	<ol style="list-style-type: none"> 1. Seed treatment for infected seed. 2. Crop rotation with non-host. 3. Plow down corn and wheat residues. 4. A triazole fungicide at flowering. 5. Do not use Strobilurin fungicide for scab. 6. Use scab forecasting system as a guide for fungicide application.
Powdery mildew	Powdery white mold growth on leaf surfaces.	High humidity; 60-75 F; high nitrogen fertility and dense stands.	<ol style="list-style-type: none"> 1. Resistant varieties. 2. Crop rotation. 3. Delayed planting. 4. Fungicides. 5. Balanced fertility.
Leaf rust	Rusty red pustules scattered over leaf surface.	Light rain, heavy dew; 60-77 F; high N fertilizer; 6-8 hour leaf wetness for germination and infection.	<ol style="list-style-type: none"> 1. Resistant varieties. 2. Balanced fertility. 3. Fungicides.
<i>Septoria tritici</i> leaf blotch	Leaf blotches with dark brown borders; gray centers speckled with black fungal bodies.	Wet weather from mid-April to mid-May; 60-68 F; rain 3-4 days each week.	<ol style="list-style-type: none"> 1. Seed treatment. 2. Plant less susceptible varieties. 3. Crop rotation. 4. Balanced fertility. 5. Fungicides.
<i>Stagonospora nodorum</i> leaf and glume blotch	Lens shaped chocolate brown leaf lesions with yellow borders; brown to tan blotches on upper half of glumes on heads.	Wet weather from mid-May through June, 68-80 F; rain 3-4 days each week.	<ol style="list-style-type: none"> 1. Seed treatment. 2. Plant less susceptible varieties. 3. Crop rotation. 4. Balanced fertility. 5. Fungicides.
Tan spot	Lens shaped, light brown leaf lesions; yellow borders.	Moist, cool weather during late May and early June.	<ol style="list-style-type: none"> 1. Plow down infested residues. 2. Crop rotation. 3. Balanced fertility. 4. Fungicides.
<i>Cephalosporium</i> stripe	Chlorotic and necrotic interveinal strips extending length of leaf.	Cold, wet fall and winter with freezing and thawing causing root damage.	<ol style="list-style-type: none"> 1. Crop rotation. 2. Bury infested residues. 3. Control grassy weeds. 4. Lime soil to pH 6.0-6.5.
Take-all	Black scurfy mold on lower stems and roots; early death of plants.	Cool, moist soil through October-November and again in April-May.	<ol style="list-style-type: none"> 1. Crop rotation. 2. Control weed grasses. 3. Balanced fertility. 4. Use ammonium forms of N for spring topdress. 5. Avoid early planting.
<i>Fusarium</i> root rot	Seedling blight (pre- and post-emergence); wilted, yellow plants; roots and lower stems with whitish to pinkish mold. Root rot plants have brown crowns and lower stems.	Dry, cool soils; drought stress during seed filling.	<ol style="list-style-type: none"> 1. Seed treatments for seedling blight. 2. Delayed planting. 3. Balanced fertility. 4. Avoid planting after corn.
Barley yellow dwarf	Stunted, yellowed plants, leaves with yellowed or reddened leaf tips.	Cool, moist seasons.	<ol style="list-style-type: none"> 1. Delay planting until after the Hessian fly-safe date. 2. Balanced fertility.
Wheat spindle streak mosaic	Discontinuous yellow streaks oriented parallel with veins of leaves. Streaks with tapered ends forming chlorotic spindle shapes.	Cool, wet fall followed by cool spring weather extending through May.	<ol style="list-style-type: none"> 1. Resistant varieties.

Figure 6-3. Feekes Wheat Growth Stage scale.



Insect Control

Several different insects can be important on wheat in Ohio. Management of insect pests affecting wheat often emphasizes nonchemical control measures. Hessian fly is controlled primarily by delaying planting until late September or early October (e.g., the fly-safe date), depending on location in the state. Cereal leaf beetle and aphids are usually controlled by beneficial parasitoids or natural pathogens. However, populations of some pests, especially cereal leaf beetle, armyworm, and sometimes aphids, may occur in numbers warranting rescue treatment with insecticides. The following text reviews the insect pests that may impact wheat.

THE HESSIAN FLY passes through two generations per year in which adult flies deposit eggs, maggots hatch on leaves and feed on stems, and then maggots pupate into the commonly recognized flaxseed stage. Flaxseed pupae are located within the leaf sheaths of plants in the spring, resulting in the broken wheat stems and lodging associated with that damage. Damage by the maggots occurs in the late spring and early fall following activity by adults in early spring and late summer. Under serious infestations, the problem is generally detected after the damage has been done and the fly is in the flaxseed stage protected from insecticides by the plant and pupal case. It is somewhat challenging to control Hessian fly with foliar applications, which is why the major tactic for controlling Hessian fly is planting wheat after the Hessian fly-safe date for

your county (see Figure 6-1). Seed treatments are available and have activity against the Hessian fly, but are usually unnecessary if following the fly-safe date.

APHIDS The **English grain aphid** and the **cherry oat aphid** may cause limited feeding injury. The **greenbug**, an aphid which produces a toxin that affects the wheat plant, rarely occurs in Ohio. To determine the need for treatment, first identify the aphid. English grain aphid has black cornicles (tailpipes on the tip of the abdomen), oat-bird cherry aphid has a red-orange spot between the cornicles, and the greenbug has a dark green stripe on the back and the tips of the cornicles are black. Keep in mind that natural predators usually control most aphid populations on small grains. In addition, planting after the fly-safe date also will limit risk of aphid infestation and disease transmission. Greenbug infestations great enough to cause economic damage are rare in Ohio. Aphids also are important in Ohio because they may transmit the barley yellow dwarf virus that causes stunting and yellowing of wheat and other small grains. However, it is not economically feasible to control transmission of barley yellow dwarf virus with insecticides because aphids can transmit the virus within six hours of landing on the plant.

OVERWINTERING CEREAL LEAF BEETLES appear in the spring and lay eggs, which hatch into larvae that feed on wheat and oat leaves. Damaged fields often have a frosted appearance due to the defoliation. Larvae appear as small black slugs due to accumulated fecal matter on

their backs. There is one generation per year with new adults appearing in late spring. A complex of parasitic wasps generally controls cereal leaf beetle, but treatment of fields may be warranted when mild winters adversely affect natural control. An infestation averaging one larva per stem may result in a loss of 3 bushels per acre.

ADULT ARMYWORMS become active in late April and early May, and are attracted to grass crops including wheat. Larvae are active in late May and June, and can feed on leaves and emerging heads. Most serious damage occurs when larvae feed on stems and clip heads completely off. Detection of larvae is initially along the edge of fields and low-lying areas. When six or more larvae can be seen per linear foot of row, or head clipping is evident and larvae are not fully grown (larvae are predominantly 1-inch long or less), a rescue treatment may be needed.

For more information on managing insect problems and for the chemicals labeled for wheat insects, see the *Agro-nomic Crops Insects* website at: oardc.ohio-state.edu/ag/pageview.asp?id=1029.

Weed Control

Wheat competes well with weeds especially when good production techniques result in an initial uniform stand establishment and when loss of stand due to winter injury is minimal. Effective weed control and prevention of weed seed production in prior crops will reduce the risk of weed problems in wheat. Some wheat fields can benefit greatly from herbicide application, and failure to scout fields and take the appropriate measures can result in yield loss and harvesting problems in these fields. The weeds that appear above the wheat canopy late in the season, such as ragweed and Canada thistle, can often be easily controlled with a spring herbicide treatment.

The most common weed problems in wheat include:

1. Winter annual weeds, such as common chickweed, purple deadnettle, shepherd's purse, and field pennycress. These weeds become established in the fall along with the wheat and can interfere with early development of wheat in the spring. Dense populations of winter annual weeds should be controlled in late fall or early spring to minimize interference with wheat growth.
2. Wild garlic, which contaminates harvested grain with its bulblets. Several herbicides are effective if applied in the spring after garlic has several inches of new growth.
3. Canada thistle, which can greatly suppress wheat growth due to its tendency to occur in dense patches. Most wheat herbicides have some activity on thistle and can suppress it adequately, if not applied too early in spring.

4. Summer annual broadleaf weeds, such as common and giant ragweed, which can begin to emerge in late March. A healthy wheat crop can adequately suppress these weeds, but herbicide application is occasionally warranted.

Specific chemical weed control recommendations can be found in the *Weed Control Guide*, Extension Bulletin 789, available at all County Extension offices and online at CFAES publications at: estore.osu-extension.org/.

Production of Other Small Grain Species

Fertilizer recommendations for the other small grain species are provided in Tables 6-12 through 6-14. Insect control recommendations can be found in Extension Bulletin 545, *Insect Pests of Field Crops*.

Table 6-12: Recommended Nitrogen for Small Grains (Pounds Nitrogen Per Acre).

	Crop	-----Yield Goal (bu/ac)-----		
	Barley	65	90	115
	Oats	90	120	150
Spring Application	(Spelt)	40**	75**	110**
Spring Application	(Barley)	55**	95**	135**
Spring Application	(Oats)	60**	90**	125**
Spring Application	(Rye)	60**	90**	60**

*Use short, stiff-strawed varieties.

**Reduce nitrogen rate by 40 pounds per acre on dark colored soils.

Table 6-13: Examples of Phosphorus (Expressed as lb P₂O₅/ac) Recommended for Small Grains.

	Crop	-----Yield Goal (bu/ac)-----		
	Barley, Spelt	50	70	90
	Oats	100	130	160
	Rye	30	45	60
Soil Test Value		Annual Recommendation (lb P ₂ O ₅ /ac)		
lb P/ac	ppm			
30	15	80	95	115
40	20	55	70	90
50-80	25-40	30	45	65
90	45	15	25	35
100	50	0	0	0

Table 6-14: Examples of Potassium (Expressed as lb K₂O/ac) Recommended for Small Grains.

Crop	Yield Goal (bu/ac)										
	50			70			90				
Barley, Spelt	50			70			90				
Oats	100			130			160				
Rye	30			45			60				
Soil Test Value	-----CEC-----			-----CEC-----			-----CEC-----				
	10	20	30	10	20	30	10	20	30		
lb K/ac	-----Annual Recommendation (lb K ₂ O/ac)-----										
ppm	50	25	150	190	230	160	195	240	165	255	300
150	75	75	140	225	85	145	235	90	155	240	
250	125	40	65	100	45	65	110	50	55	115	
350	175	0	0	40	0	0	20	0	0	0	
450	225	0	0	20	0	0	0	0	0	0	

Weed Control for Small Grains

Specific chemical weed control recommendations can be found in the *Weed Control Guide*, Extension Bulletin 789, available at all County Extension offices and online at CFAES publications at: estore.osu-extension.org/.

Chapter 7

Forage Production

By Dr. R. Mark Sulc, Dr. David J. Barker and Dr. Kelley Tilmon



The forage industry plays a major role in Ohio agriculture. Approximately 16 percent of the total value of agricultural products sold in Ohio is derived from ruminant meat and milk products (\$1.6 billion). In Ohio there are 1.25 million cattle and calves, with Ohio ranking 11th in the nation in value of milk production and 25th in value of all cattle and calves. Ohio ranks 14th in the nation in value of sheep, goats, and their products. About 34 percent of Ohio farms have cattle and calves, 5 percent have sheep and lambs, 6 percent have goats, and 21 percent have horses and ponies. In 2014, 2.7 million tons of hay was produced (19th in the nation) on 1.03 million acres and pastures comprise more than 1.4 million acres of Ohio's total farmland.

Forages are environmentally friendly. They protect soils from erosion, improve soil tilth, help reduce pesticide use, and enhance agricultural profitability. Forages are vital to Ohio agriculture, protect our soil and water resources, and add beauty to the state.

All forage crops respond positively to good management practices. Higher yields, improved nutritive value, and longer stand persistence result from paying attention to the basics of good forage management. This guide is designed to help producers achieve the high potential of forages grown in Ohio.

Perennial Forages

Species Selection

The selection of forages for hay, silage, pasture, and conservation is an important decision requiring knowledge of agronomic characteristics, forage species adaptation to site and soil characteristics, and potential feeding value of forage plants. The intended use of forages, dry matter and nutritional requirements of livestock to be fed, seasonal feed needs, harvest and storage capabilities, and seasonal labor availability influence which species to grow.

Agronomic Adaptation and Intended Use

Tables 7-1 and 7-2 outline the agronomic adaptation and characteristics of the primary forages grown in Ohio. The choice of species is limited to those adapted to the soils on the farm, so evaluate the soil adaptation factors in

Table 7-1 first when selecting species. Useful soil information describing the limitations of a particular soil for forage production can be found at NRCS offices or online through the *USDA-NRCS Web Soil Survey* (websoilsurvey.sc.egov.usda.gov/). Keep in mind that soil pH can be increased with lime; soil fertility can be improved with fertilizers and manure; and soil drainage can be modified with tiling. Soil drainage is usually the most difficult soil characteristic to modify. The following is a brief discussion of individual species that can help determine which species are best suited to a particular enterprise. Table 7-3 gives commonly recommended species to consider for general soil fertility classes and utilization methods.

Pure Stands versus Mixtures

The decision to establish a pure stand or a mixture species should be made before deciding which species to plant. Advantages of pure grass or legume stands include simpler management and more herbicide options. Pure legume stands decline in forage quality more slowly with advancing maturity than do grasses, providing a wider window of opportunity for harvesting good quality forage. Pure grass stands are usually more resilient, able to withstand more abuse, and persist longer than pure legume stands.

Legume-grass mixtures are common in Ohio and can exploit the relative strengths of grasses and legumes. Mixtures are generally more satisfactory for pastures than pure stands. Grass-legume mixtures are often more stable in yield and have more uniform seasonal production than pure stands. Including legumes in a mixture reduces the need for nitrogen fertilizer, improves forage nutritive value and animal performance, and reduces the potential for nitrate poisoning and grass tetany compared with pure grass stands. Including grasses in a mixture usually lengthens the life of a stand because they persist longer and are more tolerant of mismanagement and variable soils than legumes. Grasses reduce the incidence of bloat, improve hay drying, are usually more tolerant of lower fertility, reduce losses to insect pests and diseases, and compete with weeds more than legumes. The fibrous root system of grasses helps control erosion on steep slopes and reduces legume heaving.

Table 7-1: Agronomic Adaptation and Characteristics of Perennial Forages Grown in Ohio.

Forage Species	Minimum Adequate Drainage ¹	Tolerance to pH < 6.0	Adequate Soil Fertility	Drought Tolerance	Persistence	Seedling Vigor	Growth Habit
Legumes							
Alfalfa	WD	Low	High to medium	High	High	High	Bunch
Alsike clover	PD	High	Medium to low	Low	Low	Low	Spreading
Birdsfoot trefoil	SPD	High	Medium	Medium	Medium	Low	Bunch
Red clover	SPD	Medium	Medium	Medium	Low	High	Bunch
White clover	PD	Medium	Medium	Low	High	Low	Spreading
Cool-Season Grasses and Forbs							
Festulolium	SPD	Medium	Medium to high	Low	Low	Very high	Bunch
Kentucky bluegrass	SPD	Medium	Medium	Low	High	Low	Dense Sod
Meadow fescue	PD	Medium	Low to medium	Medium	High	Medium	Bunch
Orchardgrass	SPD	Medium	Medium	Medium	Medium	High	Bunch
Perennial ryegrass	SPD	Medium	Medium to high	Low	Low	Very high	Bunch
Reed canarygrass	VPD	High	Medium to high	High	High	Low	Open sod
Smooth bromegrass	MWD	Medium	High	High	High	Medium	Open sod
Tall fescue	SPD	High	Medium	Medium	High	High	Variable ²
Timothy	SPD	Medium	Medium	Low	High	Low	Bunch
Chicory	MWD	Medium	Medium to high	High	Medium	High	Bunch
Warm-Season Grasses							
Switchgrass	SPD	High	Low to medium	Excellent	High	Very low	Bunch
Big bluestem	MWD	High	Low to medium	Excellent	High	Very low	Bunch
Indiangrass	MWD	High	Low to medium	Excellent	High	Very low	Bunch
Eastern gamagrass	PD	High	Medium to high	Good	High	Very low	Bunch

¹ Minimum drainage required for acceptable growth; WD = well drained; MWD = moderately well drained; SPD = somewhat poorly drained; PD = poorly drained; VPD = very poorly drained.

² Under lax cutting, tall fescue has bunched growth; under frequent cutting or grazing it forms a sod.

Table 7-2: Suitability of Perennial Forage Species to Different Types of Management and Growth Characteristics.

Species	Frequent, Close Grazing	Rotational Grazing	Stored Feed	Periods of Primary Production	Relative Maturity ¹
Legumes					
Alfalfa	X ²	●	■	Spring, summer, early fall	Early-medium
Alsike clover	X	●	●	Spring, early summer, fall	Late
Birdsfoot trefoil	X	■	■	Spring, summer, early fall	Medium-late
Red clover	X	●	■ ³	Spring, summer, early fall	Medium-late
White Dutch clover	■	■	X	Spring and fall	Early-medium
White clover, ladino	X	■	●	Spring, early summer, fall	Early-medium
Cool-Season Grasses and Forbs					
Festulolium	X ⁴	■	■ ³	Spring, early summer, fall	Medium
Kentucky blue-grass	■	■	●	Early spring and late fall	Early
Meadow fescue	X	■	■	Spring, early summer, fall	Medium
Orchardgrass	X ⁴	■	■	Spring, summer, fall	Early-medium
Perennial ryegrass	X ⁴	■	■ ³	Spring and fall	Medium
Reed canarygrass	X	■	■	Spring, summer, fall	Medium-late
Smooth brome-grass	X	●	■	Spring, summer, fall	Medium-late
Tall fescue	X	■	■	Spring, summer, fall	Medium-late
Timothy	X	●	■	Late spring and fall	Late
Chicory	X	■	X	Spring, summer	Early
Warm-Season Grasses					
Switchgrass	X	■	■	Summer	Very late
Big bluestem	X	■	■	Summer	Very late
Indiangrass	X	■	■	Summer	Very late
Eastern gamagrass	X	■	●	Summer	Very late

¹ Relative time of flower or seedhead appearance in the spring. Depends on species and variety. Warm-season grasses mature in midsummer; exact time varies by species.

² ■ = Highly suitable
● = Suitable
X = Not recommended

³ Silage preferred, difficult to cure for dry hay.

⁴ Can tolerate frequent grazing if a 3- to 4-inch stubble is maintained.

Table 7-3: Suitability of Perennial Forage Species to Different Soil Fertility Classes and Methods of Utilization.

<p>Medium to high fertility soils, for hay & silage</p> <p>Alfalfa, birdsfoot trefoil, red clover</p> <p>Festulolium, meadow fescue, orchardgrass, perennial ryegrass, reed canarygrass, smooth brome, tall fescue, timothy</p> <p>Switchgrass, big bluestem, indiagrass</p>
<p>Medium to high fertility soil, pasture production</p> <p>Alfalfa, alsike clover, birdsfoot trefoil, red clover, white clover, chicory</p> <p>Festulolium, Kentucky bluegrass, meadow fescue, orchardgrass, perennial ryegrass, reed canarygrass, smooth brome, tall fescue, timothy</p> <p>Switchgrass, big bluestem, indiagrass, eastern gamagrass</p>
<p>Low to medium fertility soils, for hay & silage</p> <p>Red clover, alsike clover, birdsfoot trefoil</p> <p>Meadow fescue, orchardgrass, tall fescue, timothy</p> <p>Switchgrass, big bluestem, indiagrass</p>
<p>Low to medium fertility soil, pasture production</p> <p>Alsike clover, birdsfoot trefoil, white clover</p> <p>Kentucky bluegrass, meadow fescue, orchardgrass, tall fescue</p> <p>Switchgrass, big bluestem, indiagrass</p>

Mixtures for Hay and Silage

Keep mixtures relatively simple for hay or silage use, two to four species are usually sufficient. Hay and silage cutting schedules are easier to manage with simple mixtures. Consider the following criteria:

- **Adaptation.** All species in the mixture should be adapted to the prevailing soil conditions (drainage, soil moisture holding capacity, soil pH, fertility, etc.).
- **Rate of Establishment.** Combine species with fairly similar seedling aggressiveness. Persistent plant species are often the least competitive in the seedling stage. Excessive seedling competition in a shotgun mixture can prevent persistent and desirable species from becoming established. An exception to this rule is the use of companion crops, or fast-establishing short-lived perennial or annual species used to achieve quick ground cover. Small grains and annual or perennial ryegrass are often used for this purpose. Keep seeding rates of these temporary companions low to avoid excessive competition with the slower establishing perennial species.
- **Time of Maturity.** Species and varieties in a mixture should mature at about the same time and match your intended harvest schedule. There is considerable variation in maturity among grass species and varieties. Such information is often collected in variety testing trials and is also available from seed suppliers.
- **Management Compatibility.** Select species that are well adapted to the intended management. For example, orchardgrass is compatible with alfalfa on a four-cut schedule because it regrows quickly, while timothy and brome are compatible with alfalfa on a more lenient three-cut schedule.
- **Summer Production.** Alfalfa produces very well during the summer months while birdsfoot trefoil and red clover generally produce less summer yield. Of the grasses, orchardgrass, tall fescue and reed canarygrass produce the best summer growth. Smooth brome produces moderate to light summer aftermath, and timothy, meadow fescue and perennial ryegrass are usually lower yielding in the summer months. Moisture and temperature conditions affect aftermath production of cool-season grasses more than alfalfa.
- **Variety Performance.** Use variety testing data to select species and varieties that have stable yield performance over multiple locations and years. Stable yield performance across many environments demonstrates good adaptation to a wide range of conditions. Performance over years demonstrates yield persistence with advancing stand age and is especially important for long rotations. For Ohio variety test data and links to data in other states, see u.osu.edu/perf.
- **Disease and Pest Resistance.** Select species and varieties with resistance to important insects and diseases for your soils. For example, *Phytophthora* root rot and *Fusarium* wilt resistance in alfalfa are very important on soils with suboptimal drainage, while potato leafhopper resistant alfalfa is useful across all of Ohio. Resistance to foliar diseases can be important in grasses.
- **Forage Quality.** Varieties with improved forage quality are available in some species. If high forage quality is very important, then select varieties based on this trait.

Mixtures for Pastures

While simple mixtures are desirable for hay and silage management, studies in Ohio and the northeastern U.S. demonstrated that complex mixtures of six or more spe-

cies provide greater stability of forage production under grazing. Soil and environmental variability in pastures makes it difficult to predict which species will perform best. Species dominance and spatial distribution in a pasture will be affected by variability in fertility, soil drainage, slope aspect (north versus south facing), and animal traffic and grazing patterns, among other factors that influence the microenvironment. In addition, species vary in productivity during different seasons, i.e., between spring and summer grazing periods. Therefore, it is best to use mixtures with a range of grasses and legumes that fit the general soil conditions and management characteristics and that are not drastically different in palatability.

Seeding Rates

Table 7-4 gives recommended seeding rates for individual species in pure stands and for mixtures. Seeding rate recommendations are related to seed size, germination, seedling and established plant vigor, spreading characteristics, and mature plant size. For example, more seeds per square foot are recommended for species with low seedling vigor and smaller mature plant size (e.g., Kentucky bluegrass) in order to improve establishment success and competitiveness of that species in a mixture or against weed encroachment. Increasing seeding rates above the recommended levels does not compensate for poor seedbed preparation or improper seeding methods.

There is no reliable way to predict that a specific proportion sown will result in a similar proportion of established plants in a mixed species seeding. The seeding rates shown for mixtures are simply varying percentages of the pure stand seeding rate recommendation. Use your best judgment to adjust the seeding rate for each species based on the relative proportion desired of that species in the mixture (see sidebar). Complex mixtures will often result in a higher overall seeding rate (in seeds per square foot) than simpler mixtures. This is simply a function of having more component species, each one seeded above a minimum level to provide an opportunity for it to establish and compete in the microenvironments where it is best adapted.

Examples of Seeding Rates for Mixtures

Simple Hay Mixture: For an orchardgrass base with a small percentage of red clover, sow orchardgrass at the three-quarter rate (7 pounds per acre) and red clover at the one-quarter rate (3 pounds per acre) shown in Table 7-4.

Complex Pasture Mixture: If orchardgrass is desired to be slightly more dominant than several other species in a complex mixture, sow orchardgrass at the one-third rate and the other species at the one-eighth rate: orchardgrass (3 pounds per acre), festulolium (3 pounds per acre), smooth brome grass (4 pounds per acre), red clover (2 pounds per acre), ladino clover (1 pound per acre), and chicory (1.5 pounds per acre).

Characteristics of Perennial Cool-Season Forages

Alfalfa (Medicago sativa L.)

Alfalfa is grown on about one-third of the total hay and haylage acres in Ohio. Where adapted, it is unmatched by any other forage as high quality feed for livestock and as a cash crop. Alfalfa requires deep, well-drained soils with near-neutral pH (6.5-7.0) and high fertility. It should not be grown on soils with moderate to poor drainage. Alfalfa is best adapted to hay or silage harvest management. While it can be used in rotationally grazed pastures, it normally lacks persistence in permanent pastures compared with other legumes. Like most legumes, it can cause bloat. Alfalfa has good seedling vigor, excellent drought tolerance, and produces very well through the summer. Important insect pests on alfalfa include the alfalfa weevil and potato leafhopper.

Select newer high-yielding alfalfa varieties with adequate winter hardiness and resistance to important diseases to capitalize on alfalfa's potential. Most new varieties of alfalfa include selection for multiple disease resistance. Varieties are also available with higher forage nutritive value, high levels of resistance to potato leafhopper, traffic and grazing tolerance, and some tolerance to lodging. Round-up Ready varieties are now available as a tool for weed management. Varieties with reduced lignin content and higher fiber digestibility have recently been developed. Studies in Ohio have demonstrated that new varieties with multiple pest resistance provide higher yields and greater stand persistence with less weed invasion than older varieties. Always evaluate performance data across multiple locations when selecting varieties. For more information on varieties, see the *Ohio Forage Performance Trials* and forage trials in other states, available at Extension offices and online at u.osu.edu/perf.

Alsike Clover (Trifolium hybridum L.)

Alsike clover is a short-lived perennial legume that is tolerant of wet, acidic soils. Alsike tolerates soils with a pH as low as 5.0, which is too acidic for red clover and alfalfa. Alsike also grows better than red clover on alkaline (high pH) soils. Alsike tolerates flooding better than other legumes, making it well suited for low-lying fields with poor drainage. It can withstand spring flooding for several weeks. A cool and moist environment is ideal for alsike clover growth; it has poor heat and drought tolerance, thus usually produces only one crop of hay per year. It is susceptible to the same diseases that attack red and white clovers. Its growth habit is intermediate between red and white clover. Alsike clover must be allowed to reseed to maintain its presence in pastures, otherwise it will last only about two years. Alsike clover has good palatability, but can cause bloat and photosensitization in grazing animals.

Table 7-4: Seeding Rates of Pure Live Seed (PLS) for Forages Grown in Ohio.

Species	Approximate Seeds/lb (x 1000)	Pure Stand Seeding Rate		Proportional Seeding Rates for Mixtures ¹				
		(seeds/ ft ²)	(lb/ac)	3/4	1/2	1/3	1/4	1/8
----- lb/ac -----								
Perennial Legumes								
Alfalfa	227	80	15	12	8	5	4	2
Alsike clover	700	150	9	7	5	3	2	1
Birdsfoot trefoil	375	80	9	7	5	3	2	1
Red clover	275	70	11	8	6	4	3	1.5
White clover	860	100	5	4	3	2	1	0.5
Perennial Grasses and Forbs								
Festulolium	227	130	25	19	12	8	6	3
Kentucky bluegrass	2200	500	10	7	5	3	2	1
Meadow fescue	220	80	16	12	8	5	4	2
Orchardgrass	590	130	10	7	5	3	2	1
Perennial ryegrass	237	130	24	18	12	8	6	3
Reed canarygrass	550	130	10	8	5	3	2.5	1
Smooth brome	137	50	16	12	8	5	4	2
Tall fescue	227	80	15	12	8	5	4	2
Timothy	1230	220	8	6	4	3	2	1
Big bluestem	150	40	12	9	6	4	3	1
Eastern gamagrass	7.4	1.5	9	7	4	3	2	1
Indiangrass	175	50	12	9	6	4	3	1.5
Switchgrass	370	80	9	7	5	3	2	1
Chicory	375	50	6	4	3	2	1.5	1
Annuals and Biennials								
Italian ryegrass	228	125	24	18	12	8	6	3
Kale	140	12	4	-	-	-	-	-
Oats, spring	15	30	87	65	44	29	22	11
Pearl millet	85	40	20	-	-	-	-	-
Rape	145	12	4	-	-	-	-	-
Rye, winter	18	45	109	-	-	-	-	-
Sorghum, forage	28	8	12	-	-	-	-	-
Sorghum-sudangrass	28	15	23	-	-	-	-	-
Sudangrass	55	30	24	-	-	-	-	-
Swede	200	8	2	-	-	-	-	-
Teff	1250	140	5	-	-	-	-	-
Turnip	190	8	2	-	-	-	-	-
Triticale	16	40	109	-	-	-	-	-
Winter wheat	15	40	116	-	-	-	-	-

¹ Seeding rates for stated proportions of the seeding rate for pure stands.

Birdsfoot Trefoil (Lotus corniculatus L.)

Birdsfoot trefoil is a deep-rooted perennial legume that is best adapted to northern Ohio. Birdsfoot trefoil is tolerant of low-pH soils (as low as pH 5.0), moderate to somewhat poor soil drainage, marginal fertility, and soils with fragipans. Birdsfoot trefoil can withstand several weeks of flooding, and tolerates periods of moderate drought and heat. It has poor seedling vigor and is slow to establish. Early spring seedings are generally more successful than late summer seedings. It is best seeded with a grass companion. Birdsfoot trefoil produces excellent quality forage with fair palatability, it stockpiles well, and unlike most forage legumes, it is non-bloating. Birdsfoot trefoil should be managed to allow for reseeding to maintain its presence in forage stands. It is intolerant of close cutting or grazing, has slow recovery after hay harvest, and is susceptible to root and crown rot diseases.

Empire-type varieties have prostrate growth and fine stems, making them better suited to grazing. European-type varieties are more erect, establish faster, and regrow faster after harvest. Thus, they are better suited to hay production and rotational grazing. Most of the newer varieties are intermediate with semi-erect to erect growth habit.

Red Clover (Trifolium pratense L.)

Red clover is a short-lived perennial legume grown for hay, silage, pasture and for green manure. Red clover is better adapted than alfalfa to soils that are somewhat poorly drained and slightly acidic; however, greatest production occurs on well-drained soils with high water-holding capacity and pH above 6.0. Red clover is not as productive as alfalfa in the summer. It has good seedling vigor and is one of the easiest legumes to establish using no-till interseeding or frost-seeding techniques. Under Ohio weather conditions, red clover is often difficult to dry for hay storage. Harvesting for silage or including a grass in the stand helps alleviate this problem. When grazed, red clover can cause bloat in cattle if sufficient grass is not present.

Medium red clover varieties can be harvested three to four times per year. Mammoth red clover is late to flower and is considered a single cut clover because the majority of its growth occurs in the spring. Most of the improved varieties are medium types and have good levels of disease resistance to northern and southern anthracnose and powdery mildew. Several new medium red clover varieties have demonstrated acceptable stand persistence for three or even four years in university trials. Varieties with greater grazing tolerance are also available.

White Clover (Trifolium repens L.)

White clover is a low-growing, short-lived perennial legume that is well suited for pastures. It can cause bloat in cattle if sufficient grass is not present for grazing. White clover improves forage quality of grass pastures and re-

duces the need for nitrogen fertilizer. White clover can be frost seeded or no-till seeded into existing grass pastures. It spreads by stolons. White clover is most productive when moisture is plentiful. It has a shallow root system, so does not tolerate prolonged dry spells. Although well-drained soils improve production, white clover tolerates periods of poor drainage. It can be managed for reseeding to improve persistence in pastures.

Large white clover types, also known as Ladino clovers, are more productive and aggressive in mixtures with grasses than are the medium-leaf or the small-leaf type frequently referred to as White Dutch. The small- and medium-leaf clovers persist better under heavy, continuous grazing because they are often prolific reseederers. In contrast, the large-leaf types are better suited under hay or silage management because they can be too aggressive in grazed pastures, resulting in higher risk for animals to bloat. Purchase seed of stated quality to be certain of obtaining pure seed of the white clover variety desired.

Festulolium (xFestulolium Asch. & Graebn.)

Festulolium grass species are hybrids derived from crosses among up to four possible parents: tall fescue, meadow fescue, Italian ryegrass and perennial ryegrass. They are bunchgrasses suitable for hay, silage or pasture. The parent species used in the cross and the relative proportion of genes from each parent determines the characteristics of any given festulolium variety, thus it is difficult to generalize about this species. For example, a meadow fescue parent contributes midsummer growth, winter hardiness, forage quality, and drought tolerance, while an Italian ryegrass parent contributes rapid establishment and quick regrowth. Festulolium is generally best adapted to the northern half of Ohio; however, when tall fescue is used to contribute a significant proportion of the genetic makeup of the festulolium variety, then it would likely be adapted to southern Ohio as well. Festulolium generally grows especially well in the spring and produces palatable forage with high nutritive value. Festulolium yields well under good fertility when moisture is adequate. Like perennial ryegrass, it is a vigorous establisher. Because it is generally less winter hardy than other grasses, festulolium is best seeded in combination with other grasses and legumes. It can be grown on occasionally wet soils. Compared with orchardgrass, it is lower yielding, less competitive with legumes, and later to mature. Like orchardgrass, festulolium can withstand frequent cutting or grazing. It is difficult to cut with a sickle bar mower and is slower to dry than other grasses, so is better suited to grazing, greenchopping, and silage harvesting than for dry hay.

Festulolium varieties can differ markedly in winterhardiness and recovery from winter injury based on the parent germplasm used to produce the variety. For permanent pastures, select varieties that are proven to persist well under Ohio conditions.

Kentucky Bluegrass (Poa pratensis L.)

Kentucky bluegrass is a long-lived perennial grass especially well-suited to pastures because of its low growth habit. It forms a dense, tough sod under favorable conditions, providing good footing for grazing animals. It reproduces by seed and rhizomes. It tolerates close or frequent grazing and is one of the most forgiving grasses, able to tolerate and persist under a wide range of soil conditions and mismanagement. Kentucky bluegrass grows best under cool and moist conditions, usually going semi-dormant during the summer. Improved varieties are available.

Meadow Fescue (Schedonorus pratensis (Huds.) P. Beauv.

Meadow fescue is a cool-season semi-bunch type grass native to northern Europe and mountainous regions in southern Europe that is regaining acceptance in the U.S. because of its many positive characteristics. It grows well under cool, moist conditions and reportedly tolerates wet and sometimes flooded conditions. It was introduced into the U.S. in the early 1800s, but was essentially forgotten by the 1950s. Recently, it has gained renewed interest among forage producers because it produces palatable forage of high nutritive value. It is suitable for frequent, managed grazing systems, but is lower yielding (20 to 30 percent less) than orchardgrass and tall fescue and is less suited to hay production. It is very winter hardy and yields more than perennial ryegrass, while being more palatable with higher fiber digestibility at equal stages of maturity than either tall fescue or orchardgrass, resulting in higher animal performance. Meadow fescue is consistently about five units higher in neutral detergent fiber digestibility (NDFD) than tall fescue or orchardgrass across the entire growing season. Meadow fescue has a fungal endophyte, which does not produce alkaloids that are harmful to animals. It is not currently known if the endophyte provides any benefit to the plant. Meadow fescue does exhibit good drought tolerance on shallow soils and populations of this grass on farms have been noted as growing in deep, consistent shade of remnant oak savannas in the North Central region. Mixtures of meadow fescue with alfalfa have been shown to provide higher energy to protein ratios compared with mixtures of alfalfa with orchardgrass, timothy, tall fescue, meadow brome or Kentucky bluegrass.

New varieties are available from several grass seed sources, many developed in Europe. Varieties are being developed in the U.S., including the variety Hidden Valley, a publicly released variety developed from selections in Wisconsin.

Orchardgrass (Dactylis glomerata L.)

Orchardgrass is a versatile perennial bunch-type grass (no rhizomes) that establishes rapidly and is suitable for hay, silage or pasture. Orchardgrass along with tall fescue are usually the most productive cool-season grasses grown in Ohio, especially under good fertility management.

Orchardgrass has rapid regrowth, produces well under intensive cutting or grazing, and has better summer growth than most of the other cool-season grasses. It grows best in deep, well-drained, loamy soils. Its flooding tolerance is fair in the summer but poor in the winter. Orchardgrass is especially well suited for mixtures with tall legumes, such as alfalfa and red clover. The rapid decline in palatability and quality with maturity is a limitation with this grass. Timely harvest management is essential for obtaining good quality forage.

Improved varieties of orchardgrass are available with high yield potential, resistance to leaf diseases, and some have been developed for greater grazing tolerance. Maturity is an important consideration in variety selection and a wide range in maturity is available among new varieties. When seeding orchardgrass-legume mixtures, select varieties that match the maturity of the legume. The later-maturing varieties are best suited for mixtures with alfalfa and red clover. In pastures, early maturing varieties will often produce higher yield than late maturing varieties, but grazing management must be aggressive in the spring to manage their rapid and early maturation.

Reed Canarygrass (Phalaris arundinacea L.)

Reed canarygrass is a tall, leafy, coarse, high-yielding perennial grass tolerant of a wide range of soil and climatic conditions (Table 7-1 and 7-2). It can be used for hay, silage, and pasture. It has a reputation for poor palatability and low forage quality. This reputation was warranted in the past because older varieties produced forage containing alkaloid compounds (bitter, complex, nitrogen-containing compounds). However, varieties are now available that make this forage an acceptable animal feed, even for lactating dairy cows.

Reed canarygrass grows well in very poorly drained soils, but is also productive on well-drained upland soils. It is winter hardy, drought tolerant (deep-rooted), resistant to leaf diseases, persistent, responds to high fertility, and tolerates spring flooding, low pH, and frequent cutting or grazing. Reed canarygrass forms a dense sod. Limitations of this grass include slow establishment, expensive seed, and rapid decline in forage quality after heading.

Only low-alkaloid varieties (e.g., Palaton, Venture, Rival, Marathon) are recommended if the crop is to be used as an animal feed. These varieties are palatable and equal in quality to other cool-season grasses when harvested at similar stages of maturity. Common reed canarygrass seed should be considered to contain high levels of alkaloids, and is undesirable for animal feed.

Ryegrass (Lolium species)

Perennial ryegrass (*Lolium perenne* L.) is a bunch grass suitable for hay, silage or pasture that is best adapted to the northern half of Ohio. Perennial ryegrass produces palatable forage with high nutritive value. It has a long growing season and yields well under good fertility when moisture is plentiful. It is a vigorous establisher and is often used in mixtures to establish quick ground cover. Because it is less winter hardy than other grasses, perennial ryegrass is best seeded in combination with other grasses and legumes. It can be grown on occasionally wet soils. Compared with orchardgrass, it is lower yielding, less competitive with legumes, and later to mature. Like orchardgrass, perennial ryegrass can withstand frequent cutting or grazing. It is difficult to cut with a sickle bar mower and is slower to dry than other grasses, so is better suited to grazing, greenchopping, and silage harvesting than for dry hay.

Perennial ryegrass varieties can differ markedly in winterhardiness and recovery from winter injury. Maturity also differs widely among ryegrass varieties. Be sure to purchase endophyte-free seed of forage-type varieties; seed of many turf-type varieties is infected with a fungal endophyte (fungus inside the seed and plant), which can be harmful to livestock and cause a neurological condition known as ryegrass staggers. Forage-type varieties are either diploid (the basic chromosome number is doubled) or tetraploid (basic chromosome number is quadrupled). Tetraploid varieties have fewer, but larger, tillers and wider leaves, resulting in more open sods than diploids. Tetraploids are usually slightly higher in forage digestibility.

Hybrid ryegrass (*Lolium xhybridum* Hausskn.) is achieved by crossing perennial and annual ryegrass. It generally has characteristics intermediate between those of perennial and annual ryegrass.

Italian ryegrass (*Lolium perenne* L. subsp. *multiflorum* (Lam.) Husnot) is generally annual or biennial in longevity, and can provide short-term high yields of high-quality forage. More details on this species are provided under the *Annual Forage Crops* section of this chapter.

Smooth Bromegrass (Bromis inermis Leyss.)

Smooth bromegrass is a leafy, sod-forming perennial grass best suited for hay, silage, and early spring pasture. It spreads by underground rhizomes and through seed dispersal. Smooth bromegrass is best adapted to well-drained silt-loam or clay-loam soils. It is a good companion with cool-season legumes. Smooth bromegrass matures somewhat later than orchardgrass in the spring and makes less summer growth than orchardgrass. It is very winter hardy and, because of its deep root system, will survive periods of drought. Smooth bromegrass produces excellent quality forage, especially if harvested in the early heading stage. It is adversely affected by cutting or grazing when the stems are elongating rapidly (jointing stage), and is less tolerant of frequent cutting. It should be harvested for hay in the early heading stage for best recovery

growth. Fluffy seed makes this grass difficult to drill unless mixed with a carrier (e.g., oats, rice hulls, vermiculite or small amount of phosphate fertilizer). It is susceptible to leaf diseases.

Improved high-yielding and persistent varieties are available. Some varieties are more resistant to brown leaf spot, which may occur on smooth bromegrass. These improved varieties start growing earlier in the spring and stay green longer than common bromegrass, which has uncertain genetic makeup.

Several other brome species are now available from forage seed suppliers including Alaska brome, meadow brome, prairie brome, and mountain brome. Always ask for information on species characteristics and evaluate performance data in your region before purchasing any newer grass species or variety. Plant small areas when your experience with a particular species is limited.

Tall Fescue (Schedonorus arundinaceus (Schreb.) Dumort., nom. cons.)

Tall fescue is a deep-rooted, long-lived, sod-forming grass that spreads by short rhizomes. It is suitable for hay, silage or pasture for beef cattle and sheep. Tall fescue is the best cool-season grass for stockpiled pasture or field-stored hay for winter feeding. It is widely adapted, and persists on acidic, wet soils of shale origin. Tall fescue is drought resistant and survives under low fertility conditions and abusive management. It is ideal for waterways, ditch and pond banks, farm lots, and lanes. It is the best grass for areas of heavy livestock and machinery traffic.

Most of the tall fescue in older permanent pastures in Ohio contains a fungus (endophyte) growing inside the plant. The fungal endophyte produces alkaloid compounds that reduce palatability in the summer and result in poor animal performance. Several health problems may develop in animals grazing endophyte-infected tall fescue, especially breeding animals. Deep-rooted legumes should be included with tall fescue if it is to be used in the summer. Legumes improve animal performance, increase forage production during the summer, and dilute the toxic effect of the endophyte when it is present. For more information on this problem and solutions, refer to fact sheets available through county Extension offices.

Newer endophyte-free varieties or varieties with very low endophyte levels (less than 5 percent) are recommended if stands are to be used for animal feed. In addition, varieties are also available with novel endophytes that are not toxic to livestock. Kentucky-31 is the most widely grown variety, but most seed sources of this variety are highly infected with the toxic endophyte fungus, and should not be planted. When buying seed, make sure the tag states that the seed is endophyte-free or has a very low percentage of infected seed, or contains novel endophyte only. Because endophyte-free varieties are less stress tolerant than endophyte-infected varieties, they should be managed more carefully.

Timothy (*Phleum pratense* L.)

Timothy is a hardy perennial bunchgrass that grows best in cool climates. It generally grows better in northern Ohio than southern Ohio. Its shallow root system makes it unsuitable for droughty soils. It produces most of its annual yield in the first crop. Summer regrowth is often limited because of timothy's intolerance to hot and dry conditions. Timothy is used primarily for hay and is especially popular for horses. It requires fairly well-drained soils. Timothy is less competitive with legumes than most other cool-season grasses. It is adversely affected by cutting or grazing when the stems are elongating rapidly (jointing stage), and is less tolerant of frequent cutting. It should be harvested for hay in the early heading stage for best recovery growth.

Forage Species Identification

There are several excellent printed and online resources for identifying forage species. Below is a partial list of what is available:

Printed publications:

Identifying Pasture Grasses, University of Wisconsin Bulletin A3637

Identifying Pasture Legumes, University of Wisconsin Bulletin A3787

Forage Identification and Use Guide, University of Kentucky Cooperative Extension Service Bulletin AGR-175

Forage Legumes, 2nd Ed., University of Minnesota Station Bulletin 608-2003

Forage Field Guide, Purdue University Extension Guide ID-317

Online resources:

Purdue Forage Identification pages, agry.purdue.edu/ext/forages/ForageID/forageid.htm

Forage Information System Forage Identification, forages.oregonstate.edu/nfgc/eo/onlineforagecurriculum/instructionmaterials/availabletopics/plantid/identifyforages

University of Wyoming Forage Identification, uwyo.edu/plantsciences/uwplant/forages/

Pre-Establishment Fertilization and Liming

Soil pH

Proper soil pH and fertility are essential for optimum economic forage production. Take a soil test to determine soil pH and nutrient status at least six months before seeding. This allows time to correct deficiencies in the topsoil zone. The topsoil in fields with acidic subsoils (most common in eastern Ohio) should be maintained at higher pH than fields with neutral or alkaline subsoils.

Topsoil pH Levels for Forages:

pH 6.8 for alfalfa on mineral soils with subsoil pH less than 6.0.
pH 6.5 for other forage legumes and grasses on mineral soils with subsoil pH less than 6.0.
pH 6.5 for alfalfa on mineral soils with subsoil pH greater than 6.0.
pH 6.0 for other forage legumes and grasses on mineral soils with subsoil pH greater than 6.0.

Soil pH should be corrected by application of lime when topsoil pH falls 0.2 to 0.3 pH units below the recommended levels. With conventional tillage plantings, soil samples should be taken to an 8-inch depth and lime should be incorporated and mixed well in the soil at least six months before seeding. If more than 4 tons per acre are required, half the amount should be incorporated deeply and the other half incorporated lightly into the top 2 inches. If low rates of lime are recommended or if a split application is not possible, the lime should be worked into the surface rather than plowed down. This assures a proper pH in the surface soil where seedling roots develop and where nodulation begins in legumes.

Phosphorus and Potassium

Corrective applications of phosphorus and potassium should be applied prior to seeding regardless of the seeding method used; however, fertilizer applications incorporated ahead of seeding are more efficient than similar rates not incorporated. This is especially true for phosphorus and for no-till seedings. Phosphorus and potassium fertilizer recommendations for forages are provided in Tables 7-5 to 7-7.

Table 7-5: Annual Phosphate (P₂O₅) Recommendations for Pure Grass Forage Stands. Includes Maintenance Plus Four-Year Buildup to the Critical Level Where Needed.

Soil P Test Level ppm (lb/ac)	Yield Potential (ton/ac)		
	4	6	8
	-----lb P ₂ O ₅ per ac-----		
5 (10) ¹	100	135	140
10 (20)	75	110	115
15-30 (30-60) ²	50	85	90
35 (70)	25	45	45
40 (80)	0	0	0

¹ Values in parentheses are pounds per acre.

² Maintenance recommendations are given for this soil test range.

Table 7-6: Annual Phosphate (P_2O_5) Recommendations for Forage Legume or Legume-Grass Mixtures. Includes Maintenance Plus Four-Year Buildup to the Critical Level Where Needed.

Soil P Test Level ppm (lb/ac)	Yield Potential (ton/ac)		
	4	6	8
	-----lb P_2O_5 per ac-----		
10 (20) ¹	130	160	190
15 (30)	100	135	160
20 (40)	75	110	135
25-40 (50-80) ²	50	85	110
45 (90)	25	45	50
50 (100)	0	0	0

¹ Values in parentheses are pounds per acre.

² Maintenance recommendations are given for this soil test range.

Table 7-7: Annual Potassium (K_2O) Recommendations for Forage Grass Only, Legume Only and Legume-Grass Mixtures. Includes Maintenance and Four-Year Buildup to the Critical Level Where Needed.

Soil Test K Level ppm (lb/ac)	CEC	Yield Potential (ton/ac)		
		4	6	8
		-----lb K_2O per ac-----		
		-----10 meq/100 g-----		
75 (150) ¹		260 ²	300	300
100-130 (200-260) ³		220	300	300
140 (280)		40	60	80
150 (300)		0	0	0
		-----20 meq/100 g-----		
100 (200)		270	300	300
125-155 (250-310) ³		220	300	300
165 (330)		40	60	80
175 (350)		0	0	0
		-----30 meq/100 g-----		
125 (250)		280	300	300
150-180 (300-360) ³		220	300	300
190 (380)		40	60	80
200 (400)		0	0	0

¹ Values in parentheses are pounds per acre.

² Maximum potassium rate recommended is 300 pounds K_2O per acre.

³ Maintenance recommendations are given for this soil test range.

Sulfur

Sulfur is an essential secondary plant nutrient and is a component of plant proteins and vitamins. In the past, the supply of sulfur in Ohio soils was more than adequate for good forage growth; however, with the implementation

of the Clean Air Act, there has been a 30 to 40 percent reduction in sulfur deposition to Ohio soils since 1985. Sulfur deficiencies on alfalfa have been documented in some Ohio soils. If soils have exhibited sulfur deficiency in the past, consider applying 70 pounds per acre of elemental sulfur ahead of seeding to alfalfa. Elemental sulfur requires at least two months to be converted in the soil to the sulfate form which is available for plant uptake. If more rapid uptake of sulfur is desired in the seeding year, add 30 pounds per acre of a sulfate form of sulfur at seeding along with the elemental sulfur for subsequent years. A sulfur deficiency is unlikely on soils where manure or gypsum have been applied, since both are good sources of sulfur. Refer to the *Tri-State Fertilizer Recommendations* (Bulletin E-2567) for additional information.

Pre-Establishment Fertilization for No-till

For no-till seedings, take soil samples to a 4-inch depth to determine pH and lime needs, and to a normal 8-inch depth to determine phosphorus and potassium needs. If possible, make corrective applications of lime, phosphorus, and potassium earlier in the crop rotation when tillage can be used to incorporate and thoroughly mix these nutrients throughout the soil. When this is not feasible, be sure to make lime, phosphorus, and potassium applications at least eight months or more ahead of seeding to obtain the desired soil-test levels in the upper rooting zone. Use the finest grade of lime available at a reasonable price when surface applications are made. Lime and phosphorus move slowly through the soil profile. Once soil pH, phosphorus, and potassium are at optimum levels, surface applications of lime and fertilizers maintain those levels. Attempts to establish productive forages often fail where pH, phosphorus or potassium soil-test values are below recommended levels, even when corrective applications of those nutrients are surface applied or partially incorporated just before seeding.

Starter Nitrogen

Seedling vigor of cool-season forage grasses is enhanced on many Ohio soils by nitrogen applied at seeding time. Apply nitrogen at 10 to 20 pounds per acre when seeding grass-legume mixtures, and 30 pounds per acre when seeding pure grass stands. Starter nitrogen applications of 10 pounds per acre may be beneficial with pure legume seedings, especially under cool conditions and on soils low in nitrogen. Manure applications incorporated ahead of seeding can also be beneficial to seedling establishment of forages, including alfalfa. Obtain a manure nutrient analysis and base application rates on soil-test results. For more information on manure application to soils refer to the *Ohio Livestock Manure And Wastewater Management Guide* (Bulletin 604).

Stand Establishment

Establishing a good stand is critical for profitable forage production and requires attention to details for success.

As discussed above, begin by selecting species adapted to soils where they will be grown. Plan well ahead of time so corrective lime applications have time to neutralize soil acidity, and soil fertility deficiencies can be corrected. Make sure fields are free of any herbicide carryover that can harm forage seedlings. Refer to the current *Weed Control Guide* (Bulletin 789) and current labels for more information on herbicides with crop rotation restrictions.

An established stand having about six grass and/or legume plants per square foot is generally adequate for good yields. About 20 to 25 seedling plants per square foot in the seeding year usually results in good stands the following year. The following guidelines greatly improve the likelihood of successful establishment of productive forage stands.

Crop Rotation and Autotoxicity

Crop rotation is an important management tool for improving forage productivity, especially when seeding forage legumes. Crop rotation reduces disease and insect problems. Seeding alfalfa after alfalfa is especially risky because old stands of alfalfa release a toxin that reduces germination and growth of new alfalfa seedlings (called autotoxicity). This is especially true on heavy-textured soils. Disease pathogens accumulate and can cause stand establishment failures when seeding into a field that was not rotated out of alfalfa. Rotating to another crop for at least one year before re-establishing a new alfalfa stand is the best practice. If that is not possible, chemically kill the old alfalfa in the fall and seed the next spring, or spring kill and seed in late summer.

Seed Quality

High quality seed of adapted species and varieties should be used. Seed lots should be free of weed seed and other crop seed, and contain only minimal amounts of inert matter. Certified seed is the best assurance of securing high-quality seed of the variety of choice. Purchased seed accounts for just 20 percent or less of the total cost of stand establishment. Buying cheap seed and seed of older varieties is a false and short-lived economy. Always compare seed price on the basis of cost per pound of pure live seed, calculated as follows:

$$\text{percent purity} = 100 \text{ percent} - (\text{percent inert matter} + \text{percent other crop seed} + \text{percent weed seed})$$

$$\text{percent pure live seed (PLS)} = \text{percent germination} \times \text{percent purity}$$

$$\text{pounds of PLS} = \text{pounds of bulk seed} \times \text{percent PLS}$$

Seed Inoculation

Legume seed must be inoculated with the proper nitrogen-fixing bacteria prior to seeding to assure good nodulation. Inoculation is especially important when seeding legumes in soils where they have not been grown for several years. Because not all legume species are colonized by the same strains of nitrogen-fixing bacteria,

be sure to purchase the proper type of inoculum for the forage legume to be planted. Verify the inoculant expiration date and make sure it was stored in a cool, dry place. Because many seed suppliers distribute pre-inoculated seed, check the expiration date and reinoculate if necessary. If in doubt, reinoculate the seed before planting. The seed should be slightly damp and sticky before adding the inoculant. This can be accomplished with a syrup/water mixture or a commercial sticker solution. Soft drinks are also effective as sticking agents. Protect inoculants and inoculated seed from sun and heat as much as possible and plant soon after inoculation.

Seed Treatments

Fungicide-treated seed is highly recommended for alfalfa and may be useful for red clover. Metalaxyl and mefenoxam are systemic fungicides for controlling seedling damping-off diseases caused by *Pythium* and *Phytophthora* during the first four weeks after seeding. These pathogens kill legume seedlings and cause establishment problems in wet soils. Many companies are marketing alfalfa seed treated with either of these fungicides. Various other seed treatments and coatings are sometimes added to forage seed. It is very important to calibrate seeders appropriately, especially when the seed has been coated. For example, lime coatings can account for up to one-third of the weight of the seed, so the actual number of seeds planted can be drastically affected on a weight basis. In addition, some seed coatings affect the flowability of seed, which can dramatically affect the seeding rate output of a planter. The manufacturers' seeding calibrations for the planter are not likely to hold true for coated seed.

Spring Seedings

Plant as soon as the seedbed can be prepared after March 15 in southern Ohio and April 1 in northern Ohio (Table 7-8). Spring seeding should be completed by early May in northern Ohio and by late April in southern Ohio. With early seeding, the plants become well established before the warm and dry summer months. Weed pressure increases with delayed seeding. Annual grassy weeds can be especially troublesome with delayed spring seedings. Herbicides are usually essential when seeding late in the spring. Refer to the most current *Weed Control Guide* published by OSU Extension (Bulletin 789) for guidelines on weed management and for specific herbicide options.

DIRECT SEEDINGS without a companion crop in the spring allows growers to harvest two or three crops of high-quality forage in the seeding year, particularly when seeding alfalfa and red clover. Select fields with little erosion potential when direct seeding into a tilled seedbed. Weed control is important during early establishment when direct seeding pure legume stands. Several and post-emerge herbicide options are available for pure legume seedings (refer to the *Weed Control Guide*, Bulletin 789).

SMALL GRAIN COMPANION CROP SEEDINGS are successful when managed properly. Companion crops reduce erosion in conventional seedings and help minimize weed competition. Companion crops usually increase total forage tonnage in the seeding year, but forage quality will be lower than direct seeded legumes. When seeding with a small grain companion crop, take precautions to reduce excessive competition, which may lead to establishment failures:

- Spring oats and triticale are the least competitive, while winter cereals are often too competitive.
- Use early-maturing, short and stiff-strawed small grain varieties.

- Sow companion small grains at 1.5 to 2.0 bushels per acre.
- Remove small grain companions as early pasture or silage.
- Do not apply additional nitrogen for the companion crop.

Where the need for erosion control suggests use of a companion crop, but high-quality legume forage is desired the first year, seed oat as a companion and kill it at 4 to 8 inches with a post-emerge grass herbicide. The oats will suppress early weed growth, provide erosion protection, and protect seedlings from wind damage. After oats are killed, the legume forage will perform about the same as in a direct seeding.

Table 7-8: Suggested Seeding Dates for Forages Grown in Ohio.

Forage species	Northern Ohio	Southern Ohio
Legumes		
Alfalfa	4/1 - 5/1 or 8/1 - 8/15	3/20 - 4/25 or 8/1 - 8/30
Alsike clover ¹	2/1 - 5/1 or 7/20 - 8/10	2/1 - 4/25 or 8/1 - 8/20
Annual lespedeza	NR ²	2/15 - 4/15
Birdsfoot trefoil	4/1 - 5/1	3/20 - 4/25
Red clover ¹	2/1 - 5/1 or 7/20 - 8/10	2/1 - 4/25 or 8/1 - 8/20
White clover ¹	2/1 - 5/1 or 7/20 - 8/10	2/1 - 4/15 or 8/1 - 8/20
Perennial Grasses and Forbs		
Festulolium	3/20 - 5/1 or 8/1 - 8/20	3/5 - 4/20 or 8/1 - 8/30
Kentucky bluegrass	3/20 - 5/1 or 8/1 - 8/30	3/5 - 4/15 or 8/10 - 9/15
Meadow fescue	3/20 - 5/1 or 8/1 - 8/20	3/5 - 4/20 or 8/1 - 8/30
Orchardgrass	3/20 - 5/1 or 8/1 - 8/20	3/5 - 4/20 or 8/1 - 8/30
Perennial ryegrass	3/20 - 5/1 or 8/1 - 8/20	NR ²
Reed canarygrass	3/20 - 5/1 or 8/1 - 8/15	3/5 - 4/20 or 8/1 - 8/25
Smooth brome grass	3/20 - 5/1 or 8/1 - 8/20	3/5 - 4/20 or 8/1 - 8/30
Tall fescue	3/20 - 5/1 or 8/1 - 8/20	3/5 - 4/20 or 8/1 - 8/30
Timothy	3/20 - 5/1 or 8/1 - 10/5	3/1 - 4/20 or 8/1 - 10/15
Big bluestem	4/20 - 5/15	4/15 - 5/15
Eastern gamagrass	4/20 - 5/15	4/15 - 5/15
Indiangrass	4/20 - 5/15	4/15 - 5/15
Switchgrass	4/20 - 5/15	4/15 - 5/15
Chicory	4/1 - 5/1 or 8/1 - 8/20	3/15 - 4/20 or 8/1 - 8/30
Annual Crops		
Annual/Italian ryegrass	4/1 - 5/1 or 7/20 to 8/30	3/15 - 4/20 or 8/1 to 9/15
Pearl Millet	5/15 - 7/10	5/1 - 7/20
Sudangrass	5/15 - 7/10	5/1 - 7/20
Sorghum-sudangrass	5/15 - 7/10	5/1 - 7/20
Sorghum, forage	5/15 - 7/10	5/1 - 7/20
Teff	5/25 - 6/25	5/15 - 7/1

¹ February to early March is the recommended frost seeding period for clovers; some cool-season grasses may also be frost seeded, but this is less common.

² NR = Not recommended.

Late Summer Seedings

Late summer is an excellent time to establish many forage species, provided sufficient soil moisture is available. August is the preferred time for late summer seeding because it allows enough time for plant establishment before winter. Do not use companion crops with August seedings because they compete for soil moisture and can slow forage seedling growth to the point where the stand will not become established well enough to survive the winter. Refer to the *Weed Control Guide* (Bulletin 789) for weed control guidelines for late summer forage seedings.

Sclerotinia crown and stem rot is a serious disease threat when seeding alfalfa and clovers in late summer. The risk of infection is greatest in fields where forage legumes have been grown recently and minimum tillage is used. *Sclerotinia* infects seedlings in the fall, but injury is not visible until plants begin to die in late winter and early spring. Crop rotation, conventional tillage plantings, and seeding by early August reduce the risk of severe damage from this disease. A limited number of alfalfa varieties have some resistance to this disease.

Conventional Tillage Seeding

THE IDEAL SEEDBED for conventional seedings is smooth, firm, and weed-free. Don't overwork the soil. Too much tillage depletes moisture and increases the risk of surface crusting. Firm the seedbed before seeding to ensure good seed-soil contact and reduce the rate of drying in the seed zone. Cultipackers and cultimulchers are excellent implements for firming the soil. The lack of a firm seedbed is a major cause of establishment failures. The soil should be firm enough at planting so that a footprint is no deeper than $\frac{1}{2}$ to $\frac{3}{4}$ inch.

SEEDING DEPTH for most cool-season forages is $\frac{1}{4}$ to $\frac{1}{2}$ inch on clay and loam soils. On sandy soils, seed can be placed $\frac{1}{2}$ - to $\frac{3}{4}$ -inch deep. Seeding too deep is one of the most common reasons for seeding failures.

SEEDING EQUIPMENT Forage stands can be established with many different types of drills and seeders, provided they are adjusted to plant seed at an accurate depth and in firm contact with the soil. When seeding into a tilled seedbed, drills with press wheels are an excellent choice. If the seeder is not equipped with press wheels, cultipack before and after seeding in the same direction as the seeder was driven. This assures that seed is covered and in firm contact with the soil. Cultipacker seeders, such as the Billion seeder, provide accurate and consistent seed placement in tilled seedbeds.

FLUID SEEDING is a new technique being used to seed forage legumes. Seed is distributed in a carrier of water or in a fertilizer solution. Custom application is recommended because it requires special equipment for good seed suspension and distribution. Prepare a firm seedbed and cultipack after the seed is sprayed on. For fluid seeding, seed should be mixed into solution at the field and applied

immediately. Some producers are also having success with seeding legumes through dry fertilizer air spreaders, with cultipacking before and after the seed is broadcast.

No-Till and Minimum-Till Seeding

Many producers are successfully adopting minimum and no-till practices for establishing forage crops. Advantages include soil conservation, reduced moisture losses, lower fuel and labor requirements, and seeding on a firm seedbed. Most forage species can be seeded no-till with proper management. Species such as red clover that have good seedling vigor are the easiest to establish. No-till forage seedings are most successful on silt loam soils with good drainage. Consistent results are more difficult on clay soils or poorly drained soils. Weed control and sod suppression is essential for successful no-till establishment, because most forage crops are not competitive in the seedling stage.

SEED PLACEMENT is critical with reduced tillage. It is very easy to plant seeds too deep with no-till drills. A relatively level seedbed improves seed placement. A light disking may be necessary before attempting to seed. Plant seed shallow ($\frac{1}{4}$ to $\frac{1}{2}$ inch, in most cases) in firm contact with the soil. Crop residue must be managed to obtain good seed-soil contact. Chisel plowing or disking usually chops residue finely enough for conventional drills to be effective. When residue levels are greater than 35 percent, no-till drills are recommended.

FOR NO-TILL PLANTING FOLLOWING CORN, plant as soon as the soil surface is dry enough for good soil flow around the drill openers and good closure of the furrow. Perennial weeds should be controlled in the previous corn crop. If perennial weeds are still present, apply glyphosate before seeding. If any grassy weeds or winter annual broadleaf weeds are present in the field, use paraquat or glyphosate before seeding. Most drills can handle corn grain residue, but removal of some of the residue (e.g., for bedding) often increases the uniformity of stand establishment. Most drills do not perform as well when corn stalks are chopped and left on the soil surface. Be sure to avoid problems with carryover of triazine residue from the previous corn crop.

FOLLOWING SMALL GRAINS, no-till seeding of forages in late summer conserves valuable moisture. Weeds should effectively be controlled in the small grain crop. Ideally, wait to plant the forage crop until at least $\frac{1}{2}$ inch of rain has fallen postharvest to stimulate germination of volunteer small-grain seeds and weeds; however, do not delay planting beyond the recommended seeding date for your area. Burn down any weeds and volunteer small grain seedlings before seeding the forage crop. Glyphosate can be used if thistles, Johnsongrass or other perennial or biennial weeds are present in the small grain stubble. Remove straw after small grain harvest. It is not necessary to clip and remove stubble; however, it may be removed if additional straw is desired. Do not clip stubble and leave it

in the field, as it may interfere with good seed-soil contact when seeding forages. If volunteer small grains become a problem after seeding, apply a selective grass herbicide to pure legume seedings to remove excessive competition.

INSECT CONTROL can be a serious problem in no-till seedings, especially those seeded into old sods. Slugs can be especially troublesome where excessive residue is present from heavy rates of manure applied in previous years. Chemical control measures for slugs are limited to baits containing methaldehyde (Deadline products) and iron phosphate (e.g., Sluggo). Lorsban insecticide products are registered for use during alfalfa establishment for suppression of various soil insects.

Seeding-Year Harvest Management

Harvest management of cool-season forages during the seeding year depends on time and method of seeding, species, fertility, weather conditions and other factors. Forages seeded in August or early September should not be harvested or clipped until the following year. For spring seedings, it is best to harvest the first growth mechanically. This is especially true for tall-growing legumes. If stands are grazed, stock fields with enough livestock to consume the available forage in less than seven days. Grazing for a longer period increases the risk of stand loss. Soils should be firm to avoid trampling damage. The following are general harvest management guidelines for spring seedings, according to species.

ALFALFA Generally two harvests are possible in the seeding year when alfalfa is seeded without a companion crop; three harvests are possible with early planting and good growing conditions. The first cutting can be made 60 to 70 days after emergence. Subsequent cuttings should be made in early bloom stage (approximately 30- to 35-day intervals), with the last harvest taken by the first week of September. Fall cutting is not advisable; even a late dormant cutting is not recommended because it increases the risk of winter heaving. When seeding with a small grain companion crop, the first harvest should be taken during the late boot or early-heading stage of the companion crop.

BIRDSFOOT TREFOIL Seedling growth of trefoil is much slower than alfalfa or red clover. Seeding year harvests should be delayed until the trefoil is in full bloom. Do not harvest after September 1. When seeded with a companion crop, an additional harvest after removal of the small grain is generally not advisable.

RED CLOVER When seeded without a companion crop, red clover can usually be harvested twice in the year of establishment. Under good conditions, up to three harvests are possible. Harvest red clover before full bloom in the seeding year. If allowed to reach full bloom in the year of seeding, red clover often has reduced stands and yields the following year. Complete the last harvest by the first week of September.

COOL-SEASON GRASSES. Harvest management depends greatly on stand vigor and weather conditions. Most grasses establish slowly compared with alfalfa. Clipping may be necessary to prevent annual weeds from going to seed.

Fertilizing Established Stands

A current soil test is the best guide for a sound fertilization program. Make sure to request the current *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa* (Ohio-Michigan-Indiana) from your soil testing lab. Forages are very responsive to good fertility. Adequate levels of phosphorus and potassium are important for high productivity and persistence of legumes, especially alfalfa. Forage fertilization should be based on soil-test levels and realistic yield goals. Under hayland management, forages should be topdressed annually to maintain soil nutrient levels. Each ton of tall grass or legume forage removes approximately 13 pounds of P_2O_5 and 50 pounds of K_2O . These nutrients need to be replaced, preferably in the ratio of one part phosphate to four parts potassium. Phosphorus and potassium recommendations for forages are given in Tables 7-5 to 7-7. Exceeding the recommended levels for potassium fertilization is especially of concern. Luxury consumption of potassium by the plant will result in high forage potassium concentrations, which can lead to serious animal health problems.

Timing Topdress Phosphorus and Potassium Applications

The timing of phosphorus and potassium applications is not critical when soil-test levels are optimum. Avoid applications with heavy equipment when the soil is not firm. Soil conditions are frequently most conducive to fertilizer applications immediately following the first cutting or in late summer to early fall. Split applications may result in more efficient use of fertilizer nutrients when high rates of fertilizer are recommended. For example, apply one-half of the recommended fertilizer after the first cutting and one-half in late summer to early fall. If soil-test levels are marginal to low, fall fertilization is especially important to provide nutrients such as potassium that improve winter survival.

Nitrogen Fertilization

Nitrogen fertilization is extremely important for good production where grasses are the sole or predominant forage. Economic returns are usually obtained with 150 to 175 pounds of nitrogen per acre per year, split three times during the year—70 to 80 pounds per acre in early spring when grasses first green up and 50 pounds per acre after each cutting. Legumes fix atmospheric nitrogen. Where the forage stand is more than 35 percent legumes, nitrogen should not be applied (Table 7-9). In pastures, nitrogen application can be used to strategically increase forage production when it will be most needed. This is discussed in more detail in “Chapter 9, Grazing and Pasture Management.”

When applying nitrogen in the summer, keep in mind that many forms are subject to surface volatilization resulting in loss of available nitrogen. Ammonium nitrate is the best source choice because surface volatilization losses are minimized; however, this formulation is virtually unavailable now. For more information on nitrogen forms and volatilization losses, refer to the *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa* (Bulletin E-2567).

Table 7-9: Examples of Nitrogen Rates Recommended for Perennial Cool-Season Grass Forages.

Crop, Percent Legume	Yield Potential, ton/ac		
	4	6	8
	Annual Application (lb N/ac) ¹		
Tall grass, less than 20% legume	100	140	180
Mixed tall grass-legume, 20 to 35% legume	50	90	130
Mixed tall grass-legume, greater than 35% legume	0	0	0

¹ Make split applications of nitrogen in the early spring and after first harvest. Liquid nitrogen should be applied in early spring or immediately following foliage removal.

Sulfur Fertilization

Although sulfur deficiency in forages grown in Ohio is still quite rare, we have begun to see cases of deficiency in alfalfa on some Ohio soils. Sulfur may be needed when alfalfa and clover are grown on low organic-matter soils and course soils when yield levels are high. Sulfur deficient plants exhibit a general pale green or yellowing color, with weaker growth along with lower crude protein content. The symptoms resemble a mild nitrogen deficiency and are more apparent in new growth than in old growth. We are beginning to see sulfur deficiencies in alfalfa on some soils in Ohio. For a positive diagnosis, a tissue test should be taken, as the soil test for sulfur is not reliable since sulfate is water soluble and leaches through the soil profile in a similar manner to nitrogen. The upper third of the alfalfa plants should be collected and sent to a commercial soil and tissue testing lab to analyze the sulfur content in the plant. If the sulfur content is below 0.25 percent in the upper third of the plant, then it is likely sulfur deficient and should respond to additional sulfur. Use a sulfate form of sulfur if the application is made in the spring (for rapid uptake by the plant), and an elemental form of sulfur for fall applications (elemental sulfur requires at least two months to become available to the plant in the soil solution).

Micronutrients

Micronutrient deficiencies are rare in most Ohio mineral soils. Micronutrient fertilization should be based on demonstrated need through soil testing and/or tissue testing. Boron may be needed when alfalfa and clover are grown on sandy soils and highly weathered soils low in

organic matter. If the soil test is one part per million (ppm) or less of boron (B), or a plant tissue test shows 30 ppm or less boron, then apply a fertilizer containing two pounds of boron per acre. Refer to OSU Extension Bulletin E-2567 for more details on micronutrient fertilization.

Grass Tetany

Grass tetany occurs in animals when their demands for magnesium exceed the supply. It most often occurs in the spring when high-producing animals are consuming primarily grass forage. High soil potassium tends to reduce uptake of magnesium by plants. The risk of grass tetany is reduced by not applying potash in early spring to grasses, because grasses take up more potassium than needed for growth (luxury consumption). After the first harvest, apply needed fertilizer to maintain a balanced soil-fertility program. It may also be helpful to feed livestock a high-magnesium supplement during spring.

Established Stand Harvest Management

Harvest management is an important tool in achieving high-quality forage, high yields and stand persistence. Harvest management can also be used to reduce the impact of weeds, insects and disease pests. Harvest timing is a compromise between forage yield, quality and persistence. While forage quality decreases with maturity, dry matter yield usually increases up to full-flower stage in legumes and full-heading stage in grasses. Cutting more frequently at earlier stages of maturity results in forage with higher nutritive value but lower yield compared with cutting less frequently at more mature stages of growth.

A good compromise between forage yield, quality and stand persistence is to harvest legumes in late-bud to early-bloom stage, and grasses in late-boot to early-heading stage. Harvesting at that stage will result in the highest yields of digestible dry matter per acre. Cutting management of grass-legume mixtures should be based on the best harvest schedule for the legume.

First Harvest Timing

Make a timely first harvest to achieve the best quality possible in what is usually the largest crop of the year. Forage quality declines more rapidly with advancing maturity in the spring than it does later in the summer. Timing of the first harvest should be based on the calendar rather than on stage of maturity. Bud development and flowering are not reliable guides for proper timing of first cutting in Ohio. In some seasons, little or no bloom is present; in others, bloom is abundant. Table 7-10 gives recommended harvest dates for the first cutting of legume-grass hay meadows. Harvesting during these periods maximizes yields of digestible dry matter per acre. By using various grasses and legumes that differ in maturity development (Table 7-2), producers can spread the optimum first cutting date over one week to 10 days.

Table 7-10: Recommended Harvest Dates—First Cutting, Legume-Grass Mixtures.

Forage Mixture	Cutting Schedule A ¹			Cutting Schedule B ²		
	Southern Ohio	Central Ohio	Northern Ohio	Southern Ohio	Central Ohio	Northern Ohio
Alfalfa-Orchardgrass	5/10 - 5/20	5/15 - 5/23	5/23 - 5/28	5/15 - 5/20	5/20 - 5/25	6/1 - 6/5
Alfalfa-Tall fescue or Alfalfa-Meadow fescue	5/15 - 5/23	5/20 - 5/26	5/26 - 6/2	5/20 - 5/25	5/25 - 6/1	6/5 - 6/10
Alfalfa-Timothy	5/20 - 5/25	5/23 - 5/28	5/28 - 6/5	5/28 - 6/5	6/1 - 6/10	6/5 - 6/15
Red clover-Timothy	5/24 - 6/5	6/1 - 6/10	6/1 - 6/15	5/25 - 6/5	6/1 - 6/10	6/5 - 6/15
Birdsfoot trefoil-Timothy	5/20 - 6/1	5/25 - 6/15	6/1 - 6/20	6/1 - 6/10	6/5 - 6/15	6/10 - 6/20

¹ Cutting Schedule A—Forage cut during these periods is of high quality. Dry matter yields are lower than would be received from later harvests; however, yields of digestible dry matter per acre equal or exceed those from later harvests. Current alfalfa varieties are adapted to earlier harvest.

² Cutting Schedule B—Harvesting at these dates produces medium quality forage. Digestibility is lower than from earlier harvests. These dates may be followed in these situations: For long-lay sods where it is important to keep legume stands for several years; where soil pH and fertility levels are less than optimum; where a late fall cutting may have been taken; winter injured fields; north facing slopes.

Most grasses should be harvested in the boot stage for best forage quality; however, timothy and smooth brome-grass should not be cut until the grass is in the early heading stage. Earlier harvesting of those species may reduce regrowth and result in stand loss, because the basal buds for regrowth are not fully developed until early heading.

Summer Harvest Timing

Stage of growth is usually a reliable guide for timing summer harvests of legumes. Generally, summer cuttings are permitted to reach early bloom for alfalfa (approximately 35 days between cuttings) and half bloom for birdsfoot trefoil and red clover. High yields of good quality forage can be harvested if four cuttings are made on a 35-day schedule. Four cuttings of alfalfa can be made on soils with good fertility without any detrimental effects on the stand. Harvest schedules for legume-grass mixtures should follow closely to what favors the legume component. Smooth brome-grass and timothy are more compatible with less intensively managed stands (three-cut schedule), while orchardgrass, perennial ryegrass, tall fescue and reed canarygrass are adaptable to more frequent harvesting.

Intensive Cutting for High Quality

More intensive frequent cutting schedules are desirable where high forage quality is important. Shorter harvest intervals will usually shorten stand life, especially of legumes. Allowing legume stands to reach early flower stage once during the season improves stand persistence. This can usually be achieved in late summer without great reductions in forage quality (forage fiber levels increase at a slower rate in late summer than earlier in the year). Cutting intervals that are consistently shorter than 30 days stress legume stands because the plants do not fully replenish depleted energy reserves in the taproots and crowns. Fiber levels may be undesirably low when

legumes are cut extremely early (pre-bud to very early bud stage). Some grass species can be harvested very intensively to achieve dairy-quality forage. Pure stands of orchardgrass and perennial ryegrass (where adapted) can be maintained on harvest intervals of 24 days under good fertility management.

Fall Harvesting

Producers often want to harvest the fall growth from forage stands, but fall harvesting usually increases the risk of legume heaving and winter kill, and interferes with accumulation of root reserves required for winter survival and growth the following spring. The need for the forage or its value should be weighed against the increased risk of stand damage.

Minimizing Fall Harvesting Hazard to Tall Legumes

- Complete the last regular harvest by the following dates: September 7 in northern Ohio, September 12 in central Ohio and September 15 in southern Ohio.
- Do not harvest during late September and October. Forages are actively storing reserve carbohydrates in the crowns and roots during this period.
- If a late fall harvest is made, it should be delayed until after a killing frost (25 degrees Fahrenheit for several hours) or at least near to the time of killing frost. A word of caution: removing topgrowth at this time can dramatically increase the risk of legume frost heaving on heavy soils. Mulching with up to 4 tons per acre of straw-mannure or 2 tons per acre of old hay or straw should reduce frost-heaving potential after a late harvest. Late fall harvesting should only be attempted on healthy, established stands grown on well-drained soils with optimum pH and high fertility (high soil potassium levels are especially important).

- Avoid fall harvesting of new seedlings.
- If a mid-fall harvest is made, select fields that are well drained, have optimum pH and fertility, are planted to improved varieties having multiple pest resistance, and where at least 45 days of regrowth was allowed prior to the fall harvest.

Weed Management in Forages

Specific chemical weed control recommendations can be found in the *Weed Control Guide*, Extension Bulletin 789, available at all County Extension offices and online at: estore.osu-extension.org/. The best weed control practice is to establish and maintain a healthy and vigorous forage stand by following the forage management guidelines outlined in this chapter.

Insect Pest Management

Management of forage insect pests is important to achieve high yields of high-quality forage. The primary insect problems in Ohio are the alfalfa weevil and the potato leafhopper in alfalfa. The alfalfa weevil is primarily active in the spring. The potato leafhopper is active during the summer months and can cause severe yield and quality losses in alfalfa. New alfalfa seedlings are especially vulnerable to potato leafhopper damage.

When pest populations reach or exceed action thresholds, it is economically justifiable to either harvest the crop, provided it is near the harvestable stage; or treat the stand with an insecticide to control the pest in question. Producers should scout fields and determine if the action threshold has been exceeded.

A general threshold for potato leafhoppers in alfalfa is as follows: if alfalfa is more than seven days from a harvest for plants under normal stress, treat when the average number of leafhoppers in a single sample (10 sweeps) equals or is greater than the height of the alfalfa. For example, if the alfalfa is 8 inches tall and the average number of leafhoppers per sample is eight or higher, treatment is warranted. If the average is seven or lower, the grower should come back within a few days to see if the population is higher or lower. Vigorous alfalfa can tolerate higher numbers, and stressed alfalfa can tolerate fewer. The threshold should be lowered when the alfalfa is under stress, especially for new seedlings. Potato leafhopper-resistant alfalfa varieties offer an excellent tool for managing this insect pest in Ohio. The action threshold for leafhopper resistant varieties is about three times the normal threshold for susceptible alfalfa.

The alfalfa weevil is a small, brown, snout-nosed beetle approximately 3/16 inch in length with a wide dark stripe down its back. The larva is green with a black head and a white stripe down its back. Both the adult and larvae feed on alfalfa foliage. Foliar feeding injury by the adult is not significant. Foliar injury by young larvae is primarily confined to the growing tips. Older larvae may extensively defoliate alfalfa when abundant. In general, foliar injury by

alfalfa weevil occurs on the first cutting of alfalfa. During periods of heavy weevil activity, early growth of the second cutting may be impacted.

Over the past few decades, populations of alfalfa weevil have seldom reached economic levels of abundance due to biological control by a complex of three parasitic wasps and a fungal pathogen. Occasionally, however, a rescue treatment of insecticide is warranted. Application of an insecticide to prevent excessive defoliation is justified when one or more late instar larvae are found feeding per stem and the stand cannot be harvested early. Because alfalfa weevil is usually controlled by beneficial wasps, which are susceptible to chemical treatments, it is important that treatments not be applied unless necessary. The yield impact of weevil feeding declines as alfalfa stand height increases, and decisions to treat alfalfa for weevil should be focused on an alfalfa stand when larvae can be readily found on alfalfa that is 12 inches or less in height. Once alfalfa is 16 inches or more in height, early cutting is a preferred option for reduction of weevil impact.

More information about potato leafhopper and weevil management in alfalfa can be found at:

Potato Leafhopper: ohioline.osu.edu/factsheet/ENT-33

Alfalfa Weevil: ohioline.osu.edu/factsheet/ENT-32

Disease Management in Forages

Diseases can negatively affect stand establishment, limit yields and hasten stand decline in established forage crops. Effects of disease on individual plants vary widely. Some diseases are lethal while others cause only stunting or leaf loss, reducing yields and forage nutritive value. Sound crop production practices will lower the chances for serious losses to forage productivity due to disease because they help maintain a vigorous stand. Any practice that improves plant vigor is likely to reduce the chance of plants becoming diseased. More importantly, good growing conditions will allow surrounding uninfected plants to achieve their maximum potential and compensate for the loss in stand or productivity due to diseased plants.

Important considerations for managing diseases include matching forage species to soils where they are adapted, practicing crop rotation (especially important for forage legumes), maintaining adequate soil pH and fertility, using proper harvest schedules that don't unduly stress plants, and selecting disease resistant varieties.

It is very important to avoid compaction damage in forages as much as possible. Traffic damage allows disease organisms to invade the plants, resulting in stand and yield losses. Forage varieties with some tolerance to traffic have been developed in recent years, but every effort should be made to control and reduce compaction damage as much as possible. Especially important is avoiding traffic on wet soils. In addition, minimize traffic on the field, designate traffic lanes to reduce the field area subjected to compaction, and use lighter equipment whenever feasible.

Disease organisms are often spread from infested to healthy fields by transport of harvesting equipment, hay or manure on the farm. Care should be taken to harvest fields that are obviously diseased after harvesting healthy fields, and to clean equipment thoroughly prior to entering healthy fields.

Few fungicide options are available for most forage species, but more options are becoming available especially for alfalfa. Fungicides can reduce disease infestations, and increase yield and forage quality under conditions that are conducive to disease development—such as humid or wet conditions in spring and early summer. Check with Extension plant pathologists and forage specialists for available fungicide options that might be of benefit.

Preserving Forage as Hay and Silage

Good management practices are required for successfully storing forage as either dry hay or as silage or balage (individually wrapped bales, in plastic tubes or chopped into silo bags). In general, putting up silage or haylage will result in less forage yield loss and higher nutritive value than when stored as dry hay. Curing forage for hay requires more drying time, resulting in greater chances for rain damage, and more losses occur when the forage is handled in a drier condition. Since silage and haylage is preserved at a higher moisture content, it is faster to get to a proper dry matter content for safe preservation than it is to make dry hay. Proper dry matter content for chopping haylage can often be achieved within 24 hours as compared with three to five days for dry hay, depending on the conditions. The following practices will improve the success of preserving forage in a good condition:

MAXIMIZE EXPOSURE TO SUNLIGHT because it is the single most important weather factor that speeds drying. Make the windrows as wide as possible for maximum forage surface area exposure to the sunlight. The swath width should be at least 70 percent of the actual cut width. Another way to spread out and aerate the crop for faster drying is with a tedder. Tedders are especially effective with grass crops, but they can cause excessive leaf loss in legumes if done when the leaves are dry. Grasses in particular should be spread in wide swaths, otherwise the forage will settle together and be hard to loosen up to increase the drying rate. Tedders can be a good option when the ground is damp, because the crop can first be mowed into narrow windrows to allow more ground exposure to sunlight, and then—once the soil has dried a bit—the crop can be spread out. Spreading the forage out to dry results in lower neutral detergent fiber (NDF) and higher energy content in the stored forage compared with drying in narrow swaths.

MECHANICALLY CONDITION THE FORAGE to increase the drying rate of cut forage. Make sure the mower-conditioner is adjusted to cause 90 percent of the stems to be crimped/cracked (roller conditioners) or abraded (impeller conditioners).

CHEMICAL DESICCANTS are an option to increase drying rate, but only under good drying conditions. They are not effective when conditions are humid, damp and cloudy. They are applied at the time of mowing the crop, so consider the forecasted weather conditions and only apply them if good drying conditions are expected. The most effective desiccants contain potassium carbonate or sodium carbonate. They are more effective on legumes than grasses and most useful for making hay rather than silage or balage. Desiccants work best when applied to the crop stems with uniform coverage under good drying conditions.

RAKE THE FORAGE after a period of initial drying. For haylage under good drying conditions, you can usually rake multiple swaths into a windrow about five to seven hours after cutting and right before chopping. For dry hay under good drying conditions, rake multiple swaths into a windrow the next morning after mowing when the forage is 40 to 60 percent moisture to avoid excessive leaf loss later when the crop will likely be too dry. Raking should create a swath narrow enough to meet the width of the harvester or baler pickup. Raking also helps create a windrow density to match the harvester or baler capacity. Raking is useful to turn the crop over so the bottom forage can be exposed for faster final drying and to move the swath from wet to dry ground.

STORE AT PROPER DRY MATTER CONTENT. Proper dry matter content for silage ranges from 30 to 50 percent (50 to 70 percent moisture) depending on the structure used, while wrapped balage should be dried to 45 to 55 percent dry matter (45 to 55 percent moisture). Dry hay should be baled at 80 to 87 percent dry matter (13 to 20 percent moisture), depending on the size of the bale package. The larger and more dense the package, the dryer it has to be to avoid spoilage; small rectangular bales can be baled safely at 20 percent moisture or less, large round bales at 15 to 18 percent moisture, and large rectangular bales at 13 to 15 percent moisture content. If the forage is wetter than these ranges for hay, use hay preservatives (see below).

PACK AND SEAL UP SILAGE AND HAYLAGE quickly to minimize exposure to oxygen and hasten the fermentation process. For silage, ensure sufficient packing to eliminate oxygen from the pile. For wet wrapped bales, ensure tight bales and wrap them with a minimum of four layers of 1.5 mil thickness of plastic (two turns at 50 percent overlap) as quickly as possible after baling. More layers are needed when moisture is below the recommended range, in more mature crops, and when baling crops with sharp stems that can puncture the plastic.

HAY PRESERVATIVES can be applied at baling when the hay is a little wetter than ideal for safe preservation of dry hay. The most common and effective preservatives are based on propionic acid. This acid can be caustic to equipment, but many buffered propionic preservative products are available on the market that reduce this cor-

rosion problem. The preservatives inhibit mold growth and allow safe baling at moisture contents a little higher than the normal range for dry hay. Preservatives have been most effective on rectangular bales and have questionable effectiveness in large-round bales. Carefully follow the manufacturer's directions and application rates when using preservatives. Keep in mind that the preservative effect is temporary, so the hay must be dried down to a safe moisture content for long-term storage or used within several months to avoid spoilage.

SILAGE INOCULANTS are often very useful for legume haylage when the wilting phase is short and conditions are cool. For example, lactic acid bacteria inoculants improve fermentation and often provide a good return on investment when putting up alfalfa haylage. In contrast, the return on investment for silage inoculants on corn silage is less likely if good management practices are followed.

Some excellent guidelines for putting quality hay and silage, including management guidelines and information on equipment adjustments, can be found at the University of Wisconsin Extension website: uwex.edu/ces/crops/uw-forage/storage.htm.

Perennial Warm-Season Grasses

The native, perennial, warm-season grasses have the potential to produce good hay and pasture growth during the warm and dry mid-summer months. These grasses initiate growth in late April or early May, and produce 65 to 75 percent of their growth from mid-June to mid-August in Ohio. Warm-season grasses complement cool-season grasses by providing forage when the cool-season grasses are less productive. Warm-season grasses produce well on soils with low moisture holding capacity, low pH and low phosphorous levels. However, they do best on deep, fertile, well-drained soils with good water-holding capacity. They generally require much lower levels of nitrogen fertilization than cool-season grasses.

The following species are winter hardy and grow in all areas of Ohio. They can be seeded alone or as a mixture, but seeding a single warm-season grass species is easier to manage. Legumes or cool-season grasses generally are not suited for planting with warm-season grasses because they compete too much during stand establishment. Even in established mixed stands, cool-season species may compete too much because they begin spring growth much earlier and suppress growth of the warm-season species.

SWITCHGRASS (*Panicum virgatum* L.) is a tall, rhizomatous perennial that grows 3 to 5 feet tall. It appears bunch like, but the short rhizomes may produce a coarse sod under grazing. Later in the season, leafy regrowth develops from basal tillers and shoots emerging along the lower stems at leaf nodes. Switchgrass tolerates poorly drained soils, occasional flooding and perched water tables better than other warm-season grasses. Leaves and stems

of switchgrass have good forage value and are readily grazed by livestock in the immature stage; however, it is considered to be of lower forage quality than big bluestem or indiangrass. Palatability and nutrient content of switchgrass stems decline rapidly after heading. Switchgrass is often the first choice among farmers trying a warm-season grass for the first time. The seed is clean, free flowing and can be seeded with standard forage seeding equipment.

BIG BLUESTEM (*Andropogon gerardii* Vitman) is an erect, robust, perennial bunchgrass that grows 3 to 6 feet tall and is often reddish-purple at maturity. It produces foliage in late spring from buds at basal nodes and from short, scaly rhizomes. Growing points stay close to the ground until late summer when heads appear. It is considered more palatable than switchgrass or indiangrass, especially after maturity. Big bluestem is more drought tolerant than other warm-season grasses and better adapted to excessively drained soils with low water-holding capacity. The seed is light, chaffy and difficult to seed without a special grassland drill.

INDIANGRASS (*Sorghastrum nutans* L. Nash) is an erect, robust perennial growing 3 to 6 feet tall. It has short, knobby rhizomes and spreads slowly. Indiangrass starts growth somewhat later than switchgrass or big bluestem and provides good quality forage during much of the summer. It is moderately palatable after heading. Indiangrass can be planted on moderately well-drained soils and can withstand occasional flooding. The seed is light, chaffy and difficult to seed without a special grassland drill.

EASTERN GAMAGRASS (*Tripsacum dactyloides* (L.) L.) is a robust, upright, leafy bunchgrass that grows 6 to 12 feet tall. It is adapted to deep soils with good water-holding capacity. In natural habitats, it grows in fertile bottomland, swamps and along streambanks. Eastern gamagrass is one of the earliest warm-season grasses to begin growth in the spring. It has high-yield potential and maintains its quality better when mature than the other species. One drawback to eastern gamagrass is its need for a long, late summer rest period beginning by mid-August.

Establishment

Soil pH should be at least 6.0, and phosphorus and potassium should be applied based on soil-test recommendations. Do not apply nitrogen fertilizer at seeding, which will only stimulate excessive weed competition. About 30 pounds per acre of nitrogen can be applied on low fertility sites in July after the grasses have started growing provided the stand is very good and weed competition is not high.

The perennial warm-season grasses are slow to establish and are weak competitors with weeds until established. Attempts to establish warm-season grasses under heavy weed infestations may fail completely or will at best require two to three years before acceptable growth is achieved. Fields previously in row crops where weeds were controlled are ideal sites. Two years is generally

required for successful establishment of warm-season grasses. Plateau herbicide (ammonium salt of imazapic) can be used to control weeds during establishment of big bluestem and indiagrass, as well as established stands of those species. Consult the herbicide label for further details.

Spring seedings should be made from mid-April to mid-May, the earlier dates being especially better for southern Ohio. Use the seeding rates listed in Table 7-4. Switchgrass and eastern gamagrass can be planted with standard drills equipped to handle cool-season grasses, but big bluestem and indiagrass require special grassland drills unless the seed is debarbed. These grasses can be seeded in conventionally tilled seedbeds or no-tilled where existing competition is eliminated. Seed should be planted ¼- to ½-inch deep, except eastern gamagrass which has a larger seed and should be planted ½- to 1-inch deep. Seed stratification requirements of eastern gamagrass need to be followed closely to assist in germination of this species.

A seeding year stand of warm-season grass should not be harvested unless growth is unusually vigorous and the stand is strong. Weed competition in the seeding year can be reduced by clipping weeds above the warm-season grass seedlings. Adjust the clipping height upward as the season progresses to prevent clipping off the warm-season grass seedlings, as that would reduce their vigor. Do not clip or graze new seedlings after August 1. It is usually best not to graze warm-season grasses during the seeding year.

Managing Established Stands

Perennial warm-season grasses are more tolerant of low pH and fertility than the cool-season species, but they will respond to higher levels of fertility. Soil testing at least every three years is the best guide for maintenance rates of phosphorus and potassium. The timing of phosphorus and potassium application is not critical, and rates are similar as those for cool-season grasses. Lower nitrogen rates are suggested for warm-season grasses than for cool-season grasses. If a single application is made, 60 to 80 pounds of nitrogen per acre can be applied in mid-to-late May. For higher rates, split the application with half in mid-May and half in early July. Higher rates should only be used on highly managed excellent stands.

Harvest or graze these grasses when they are 16 to 20 inches or more in height (boot stage). Once seedheads emerge, the quality decreases rapidly. Heading will occur in late June to early July depending on location, year and species. Leave at least a 5-inch stubble for rapid regrowth. Mowing or grazing closer than 5 inches will remove important plant carbohydrate storage organs and areas of new bud development. Rotational grazing is advised for good persistence. Enough time should be allowed for at least 12 inches of fall regrowth before frost on all species, so do not graze or harvest after mid-September. Plants

can be harvested after a killing frost without damage to the stand and the forage is safe for livestock. Removal of dead stubble in December will increase grass yields during the following growing season. This can be done with grazing animals but these animals will need protein supplement to balance protein needs. Leave at least an 8-inch stubble cover for the winter.

Annual Forage Crops

Annual forage crops can be used effectively in forage production systems. These crops can be used to provide supplemental feed when perennial forages are less productive; emergency feed when perennial crops fail; serve as interim crops between grazing periods of perennial forages when long rest periods are needed; and extend the grazing season in the fall and early spring. Most annual forage crops are best used for pasture or silage rather than for hay. Double-cropping combinations are feasible with these annual forage crops (for example, small grains followed by summer annual grasses or brassicas).

Corn Silage

Production of corn for silage is a primary component of most confinement dairy operations, but it should also be considered for any operation in need of supplemental forage during the summer months. Corn produces high yields of energy dense forage. Even if planted late and harvested before grain formation, the feeding value of corn is at least equal to that of the other summer annual grasses such as sorghum-sudangrass and forage sorghum, and yields are likely to be higher for corn silage. Hybrids are available that combine both high forage yield and high nutritive value, which is often determined by neutral detergent fiber digestibility. Production of corn for silage is covered in "Chapter 4, Corn Production."

Small Grains for Forage

SPRING OAT (*Avena sativa* L.) is commonly used as a companion crop for seeding forage legumes. It can be used for silage or spring and early summer pasture when sown early. Oats grazed or chopped early regrow and provide a second period of grazing or greenchop. Highest yields are achieved with a single harvest in early heading to milk stage. Oats can be used for hay; however, as with the winter cereals, oats are coarse, slow to dry and often produce dusty hay. Ohio producers have also successfully used oat for late fall grazing, by seeding it in August (after winter wheat) or following an early corn silage harvest. Oat has also been aerially seeded into standing corn in mid-August to provide high-protein forage as a supplement to the lower quality corn stover when grazed in late fall after corn grain harvest.

WINTER BARLEY (*Hordeum vulgare* L.) is not as winter hardy as other winter cereal grains and is more sensitive to poorly drained soils. It can tolerate moderate droughts, but does not produce well under moist, hot conditions.

Barley provides good quality forage for grazing in the fall if seeded early, but it should not be grazed as close or as late in fall as wheat or rye. Barley makes good quality silage, but is less desirable for hay after heading because it has awns.

WINTER WHEAT (*Triticum aestivum* L.) provides highly digestible fall and spring pasture. Winter wheat can be sown later in the fall than barley because it is more winter hardy and able to withstand wetter soils than barley. Wheat produces more tonnage than barley and is of higher quality than rye. With careful fall or early-spring grazing, it can be subsequently harvested for grain, silage or hay. Varieties of winter wheat used for grain may also be used for forage.

WINTER RYE (*Secale cereale* L.) is the most winter hardy of the small grains. Quick growth in both fall and spring make it the most productive of the small grains for pasture. Forage-type varieties are available that have greater fall growth and extend the grazing season in late fall. Although best production is on fertile, well-drained soils of medium or heavier texture, it is more productive than other small grains on soils with lower pH and fertility, higher clay or sand content, or poorer drainage. Winter rye matures the earliest of the small grains, making it the most difficult of the small grains to manage for high quality in the spring. Palatability and quality of rye are unacceptable if allowed to mature past the boot stage.

TRITICALE (*Triticum* x *Secale*) is a hybrid of wheat and rye. Varieties are available for fall or spring seeding. Fall-seeded winter triticale varieties can be used for late fall and early-spring pasture, as well as for silage or hay. Under good management, triticale produces good forage yields; high animal performance is possible when it is harvested at the right stage. Winter triticale should be managed similarly to wheat, but matures about five to 10 days after wheat.

MIXTURES of small grains or small grains with annual legumes (e.g., field peas, soybean) can be used to achieve specific production objectives. For example, oat can be mixed with the winter grains to increase fall growth for grazing without sacrificing yield of the winter cereals the following spring. Small grain-annual legume mixtures are especially useful when harvested as silage. The seed cost of annual legumes is usually higher, and should be weighed against the value of the harvested forage. Adding annual legumes, such as peas, improves forage quality and expands the harvest window for achieving good quality forage. These mixtures do not yield as much as corn silage, but their production in the spring may fill an important niche in a forage system. Harvest timing should be based on the proper time for the small grain species in the mixture.

Establishment and Fertilization

Seed small grains for forage in the same way as for grain (see Chapter 6). When seeding small grains for fall pasture,

either plant in mid- to late August or follow normal seeding date guidelines. If small grains are planted only for pasture use, use the seeding rates given in Table 7-4 and apply nitrogen at a rate of 50 to 70 pounds per acre at planting time.

Harvest Management

For the best compromise between yield and quality, harvest oats, barley and wheat in the early heading stage. Although harvesting later (up to early milk stage) increases tonnage, quality declines rapidly. Triticale should be harvested in the late boot to early heading stage. Rye should be harvested in the boot stage to avoid palatability problems and large reductions in forage quality. Always use a mower conditioner to increase drying rate of small grains.

Grazing Management

Fall and spring grazing of small grains should begin when sufficient growth is available to support livestock. Delayed planting dates and wet fields during the prime grazing season often make grazing of small grains difficult in Ohio. In the fall, graze only early-seeded small grains. Begin grazing when 6 inches of growth is available, and leave 3 inches of stubble after grazing. Heavy fall grazing can increase the risk of winterkill. Do not graze when the small grain is dormant or when the ground is frozen if subsequent spring growth and/or grain production is desired. In the spring, graze only when fields are firm. Heavy or late-spring grazing greatly reduces grain yields. Remove livestock from small grain fields to be harvested for grain as soon as the plants begin stem elongation (jointing stage).

Animal Health Concerns with Small Grains

Animal health hazards are not as common with the small grains as they are with the sorghum species grasses; however, the following precautions should be taken:

- Supplement lush spring pastures with high-magnesium mineral blocks or mineral-salt mixes to reduce the risk of grass tetany.
- When using seed treated with fungicides, observe harvest and grazing restrictions on the label.
- Remove lactating dairy animals from small grain pastures two hours before milking to reduce the problem of off-flavored milk.
- Split nitrogen applications to avoid nitrate poisoning.

Italian Ryegrass

Italian ryegrass (*Lolium perenne* L. subsp. *multiflorum* (Lam.) Husnot) is generally annual or biennial in longevity, and can provide short-term high yields of high-quality forage. The Westerwold types do not have a vernalization (cold temperature) requirement for flowering, so they will head out throughout the seeding year and usually complete their life cycle by late summer when planted in the spring. The types known in the industry as true Italian

ryegrass varieties have a vernalization requirement for flowering, so they will not head out until the second year. They usually grow through the second year and sometimes into the third year.

Italian ryegrass can be planted in April or in August through mid-September. The late summer to early autumn seedings can be made after wheat or corn silage and may produce enough forage for grazing by November if rainfall is sufficient during the fall. Late summer to autumn plantings survive the Ohio winters (except for the occasional severe winter) and produce forage the next spring and into mid-summer. The Italian ryegrass varieties can differ greatly in winter hardiness, so consult the *Ohio Forage Performance Trials* (u.osu.edu/perf) for evaluations of yield and winter survival in Ohio.

Establishment and management of Italian ryegrass is similar to the perennial cool-season grasses, including fertilization and harvest and grazing management. This species can be planted no-till and has vigorous seedling growth. This species can be difficult to cut with a sickle bar mower, but disk mowers handle it very well. For optimal yield and nutritive value, harvest or graze it in the boot stage before heading.

When establishing Italian ryegrass after corn silage in early autumn, be aware of the potential for nitrogen carryover in the Italian ryegrass in the autumn growth, especially following a dry summer. Nitrates can accumulate to toxic levels to animals in the autumn growth of Italian ryegrass. If there is potential of high nitrogen carryover, it would be prudent to test the forage for nitrate content before harvesting or grazing it.

Summer-Annual Grasses

These grasses grow rapidly in late spring and summer and when managed properly provide high-quality forage. They are well suited as supplemental forages during hot, dry periods when perennial cool-season forages are less productive. Because the need for extra forage usually becomes apparent after row crops have been planted in early spring, summer-annual grasses are a good double-crop option when planted after a small grain harvest. They have the potential to produce forage yields of 3 tons of dry matter per acre within 45 to 50 days. With the exception of pearl millet, the summer-annual grasses are members of the sorghum family and have the potential for prussic acid poisoning (see *Animal Health Concerns* below).

SUDANGRASS [*Sorghum bicolor* (L.) Moench.] is fine-stemmed, leafy and grows between 3- to 8-foot tall. Sudangrass regrows following each harvest, until cool temperatures or lack of moisture inhibit growth. It is the preferred summer-annual grass for pasture, and can be used for hay. Solid stands grow shorter than when seeded in rows. Sudangrass usually contains lower levels of prussic acid and is usually lower yielding than the other sorghum family grasses.

Sudangrass hybrids are generally slightly higher yielding and have slightly higher prussic acid potential than sudangrass at comparable stages of growth. New varieties with higher digestibility are available, known as brown midrib varieties. Those varieties have a characteristic brown discoloration on the main vein (midrib) of the leaves, which is a marker for the mutation for lower lignin content. The brown midrib varieties have greater animal preference and animal performance (intake and gains) compared with the normal varieties.

SORGHUM-SUDANGRASS HYBRIDS are crosses of sorghum with sudangrass. They resemble sudangrass in growth habit, but are generally taller, have larger stems and leaves, and are higher yielding. This grass can become coarse and unpalatable if not properly utilized. It is not as well suited for hay production as sudangrass. Sorghum-sudangrass hybrids regrow following each harvest, barring restrictive environmental conditions. Brown midrib varieties with higher digestibility are available, as described above for sudangrass.

FORAGE SORGHUM [*Sorghum bicolor* (L.) Moench.] grows 6- to 15-feet tall and has potential for high yields. It is utilized as a one-cut silage or greenchop crop. Forage sorghum produces silage containing more digestible energy than legume and cool-season grass silage. Making high-quality silage from forage sorghum is generally easier than from forage legumes because of the high levels of nonstructural carbohydrates, which enhance fermentation. The high-energy, low-protein characteristics of forage sorghum silage make it a good supplement for high-protein forage legumes. Because the feeding value of forage sorghum silage is considered to be about 85 percent that of corn silage, corn silage is usually the preferred high-energy silage grown in Ohio. Forage sorghum has the potential, however, to grow better than corn on light-textured, shallow soils that tend to be droughty. Brown midrib varieties with higher digestibility are available, as described above for sudangrass.

PEARL MILLET (*Pennisetum glaucum* L.) is not in the sorghum family, and prussic acid is not produced in the plant. It tends to have smaller stems and is leafier than the sorghum grasses. Pearl millet regrows after each harvest, but not as rapidly as sudangrass or sorghum-sudangrass hybrids. It may also be more sensitive to cutting height for regrowth than sudangrass. Other types of millets include: German, Foxtail and Japanese millet. German and Foxtail millet do not regrow after harvest. Japanese millet grows best in wet soils.

TEFF (*Eragrostis tef* (Zuccagni) Trotter) is an annual grass native to Ethiopia that can be used for hay and silage. Its use for grazing is questionable because grazing animals can pull plants out of the ground. Teff produces several cuttings and can tolerate both drought-stressed and waterlogged soils. It is fairly easy to establish, provided the very small seed is placed 1/8- to 1/4-inch deep. It should

be seeded in late May to early June once soils are warm. It emerges quickly and produces harvestable forage within 40 to 50 days (early heading stage), with subsequent harvests expected every 30 to 35 days in Ohio. When harvested in the early boot stage, it produces relatively high-quality forage. In Ohio, teff can be harvested three times with total forage yields reaching a total of 3 to 4 tons of dry matter per acre. A 4-inch cutting height will promote vigorous regrowth. Teff is very sensitive to frost, so growth ceases with the first frost. More details on managing this forage can be found in a fact sheet from Cornell University (nmsp.cals.cornell.edu/publications/factsheets/factsheet24.pdf).

SUMMER-ANNUAL GRASS-LEGUME MIXTURES are marketed by some seed dealers. The legumes (e.g., field pea, soybean) generally improve protein content compared with summer-annual grasses grown alone. The annual legumes included in these mixtures would be present in the first growth only; regrowth would occur only from the grasses. The additional cost of the legume seed should be weighed against the improved forage quality potential.

Establishment

Summer-annual grasses require well-drained to moderately well-drained soils. They grow best in warm weather and should be planted from about two weeks after corn planting until the end of June in northern Ohio and mid-July in southern Ohio. Soil temperatures should be at least 60 to 65 degrees Fahrenheit. Late plantings (after mid-July) shorten the growing season and may result in low yields because of poor establishment in dry soils in the summer followed by cool fall temperatures. Making two seedings about three weeks apart staggers the maturities and makes rotational grazing or harvest timing easier to manage.

Seeds should be planted on a well-prepared, firm, and moist seedbed at a depth of ½- to 1-inch, except teff which should be planted ⅛- to ¼-inch deep. The seed can be broadcast and harrowed, lightly disked (except teff), or seeded with a grain drill. Forage sorghums should be planted in rows with row-crop planters to facilitate harvest and minimize lodging. These summer-annual grasses may also be established in grass sods or stubble with no-till equipment (except teff which does not establish well into existing sods), but this is less desirable than conventional seedbed preparation. Refer to Table 7-4 for suggested seeding rates.

Fertilization

Determine lime and fertilizer needs by soil test. Fertilization is similar to that used to grow 100 to 150 bushels per acre corn. Incorporate fertilizer in the soil prior to seeding, or apply at least six months before for no-till seedings. The soil pH should be maintained between 6.0 and 6.5 for best results. Nitrogen fertilization is critical to achieve high yields, and varies by previous crop (Table 7-11). Nitrogen rates for teff are generally lower, about 50 to 60 pounds of

nitrogen per acre at planting. For the other species, split applications of nitrogen should be made; half applied prior to seeding, and the remainder divided equally and applied after each cutting or grazing to achieve the most efficient use. Keep in mind possible volatilization losses of some forms of nitrogen when applied in the summer. Refer to Bulletin E-2567, *Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa*, for more information on nitrogen volatilization losses.

Table 7-11: Nitrogen Recommendations for Summer-Annual Grasses.

Previous Crop	Yield Goal (tons dry matter/ac)		
	3-4	5-6	6+
	lb N/ac		
Good legume stand (5 plants/sq ft)	0	0	40
Average legume stand (3 plants/sq ft)	0	40	80
Grass sod	60	100	140
Soybeans	70	110	150
Other	100	140	180

Harvest Management

Table 7-12 summarizes the guidelines for harvest management of the summer-annual grasses.

DIRECT-CUT SILAGE Forage sorghum and sorghum-sudangrass hybrids are well suited as silage crops. Harvesting forage sorghum in the dough stage and sorghum-sudangrass in the heading stage should provide sufficient dry matter content for ensiling without wilting.

GREENCHOP OR WILTED SILAGE Sudangrass should be cut at 18 to 40 inches of growth. Sorghum-sudangrass hybrids should be cut when at least 30-inches tall, teff in pre-boot to early boot stage, and pearl millet in late-boot to early bloom stage.

HAY Sudangrass, sorghum-sudangrass hybrids, pearl millet and teff can be cut for hay. Harvest when the grasses are vegetative (boot stage, before heading) or the plant reaches a height of 3 to 4 feet. Always use a hay conditioner to mow and crush the stems to improve drying. Even with a hay conditioner, it is difficult to field cure most of these grasses adequately for safe storage as hay. Teff can be made into hay.

GRAZING All of the summer-annuals, except forage sorghum, are suitable for grazing. Sufficient height must be achieved before grazing to reduce animal health problems and to optimize production. Grazing plants that are less than 18-inches tall will weaken them, resulting in delayed regrowth. The chance of prussic acid poisoning is higher when grazing the sorghums before a full 18 inches of growth is present. Grasses in the vegetative stage are more palatable and nutritious. Trampling and wastage

Table 7-12: Harvest Information for Summer-Annual Grasses and Brassica Crops.

Crop	Silage	----- Fall Pasture -----		----- Summer Pasture -----		
		When to Graze	When to Terminate Grazing	When to Graze	Height After Grazing	Between Grazings
Sudangrass	Late boot to early bloom	18-24 in. tall	At frost, may resume 5-7 days after killing frost.	18-24 in. tall	6-8 in. tall	2-3 weeks
Sorghum x Sudangrass	Late boot to early bloom	30+ in. tall	At frost, may resume 5-7 days after killing frost.	30+ in. tall	6-8 in. tall	2-3 weeks
Pearl millet	Late boot to early bloom	18-24 in. tall	When utilized.	18-24 in. tall	6-8 in. tall	3-4 weeks
Forage sorghum	Soft dough to medium dough	----- Not recommended for pasture -----				
Teff	Pre-boot to early boot	16-24 in. tall	When utilized.	16-24 in. tall	4 in. tall	3-4 weeks
Rape	Not recommended	80-90 days after summer seeding	When herbage utilized.	80-90 days after spring seeding	6-10 in. tall	4 weeks
Turnip	Not recommended	80-90 days after summer seeding	When herbage & roots utilized.	80-90 days after spring seeding	6-10 in. tall	4 weeks
Kale ^a	Not recommended	150-180 days after summer seeding	When herbage utilized.	Growth insufficient for summer grazing, not recommended.		
Swede	Not recommended	150-180 days after summer seeding	When herbage & roots utilized.	Growth insufficient for summer grazing, not recommended.		

^a Stemless kale varieties exist that are ready for harvest 80 to 90 days after seeding (e.g., Premier forage kale) and will regrow after harvest if not grazed below 3 to 4 inches; therefore, Premier stemless kale provides summer grazing when spring seeded.

increases when grazing is delayed past the boot stage. Plants reach the grazing height of 18 to 30 inches about six to eight weeks after planting. Rotational grazing or strip grazing management should be practiced. A sufficient number of animals should be placed on the pasture to graze the grass down in less than 10 days. After grazing, clip the residue to about 8 inches if old stems remain. This improves forage quality for the next grazing period.

Animal Health Concerns

PRUSSIC ACID POISONING can occur when feeding sudangrass, sorghum-sudangrass hybrids, forage sorghum or grain sorghum. These species contain varying concentrations of cyanogenic glucosides, which are converted to prussic acid, also known as hydrogen cyanide (HCN). As ruminants consume forage containing high levels of cyanide-producing compounds, prussic acid is released in the rumen and absorbed into the bloodstream, where it binds hemoglobin and interferes with oxygen transfer. The animal soon dies of asphyxiation. Prussic acid acts rapidly, frequently killing animals in minutes. Symptoms include excess salivation, difficult breathing, staggering, convul-

sions and collapse. Ruminants are more susceptible than horses or swine because cud chewing and rumen bacteria help release the cyanide.

Species and varieties differ in prussic acid poisoning potential—sudangrass varieties are low to intermediate in cyanide potential; sudangrass hybrids are intermediate; sorghum-sudangrass hybrids and forage sorghums are intermediate to high; and grain sorghum is high to very high. Piper sudangrass has low prussic acid poisoning potential. Pearl millet is virtually free of cyanogenic glucosides and no cases of prussic acid poisoning have been reported for teff.

Any stress condition that retards plant growth may increase prussic acid levels in plants. Hydrogen cyanide is released when leaf cells are damaged by frost, drought, bruising, cutting, trampling, crushing or wilting. Plants growing under high nitrogen levels or in soils deficient in soil phosphorus or potassium tend to have high levels of cyanogenic glucosides. Fresh forage is generally higher in cyanide than in silage or hay because cyanide is volatile and dissipates as the forage dries.

Reducing the Risk of Prussic Acid Poisoning in Sorghum Species

When grazing or greenchopping:

- Graze or greenchop only when grass exceeds 18 inches in height.
- Do not graze wilted plants or plants with young tillers.
- Do not graze plants during or shortly after a drought when growth has been reduced.
- Do not graze on nights when frost is likely. High levels of the toxic compounds are produced within hours after a frost occurs.
- Do not graze after a killing frost until the plants are dry. Wait five to seven days to allow the released cyanide to dissipate.
- After a non-killing frost, do not allow grazing because the plants usually contain high concentrations of toxic compounds. Once the first frost has occurred, grazing should not begin until five to seven days after a killing frost.
- Don't allow hungry or stressed animals to graze young sorghum grass growth. To reduce the risk, feed ground cereal grains to animals before turning them out to graze.
- Use heavy stocking rates (four to six head of cattle per acre) and rotational grazing to reduce the risk of animals selectively grazing leaves that can contain high levels of prussic acid.
- Feeding greenchopped, frost-damaged plants has lower risk than grazing because animals have less ability to selectively graze damaged tissue; however, the forage can still be toxic, so feed with great caution.
- Always feed greenchopped forage of these species within a few hours (even in absence of frost), and do not leave greenchopped forage in wagons or feedbunks overnight before feeding.
- Split applications of nitrogen decrease the risk of prussic acid toxicity, as do proper levels of phosphorus and potassium in the soil.

When making hay or silage:

- Frost-damaged annual sorghum grasses can be made into hay with little or no risk of toxicity. When plants are wilted enough to make dry hay, most of the volatile cyanide gas will have dissipated.
- Normal silage making allows most of the cyanide to dissipate from frost damaged annual sorghum grasses. Delay feeding of silage for six to eight weeks after ensiling.
- Silage that likely contained high cyanide levels at harvest should be analyzed for HCN content before feeding.

NITRATE POISONING can occur under conditions of high nitrogen fertilization, heavy manure applications, drought,

overcast weather, freezing or other stress conditions that retard plant growth. Under these stressful conditions, high nitrate levels accumulate in the crop. Once forage is fed, nitrate is converted to nitrite in the animal. When nitrite levels are high, the animal cannot metabolize it quickly enough, and nitrite inhibits oxygen transport in the blood. Symptoms include rapid breathing, fast and weak heart-beat, muscle tremors, staggering and death if corrective steps are not taken.

The same management precautions for prussic acid poisoning help prevent nitrate poisoning. Pearl millet does accumulate high nitrate levels leading to nitrate poisoning. As mentioned above, pearl millet does not accumulate prussic acid. High nitrate levels persist when forages are cut for hay, but ensiling the crop reduces nitrates by one-half. If you suspect that forage contains high nitrate levels, have it tested before feeding.

POISONING OF HORSES fed sudangrass, sorghum-sudangrass hybrids and forage sorghum has been reported. The exact cause of poisoning is not known. Do not feed horses any of these summer annual grasses.

Brassica Crops

Forage brassicas are fast-growing annual crops that are highly productive and digestible. Crude protein levels range from 15 to 25 percent in the herbage and 8 to 15 percent in the roots, depending on nitrogen fertilization rate and weather conditions. The most commonly used forage brassica crops are rape, turnip, kale and swede. They can be grazed from 80 to 150 days after seeding depending on species (Table 7-12). These crops offer great potential and flexibility for improving livestock carrying capacity from August through December. Spring-seeded brassicas boost forage supply in late summer. Summer-seeded brassicas extend the grazing season in late fall and early winter.

RAPE (*Brassica napus* L.) is a short-season, leafy crop whose stems and leaves are eaten by the grazing animal; rape can also be greenchopped. It has fibrous roots, and each plant produces many stems. Rape regrows after harvest and is the easiest brassica species to manage for multiple grazings. Mature rape is excellent for fattening lambs and flushing ewes. Yields are generally maximized with two 90-day growth periods, but some varieties yield better with one 180-day growth period while rape hybrids yield best with 60 days of growth for the first harvest followed by 30 days for the second harvest.

TURNIP (*Brassica rapa* L.) is a fast-growing crop that reaches near maximum production 80 to 90 days after seeding. Roots, stems and leaves are grazed. The relative proportion of tops and roots varies markedly with variety, crop age, and planting date. The crude protein concentration of roots (8 to 10 percent CP) is approximately one-half of that in turnip top growth; however, stockpiled tops are more vulnerable to weather and pest damage than roots.

KALE (*Brassica oleracea* L.) is a long-season, leafy brassica that produces some of the highest yields of the brassica family when it is spring-seeded. Some varieties are very cold tolerant, which allows grazing of leaves and stems into December and January most years. Stemless varieties reach about 25 inches in height, whereas narrow stem kale grows to 5 feet with primary stems 2 inches in diameter. Stemless kale (e.g., Premier) establishes quickly and reaches maturity in about 90 days. Narrow stem kale is slower to establish and requires 150 to 180 days to reach maximum production.

SWEDE (*Brassica napus* L.) is a long-season brassica that produces a large edible root like turnip. Swede produces higher yields than turnip, but it grows more slowly and requires 150 to 180 days to reach maximum production. Swede produces a short stem when not shaded. If plants are shaded, it produces stems 30-inches tall. Swede does not regrow after harvest.

HYBRIDS OF CHINESE CABBAGE with rape, turnip or swede can also be used for forage. Research information on the production and management of these hybrids is limited.

Establishment

Brassica crops germinate quickly, and can be planted to provide either summer or late fall/winter grazing:

- Plant rape, turnip and stemless kale in the spring (mid-April through May) to provide pasture in August and September.
- Plant rape and turnips in July and August to provide grazing in November and December.
- Plant swede and kale in the spring for grazing in November and December.

Brassica crops require well-drained soils with a pH between 5.3 and 6.8 for good production. Seeding rates for rape and kale are 3.5 to 4.0 pounds per acre while turnip and swede are 1.5 to 2.0 pounds per acre. In the spring, use the higher side of the suggested seeding rates. Plant seeds in 6- to 8-inch row spacings at ¼- to ½-inch deep in a firm seedbed. Apply 50 to 75 pounds of nitrogen per acre at seeding to stimulate establishment and seedling growth. Weed competition should be controlled during brassica establishment, otherwise stand establishment failures are very likely.

On conventionally prepared seedbeds, brassica seed can be broadcast and incorporated with cultipacking. No-till seeding into grain stubble or grass sod is recommended, but weeds and sod must be suppressed for two to three weeks to allow the brassicas to establish. Apply either paraquat or glyphosate for sod suppression. Another alternative is to apply a manure slurry or liquid nitrogen solution to burn the sod back, then no-till plant the bras-

sica seeds. Brassicas can also be seeded with rye to provide forage growth and protect the soil after brassicas are consumed.

Fertilization

Determine lime and fertilizer needs by a soil test. Adequate phosphorus and potassium are important for optimum growth. In addition to the nitrogen applied at planting (50 to 75 pounds per acre), another 70 pounds per acre should be applied when multiple grazings are planned with rape and turnips. This second application should be made from 60 to 80 days after seeding. Nitrogen application in a chemically-suppressed grass sward tends to increase the efficacy of the suppressing herbicide. This reduces the proportion of grass in the brassica-grass sward, which is not always advantageous. Avoid excessive nitrogen and potassium fertilization to prevent animal health problems (see *Animal Health Concerns with Brassicas*).

Harvesting

Although brassicas can be harvested for greenchop, they are most often grazed. Rotational grazing or strip grazing helps reduce trampling and waste by livestock. Graze small areas of brassicas at a time to obtain efficient utilization. Rape is most easily managed for multiple grazings. Leave 6 to 10 inches of stubble to promote rapid regrowth of rape. When turnips are to be grazed twice, allow only the tops to be grazed during the first grazing. Turnip regrowth is initiated at the top of the root. Both rape and turnips should have sufficient regrowth for grazing within four weeks of the first grazing.

Stockpiling these crops for grazing after maturity should only be attempted when plants are healthy and free of foliar diseases. Some varieties are more suited for stockpiling because they possess better disease resistance. Do not grow brassica crops on the same site for more than two consecutive years to prevent the buildup of pathogens that limit stand productivity. Insect problems are not a consistent problem in Ohio.

Animal Health Concerns with Brassicas

Brassica crops are high in crude protein and energy, but low in fiber. The low fiber content results in rumen action similar to when concentrates are fed. Sufficient roughage must be supplemented when feeding brassicas to livestock. If grazing animals are not managed properly, health disorders—such as bloat, atypical pneumonia, nitrate poisoning, hemolytic anemia (mainly with kale), hypothyroidism and polioencephalomalacia—may occur.

These disorders can be avoided by following two guidelines:

- Introduce animals to brassica pastures slowly and avoid abrupt changes from dry summer pasture to lush brassica pasture. Do not turn hungry animals into brassica pasture, especially if they are not adapted to brassicas.
- Only two-thirds of the animal's diet should be comprised of brassica forage. Supplement with dry hay or allow grazing animals access to grass pastures while grazing brassicas. No-tilling brassicas into existing grass pastures helps reduce the risk of these disorders, if sufficient grass growth is available for grazing.

Chapter 8

Multiple Cropping

By Dr. Laura Lindsey



Multiple cropping is the establishment and harvest of a second crop in the same season that a first crop is harvested. A number of multiple cropping systems using winter cereals (wheat, barley, rye and spelt) as a first crop and soybean, sunflower, forage seedings and rapeseed (canola) as a second crop are either commonly used or are feasible. Corn grown for silage following a first cutting of hay and soybean after winter wheat are the most widely used double crop systems in Ohio. There are two forms of multiple cropping: double cropping and relay cropping. With double cropping, the second crop is planted following the harvest of the first. Relay cropping consists of interseeding the second crop into the first crop before it is harvested. Both systems are employed in Ohio, with double cropping being the preferred system south of I-70 and relay cropping to the north of I-70. The relay technique enables the production of a second crop in the northern part of Ohio where time for a second crop following wheat harvest is usually inadequate.

Multiple Cropping Requirements

Multiple cropping drastically reduces the elapsed time between successive crops and therefore can greatly increase the disease pressure for both crops. Where intense multiple cropping is practiced, the beneficial effects of crop rotation (weed, insect and disease control) are totally negated.

There are **two primary requirements** for profitable multiple cropping:

1. There must be adequate time for the production of a second crop.
2. There must be adequate water to produce two crops, whether from stored soil moisture, rainfall or irrigation.

Because the soybean crop is photoperiod sensitive and matures in response to day length, it is ideally suited for multiple cropping systems where planting dates for the second crop are later in the season and can be variable due to weather.

Currently, most multiple cropping systems depend solely on a combination of rainfall and stored soil moisture to supply adequate water for two crops. Irrigation can be used as a supplement for soils with a less than adequate water supplying capacity and/or inadequate rainfall. While irrigation can greatly increase the consistency of crop

yields, it also increases the cost of production. In the eastern Corn Belt, the small grain crop generally removes water from only the top foot of soil and rainfall is typically greater than 3 inches per month. If the top 3 inches of soil is dry when the second crop is planted, germination can be greatly slowed until the receipt of adequate rainfall. There also must be adequate surface soil moisture to enable the root system to grow into moist soil where water availability is more consistent. Because the water requirement is so large for multiple cropping, it is generally most successful on soils with large water supplying capacities. These soils are typically deep (54 to 72 inches) with loamy textures throughout the soil profile, and have high water supplying capacities in the range of 0.15 to 0.25 inches of available water per inch of soil. They also have good internal drainage, either natural or artificial, and little restriction to root development and water movement such as zones where the soil bulk density is greater than 1.6. Depending on the weather during the growing season, a soybean crop can produce about 2.5 bushels of soybean for each inch of rainfall and water removed from the soil. A wheat crop will usually use 6 to 8 inches of rainfall and/or soil water. The receipt of 18 inches of rain distributed somewhat evenly during May through September will usually allow the production of a 70-bushel wheat crop followed by a 30- to 40-bushel soybean crop. Soil pH throughout the rooting zone should be in the range of 5.8 to 7.2 (plow layer 6.5 to 7.0) to allow for maximum root growth and water uptake. Soil permeability should be greater than 0.6 inches per hour to allow rainfall to move into and through the soil. The soil shrink-swell potential should be low to moderate to reduce damage to the root system as the soil dries and cracks.

Double Cropping with Forages

Legumes and grasses (alfalfa, clovers, brome, tall fescue, orchard, timothy) in mixtures or in pure stands are sometimes broadcast seeded into small grains in late winter when the ground is still frozen. In these instances the primary purpose of the small grain is weed control, although some grain or forage is sometimes harvested. These forage seedings are usually intended for either livestock pasture, hay production or for soil improvement. Requirements for all methods of forage establishment are discussed in "Chapter 7, Forage Production." Seeding a forage crop without a cereal companion crop is the preferred method.

A legume cover crop, such as red clover or vetch, is sometimes interseeded into winter grains to provide a source of nitrogen for a corn crop the following year. Red clover is easily established, and the amount of nitrogen produced by one year of growth is sometimes adequate to support a normal corn crop. Herbicides that could injure the clover must be avoided if weeds are a problem in the small grain. Legume cover crops are also used intermittently for hay or grazing, but this would reduce their nitrogen value for a subsequent corn crop. In most situations, a legume cover crop is used to benefit the following crop, but its value as a nitrogen source varies, and the following crop may need additional nitrogen fertilizer. With emphasis on no-till crop production, the nitrogen value of various legume cover crops is reduced by 40 to 70 percent, because the legume residue is not incorporated into the soil. See “Chapter 10, Considerations for Using Cover Crops,” for more information.

Double Cropping Wheat and Soybean

Early planting of the second crop is essential for success, which requires harvest of the wheat as early as possible. Potential double crop soybean yield decreases by 1 bushel for each day that planting is delayed after June 20. Early wheat harvest can be accomplished by planting an early to mid-maturity wheat variety soon after the fly-free date in the fall and harvesting when the grain moisture decreases to 18 to 20 percent, and then using air with or without supplemental heat to dry the grain. These actions combined can save several days that would normally be used to field-dry wheat to 10 to 14 percent moisture. If a grower wishes to maximize wheat production because of the high value of wheat relative to a following crop, early harvest may be less important. Using later maturing varieties and optimum levels of nitrogen fertilizer generally increases wheat yields, but delays harvest.

Below-normal temperatures in June delay wheat maturation, which may require growers to reconsider planting the second crop. For someone considering double cropping, it may be necessary to have two wheat varieties differing in maturity available in the event that wheat maturation is delayed. In southern Ohio, soybean varieties with maturity ratings of 3.4 to 3.9 will usually mature before the first freezing temperature if planted in June. Other than selecting a variety that matures before the first freeze, variety selection is not as important for double cropping as it is for a full season crop. Ohio studies have shown that early planting and July-August rainfall have a much greater impact on double crop soybean yield than does variety.

Straw remaining after grain harvest must be managed so as not to interfere with planting the second crop. Some stubble may be left to provide mulch cover. Leaving an 8- to 12-inch stubble with the combine and baling the cut straw is an efficient practice and marketing the straw adds income from winter wheat. Alternatively, the straw can be chopped and spread evenly on the field. Usually, a no-till planter or no-till drill can plant through chopped straw, if the soil is not excessively wet or dry and hard.

Soil moisture at the time of planting the second crop is critical for its success, because average rainfall in July and August often does not replace the moisture used by the second crop. Table 8-1 shows that the probable soil moisture deficit is less than the potential maximum deficit, because a crop does not usually transpire moisture at a maximum rate as the soil dries. In most years, moisture used by wheat in May and June is replaced by rainfall, but in dry seasons some subsoil moisture may be used, leaving an inadequate amount of water for the second crop. Soils with low available water holding capacity are not suitable for double cropping soybeans. Generally, such soils are poorly drained, somewhat poorly drained without tile, eroded or sandy. Growers should also be aware of the water holding capacity of their soil, and rainfall in May and June when planning to double crop soybeans after wheat. An important rule of thumb to consider is: “if June is dry, don’t try to double crop.” Increased nitrogen application for the small grain produces more vegetation, which increases soil moisture use. Because wheat uses moisture from the upper 8 to 12 inches of soil, growers should be aware of the moisture remaining below that depth.

*Table 8-1: Estimated Moisture Balance (inches) in North Central Ohio Soils for Double Crop Winter Wheat and Soybeans.**

Month	Average precipitation	Average Open Pan Evaporation	Cumulative Soil Moisture Deficit	
			Potential	Probable
May	4.0	5.2	1.2	1.0
June	4.0	6.2	3.4	2.8
July	4.2	6.6	5.8	4.2
August	3.7	5.8	7.9	5.9
September	3.1	4.2	9.0	6.5

*Poorly drained soils with fragipans may hold as little as 5 inches available water at field capacity, whereas well-drained deep soils may hold more than 10 inches in the rooting zone.

Because of the short growing season remaining after wheat harvest and other time constraints, double crop soybeans should be planted no-till. The surface residue associated with no-till planting helps reduce moisture lost by evaporation and increases rainfall infiltration. In dry years, no-till planting can make a difference between satisfactory and unsatisfactory seed germination resulting from the moisture saved. A goal should be to plant the second crop on the same day the first is harvested. Narrow row, no-till planters equipped with residue cutting coulters and double disk openers have performed well for double cropping, but modern no-till drills are excellent implements also. Because double crop soybeans do not grow very tall, they should be planted in narrow rows (7.5 inches) and planted at high seeding rates (minimum of 250,000 seeds per acre) to obtain maximum leaf canopy and yield.

Relay Intercropping Wheat and Soybean

Central and northern Ohio are near the limit where ordinary double cropping of soybeans is practical because of late harvesting of wheat and early autumn frosts. For these areas, relay intercropping offers increased yield potential because the second crop is already established at the time the first crop is harvested. Improvements in winter wheat and soybean varieties, as well as equipment and crop management, make these two species especially well suited for relay intercropping.

For the relay intercropping system, soybeans are planted into standing wheat with a no-till planter or drill beginning in early May and can continue as long as damage to the wheat can be minimized. Early June should be the latest interplanting time because of a significant decrease in soybean yield potential after that period and increased potential to damage the wheat crop. The optimum time for interplanting soybeans into the 10- to 15-inch space between wheat rows is late May to very early June. Growing wheat in wide rows facilitates the interplanting of soybeans. See “Chapter 6, Small Grain Production,” for information regarding producing wheat in wide rows. The spacing between wheat rows may vary as needed to accommodate implement wheels. When planting wheat, plugging various seeding units allows the placement of disk openers in a pattern to accommodate tractor and planter wheels. Both wheat and soybeans can be planted with the same equipment or different planting tools may be used for the two crops. Any planting tool is satisfactory, provided that 18 to 24 wheat seeds are planted per foot of row and are evenly spaced. Row arrangement depends on available equipment and whether or not the grower emphasizes production of wheat or soybeans.

The use of early-maturing wheat varieties is not as important for relay intercropping as for double cropping, but harvesting wheat at high moisture (18 to 20 percent) allows for early release of the soybeans and decreases interference of soybeans with wheat harvesting. Test weight and quality of wheat is improved by early harvest (higher grain moisture), but the wheat must be dried for storage. It is important to understand that somewhat vigorous wheat is required in this cropping system to suppress soybean growth until the wheat is mature. Otherwise, soybeans grow too tall and are damaged during wheat harvest. If soybeans get too tall and wide row spacings are being used, shields may be added to the combine cutter bar to cover the cycle and push the beans down to prevent cutting the tops off excessively tall soybeans while harvesting wheat. If the wheat stand and its vigor are poor in the spring, either refrain from interplanting soybeans or wait until wheat is headed before interplanting. In several research trials, the height of early May interplanted soybeans was about two-thirds that of wheat at harvest in

early July, and were damaged during wheat harvest. Best results with intercropping in Ohio to date have been with soybeans planted in late May to early June when wheat heads are emerging. Traffic associated with plantings after this time tends to damage wheat and reduce its yield.

Improvements in machinery design, wider equipment, and modifications to confine traffic to the barren strips in skip-row wheat plantings eliminates some crop damage. Shields to protect wheat from tires and planter units are useful additions to the equipment when wheat rows are spaced 10 to 12 inches apart. Narrow rows should be carefully managed with respect to making wheel width and equipment adjustments to avoid damage to the wheat from soybean interplanting or to soybeans from wheat harvesting. In some cases, using narrow dual wheels on combines will reduce damage to the soybean crop during wheat harvest. Damage to soybeans increases progressively with decreasing wheat row spacing. During wheat harvests straw should be chopped and evenly spread to avoid smothering the soybeans.

It is very important that the wheat not lodge prior to harvest so that it can be harvested without excessive damage to the soybeans. To prevent lodging, use stiff straw, lodging resistant varieties and limit applications of nitrogen fertilizer. Ohio results have shown that the spring application of 75 pounds of nitrogen per acre (following soybeans) maximizes wheat yield without causing excessive lodging. Seeding rates for soybeans should be six to seven seeds per foot in 15-inch rows and four to five seeds per foot of 10-inch wide rows. The recommended seeding and nitrogen application rates for the wheat should not be exceeded to ensure that lodging of the wheat does not occur. The least amount of wheat lodging slows harvest, reduces grain quality and increases the potential of damaging the soybean plants during wheat harvest.

In northern Ohio, full season soybean varieties (relative maturity 3.5 to 3.8) have performed best in this cropping system when planted at the end of May. Later maturing varieties can be used in central Ohio. Early June plantings require slightly earlier maturing varieties than late May plantings. Short season varieties, (relative maturity 2.8 to 3.1), flower too soon after planting and do not produce enough vegetative growth to provide a complete leaf canopy for maximum sunlight interception and therefore produce poor yields.

Soil phosphorous and potassium levels should be greater than 15 and 150 ppm, respectively. Twenty to 30 pounds of nitrogen should be applied at wheat planting to encourage increased fall growth, and earlier jointing and heading in the spring. Spring nitrogen applications should be made between March 1st and April 15th at the rate of one pound per bushel of yield goal.

Emergency Aerial Seeding

Aerial seeding is primarily an emergency seeding method for fall-seeded small grains, but can be used to save time when other crops are being harvested. The time saved can sometimes offset the increased seed and seeding costs by permitting the timely harvest of other crops.

Planned aerial seeding of small grains are sometimes made into soybeans just before leaf drop so that the soybean leaves will provide some mulch cover for the seed. Sometimes, this occurs some weeks before the fly-free date. If the seed germinates before the fly-free date, there

is an increased risk of infestation of Hessian fly, and viral and foliar diseases. However, there is often insufficient soil moisture and/or rainfall for germination of seed due to greatly reduced seed-to-soil contact. This usually results in delayed germination and an extended germination and emergence period. Seeding rates should be increased by at least 50 percent to compensate for these adverse seeding conditions. If the seed has not germinated by the time of soybean harvest, shallow tillage to cover the seed will improve germination.

Chapter 9

Pasture and Grazing Management

By Dr. R. Mark Sulc and Dr. David J. Barker



Livestock have unique effects on pasture that vary from the effects of mowing on forage-lands. Factors such as selective grazing, uneven defoliation, manure, treading and the variable energy requirements of livestock make grazing management complex. Balancing these sometimes conflicting effects takes a good understanding of soil – plant – animal interactions that can best be gained from knowledge, practice and experience.

Pastures are often the most economical way to provide forage for livestock. A 50 percent reduction in feed costs can be achieved during the grazing season with well-managed pastures. Lowering feed costs is especially critical in livestock production systems that have a small margin of return, such as cow-calf enterprises. In such systems, techniques to extend the grazing season (especially into November and December) can keep costs to a minimum. Even on dairy farms, however, where pasture comprises a significant portion of the forage program, feed costs have been reduced by an estimated \$0.50 to \$1.00 per cow per day during the grazing season. Although grazing systems usually result in lower production per animal, the reduced costs usually result in grazing systems being profitable.

Productive pastures that provide good animal performance do not happen by accident. They are a result of careful planning and sound management. To achieve profitable returns from a pasture program, the manager must have knowledge of animals, plants, and soils, and be able to respond to their needs. This chapter aims to introduce the basic principles and practices involved in grazing pastures for profitable animal production.

Grazing Systems

The goal of a grazing system is to provide sufficient pasture of adequate quality for livestock throughout the grazing season. Major feed deficits that occur in winter and during drought in summer, can be offset by feeding forage conserved from the surplus in spring or growing drought tolerant forages such as the summer annual grasses. Forage species differ in primary periods of growth and production (Figure 9-1), and these differences can be exploited to optimize the length of the grazing system for a particular enterprise. Cool-season pastures are the foundation of pasture systems in Ohio. Permanent cool-season pastures can be supplemented with semi-permanent cool season pasture (e.g., hayland providing temporary

supplemental pasture), perennial warm-season pasture, and annual pastures (e.g., brassicas, small grains, annual warm-season grasses). There is no one best combination of types of grasses. It is important to maintain flexibility when designing pasture systems, because needs and conditions change from season to season and year to year.

Pasture areas can also be stockpiled (left ungrazed) during certain seasons to accumulate forage for grazing when pasture production is not sufficient to meet animal needs. For example, tall fescue can be stockpiled in late summer and fall for winter grazing. Tall fescue has an exceptional capacity to remain upright during snowfall, and cows can gain adequate nutrition during February and March by grazing tall fescue that is buried in snow. Stockpiling pasture growth provides available forage during seasons when low productivity of pastures might force the producer to feed hay or sell livestock.

Adding to the complexity of designing a grazing system is the varying nutritional requirements of livestock. Within a season, livestock will require different amounts and quality of forage depending on their physiological state. For example, dry cows and early pregnancy cows have a low nutritional requirement, with their energy intake only meeting their maintenance requirement. Lactating females have an energy requirement two to three times greater than non-lactating females. The timing of calving/lambing has a large impact on the demands on forage supply; traditional systems will have peak demands coincide with spring forage production, however, there are many exceptions from that pattern. Young livestock have a higher requirement than mature (male and dry female) livestock. Balancing the nutritional requirements of diverse groups of livestock within a season requires considerable skill and planning.

Stocking Rate

The most important variable for grazing management is stocking rate. No grazing system can adjust for a long-term mismatch between forage supply and forage consumption. Grazing management means controlling the frequency and intensity of grazing by livestock (Table 9.2). These each have unique effects on individual pasture species, livestock intake and the resultant forage production.

Controlling grazing pressure is important to maintain desirable forage species in pastures. Long periods of low

Table 9-1: Pasture Calendar Guide. Annual Forage Yield for Various Pastures, and the Seasonal Pattern of Growth (Approximate Percentage of Annual Yield That is Available for Grazing Each Month).

Pasture Type Fertility and Management	Annual Yield ¹ lb DM/ ac	Percentage of Annual Yield That is Available for Grazing Each Month												
		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bluegrass Pasture														
unfertilized – poor	2,000	100	..	..	..	..	35	30	10	5	10	10	..	..
unfertilized – fair	3,000	100	..	..	..	..	30	30	10	5	15	10	..	..
fertilized (L-P-K) ² – good	5,000	100	..	..	..	5	30	25	10	5	10	10	5	..
fertilized (L-N-P-K) ² – very good	7,000	100	..	..	..	5	30	30	10	5	10	5	5	..
extended grazing ³	7,000	100	..	..	..	5	15	15	15	10	10	15	10	5
deferred grazing	7,000	95 ⁴	..	..	..	5	30	25	..	..	5	10	10	10
Orchardgrass														
unfertilized - fair	5,000	100	..	..	..	10	25	25	15	5	10	5	5	..
fertilized (L-N-P-K) ²	11,000	100	..	..	..	10	25	25	15	5	10	5	5	..
Tall Fescue														
unfertilized – fair	5,000	100	..	..	..	10	25	25	15	10	5	5	5	..
fertilized (L-N-P-K) ²	11,000	100	..	..	..	10	25	20	5	5	15	10	5	..
fertilized winter stockpile ³	11,000	90 ⁴	15	10	10	5	20	20	..	..	..	..	..	10
Timothy (L-N-P-K) ² – very good	6,400	100	..	..	..	10	35	30	5	..	10	5	5	..
Smooth brome (L-N-P-K) ² – very good	8,000	100	..	..	..	10	30	25	5	5	10	10	5	..
Alfalfa-Grass														
unfertilized – fair, pastured	6,000	100	..	..	..	5	25	35	15	15	5	..	..	..
fertilized (L-P-K) ⁵ – very good, pastured	12,000	100	..	..	..	5	25	25	20	20	5	..	..	..
unfertilized – fair, hayed then grazed	6,000	50 ⁴	..	..	..	..	..	..	20	20	10	..	..	..
fertilized (L-P-K) ⁵ – very good, hayed then grazed	12,000	45 ⁴	..	..	..	..	..	..	15	20	5	..	..	..
Mixed Meadow (0-30% legume)														
unfertilized – fair, pastured	4,000	100	..	..	..	5	30	35	15	10	5	..	..	..
fertilized (L-N-P-K) ⁵ – very good, pastured	9,000	100	..	..	..	5	25	30	15	15	5	..	5	..
unfertilized – fair, hayed then grazed	4,000	50 ⁴	..	..	..	..	..	..	20	20	10	..	..	..
fertilized (L-N-P-K) ⁵ – very good, hayed then grazed	9,000	45 ⁴	..	..	..	..	..	..	15	20	10	..	..	..
New Pasture - Spring Seeded (L-N-P-K)	4,000	35 ⁴	..	..	..	..	..	..	10	15	10	..	..	..

continued on next page

(Table 9-1 Continued) Pasture Calendar Guide. Annual Forage Yield for Various Pastures, and the Seasonal Pattern of Growth (Approximate Percentage of Annual Yield That is Available for Grazing Each Month).

Pasture Type Fertility and Management	Annual Yield ¹ lb DM/ ac	Percentage of Annual Yield That is Available for Grazing Each Month												
		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Oats – seeded March (L-N-P-K)	4,500	100	..	..	..	10	50	40	..	..	..	..	..	..
Oats – seeded August (L-N-P-K) ³	4,000	100	..	..	..	..	..	..	..	..	10	35	35	20
Sudangrass/Sorghum-sudangrass – seeded May (L-N-P-K)	8,000	100	..	..	..	..	..	10	35	35	15	5	..	..
Winter cereal – seeded September ³ (L-N-P-K)	5,000	100	15	10	10	25	..	..	..	..	..	10	15	15
Gleaning corn stalks ³	6,000	30 ⁴	..	..	..	..	..	..	..	..	..	..	25	25
Brassica (turnips, kale, rape) ³ – seeded August	4,000	100	20	..	..	..	..	..	..	..	..	20	30	30

¹Annual yield that is available for grazing. Yield can be converted to animal unit (AU) grazing days, by dividing by an average consumption of about 30 pounds per day (approximately 2.5 percent of live weight). An AU is the equivalent daily intake by one cow (1000 pounds of animal), one dairy cow, two heifers/stockers, five ewes, one horse, six goats or six sows.

²L=lime (pH greater than 6), N=nitrogen (100 pounds nitrogen per acre per year), P=phosphorus (soil phosphorus greater than 50 pounds phosphorus per acre), K=potassium (soil potassium greater than 250 pounds potassium per acre).

³Variation in the seasonal distribution of utilization is achieved by rationing feed within selected areas of pasture. Different seasonal patterns can be achieved by re-allocating rations.

⁴Utilization by grazing values less than 100 percent are the result of some forage being used for hay production, grain harvest or losses occurring during deferred grazing management.

⁵Nitrogen not recommended for alfalfa. Nitrogen only recommended on mixed pasture if legume less than 30 percent.

grazing pressure typically cause a loss of legumes from the stand, because they are selectively and frequently grazed, which weakens the plant (new regrowth is grazed off). Long periods of high grazing pressure may result in temporary or long-term decreases in pasture productivity and loss of desirable species from the stand.

Grazing Management

One of the biggest debates among graziers is the comparison between continuous and rotational grazing.

- **Continuous grazing** involves stocking a (usually fixed) number of livestock in a large area for a prolonged (more than two-month) period. Animals have a high degree of selectivity during the first part of the grazing period. If the grazing period is too long, plants grazed at the beginning of the grazing period are likely to have regrowth that is grazed off again before the grazing period ends, resulting in reduced plant productivity.
- **Rotational grazing** involves fencing a pasture into several smaller sections called paddocks so that only one paddock is grazed at any given time while the remainder of the pasture is rested. This subdivision of the pasture

area puts the manager in control of the grazing pressure. Putting the herd in a small paddock results in rapid utilization of available forage. Once the paddock is grazed to the desired degree, animals are moved to a fresh paddock. This grazing of paddocks in sequence allows forage in each paddock to rest between grazings; thus, the forage plants are able to regrow and renew energy reserves for vigorous regrowth.

- **Management intensive grazing systems** is a form of rotational grazing that usually involves 20 to 40 paddocks with grazing periods of one to five days. The most intensive rotational grazing systems have two to three moves per day. In these systems, there is more control of what the animal eats and normally better growth and persistence of desirable pasture plants. The stocking rate is very high within one paddock (high grazing pressure) and overgrazing can occur rapidly. The manager must be careful to move animals to the next paddock when the available pasture falls below its optimum range. In general, begin grazing tall grasses when they are 7- to 8-inches tall, and remove animals when grass has been grazed down to a 3-inch height or less. Begin grazing short grasses, such as Kentucky bluegrass, when they

Table 9-2: Grazing Frequency and Grazing Intensity Combinations Within Grazing Systems.

		Frequency (Rotation Rate)				
		V. High (<15 days)	High (15-25 days)	Medium (~30 days)	Low (>40 days)	V. Low (4-6 weeks)
Intensity	Very High (2" residual)					'Hay' management
	High	Overgrazing/overstocking		Fall and winter grazing		
	Medium (4" residual)			Summer grazing		
	Low	Late-spring/early-summer grazing		Understocking/undergrazing		
	Very Low (6" residual)	Spring grazing				

are 5 to 6 inches tall, and remove animals when grass is grazed down to a 1- to 2-inch height. These general guidelines should be modified based on the predominant pasture species. Highly productive dairy animals may need to be removed from paddocks before the plants reach these heights, or milk production levels are likely to fall. In such situations, an excellent grazing management practice is to let highly productive animals (such as lactating cows) topgraze the paddock first, then follow with a lower producing group of animals (such as dry cows) to complete the grazing of the paddock to the desired height.

When managing a rotational grazing system, optimize stocking rate and available pasture. Growth rate of the pasture varies depending on the season, weather conditions, and soil productivity. Consequently, in most pasture systems, growth rate varies among pasture areas. Because rest periods should be based on the growth rate of the pasture, they need to be flexible (Table 9-2). It is best to not use a rigid rotational scheme, but to move animals to those paddocks that have reached their optimum available pasture (optimize forage quantity and quality). Spring management usually involves diverting some of the pasture acreage for hay or silage production to use the excess forage growth produced.

There are numerous combinations of grazing frequency (rotation rate) and grazing intensity within grazing systems. There are a few "rights" & "wrongs" with grazing management, and graziers need to find a system that satisfies their overall objectives. Some commonly recommended grazing frequencies and intensities for different seasons are shown below. It should be noted, that within a farm with fixed area and stocking rate, increasing the grazing frequency (i.e., a slower rotation) will also result in closer grazing. Pastures can compensate from an intense grazing by having a longer period for recovery. As a generalization, we use fast rotations during periods of high pasture growth rate, and slow rotations during periods of slow growth rate. Repeated and close grazing (i.e., overgraz-

ing) can only occur on isolated paddocks, or on an overstocked farm. Infrequent and lax grazing (undergrazing) can only occur on isolated paddocks or on an understocked farm.

The species and class of grazing animal may determine the grazing period. Because lactating dairy cows need consistent quality forage their grazing period may be anywhere from a half day to two days. Beef cows, brood ewes, and most other ruminants do not require as consistent quality forage, and longer grazing periods should suffice.

The advantages of rotational grazing systems include: less grazing selectivity, better nutrient dispersal, familiarity with the livestock and regular field inspections (because of more frequent pasture visits), ease of switching an area to hay/silage conservation, better control of forage utilization, ease of quantifying livestock intake (pre- and post-grazing yield measurement) and livestock can maximize intake on taller forage. There are also disadvantages that include: more fencing and water sources, more time with (typically daily) stock movement, livestock can be forced to eat forage they might have otherwise rejected.

Contact your county Extension office for resources available to assist you in developing a rotational grazing system.

Feed Budgeting

Inventory control is an essential component of any business, including a grazing system. While measurement of the merchandise on hand might be easy for many businesses, it is more difficult (but not impossible) for a grazing farm. In an ideal system, the rate of forage growth matches the rate of intake by livestock, but life is seldom ideal. With grazing there are distinct periods of surplus forage (in spring) and of deficit forage (in summer and winter). Grazers expect these surpluses and deficits and have strategies in place to address those events. In addition, other climatic variables such as a cooler spring, wetter summer,

or late fall can present opportunities for grazing once they are identified. A well-monitored grazing system should have targets for farm cover (available forage) for every month of the grazing season, and a monitoring system to ensure targets are met.

Pasture can be measured using various systems including, eye estimation, pasture height and the conversion of 300 pounds per inch (400 pounds per inch for perennial ryegrass and Kentucky bluegrass), rising plate meter, and pasture meter (e.g., capacitance). Measurement of each paddock on a farm is suggested on a one- to four-week basis, and most farmers monitoring this data employ a computer to take care of the many calculations. One estimate calculated a one hour per day investment in feed budgeting could increase farm profit by \$6 to \$48 per cow.

Improving Production

When developing a pasture improvement program, the producer should begin by considering his or her goals and the resources present. The current condition of a pasture and its anticipated use, should determine whether to reestablish, renovate or leave the pasture as is. It usually is not necessary to tear up current pastures to achieve significant improvement in productivity. Most pastures can be improved without renovation simply by implementing good grazing management, controlling weeds, and applying lime and fertilizer where needed.

Improvements in forage production are of little benefit unless there is also an increase in farm stocking rate. Often, identifying the correct stocking rate is the most important attribute of a grazing system. Increases in forage production can result in a small increase in per-head performance of livestock; however, such increases usually have a minor effect on farm profitability compared to the benefits resulting from additional livestock. In grazing systems we need to think more about product per acre, than product per animal.

Fertilization

Fertilization is usually the easiest management practice for increasing pasture production (Table 9-1). Good fertility usually enables earlier spring grazing, extends the pasture season, increases pasture quality, and is more profitable. Good soil fertility is usually necessary to retain the most productive species. A soil test is the best guide for proper fertilization. In pasture, 20 to 50 samples should be taken throughout the area to be tested, avoiding manure piles since these have enriched nutrient status. Pastures frequently have low pH, phosphorus (P), potassium (K), and nitrogen (N). Each nutrient needs to be considered separately.

SOIL pH is a measure of soil acidity. Soils with a pH less than 5.5 can be a problem for certain species and correction with lime is recommended. Responses of pastures to lime are similar for hayed forages and are addressed in Chapter 7.

PHOSPHATE fertility is necessary to encourage legume growth. In general, legumes are less competitive for phosphate than grasses, due to having fewer and coarser roots. One unique aspect of grazing is that phosphate is enriched in dung piles, and some researchers argue a lower efficiency of phosphate fertilization under grazing. Over time, however, phosphate achieves an equilibrium, and recommendations for phosphate in pastures are similar to hayed forages (see Chapter 7).

POTASSIUM fertilizer requirements are frequently less for pastures than for hayed forages. Potassium comprises 2 to 4 percent of forages, and losses from hay removal should be corrected by fertilizer application. Potassium losses under grazing are much less, and fertilization according to a soil test will address any requirements.

NITROGEN fertilization requirements in pastures depend a great deal on the legume content. Many pastures vary from hayed meadows by having a significant legume content. If legumes constitute over 35 percent of the pasture, then nitrogen is not recommended, because the legume contributes adequate nitrogen through nitrogen fixation. In the absence of legumes, nitrogen is the most limiting factor to growth of pasture grasses, especially the tall-growing species. Pasture grass yields can be increased two- to five-fold by adequate fertilization with nitrogen. Nitrogen can also be strategically used to stimulate extra growth during certain seasons. An example is late summer nitrogen fertilization of tall fescue to stimulate fall growth for stockpiling. For more details on nitrogen fertilization, refer to "Chapter 7, Forage Production."

Nutrients should cycle naturally in a well-managed pasture through nitrogen fixation from legumes and livestock excrement. Because grazing animals return only 60 to 80 percent of available pasture nutrients, additional fertilizer is required.

The distribution of recycled nutrients through grazing animals is dramatically affected by grazing management. An assessment of the uniformity of animal manuring across the pasture should be made before crediting the returned nutrients to the entire pasture acreage. Soil test every three to four years to monitor changes in fertility status across pastures.

Weed Control

A properly maintained pasture promotes a vigorous sod that competes well against most weeds. Good grazing management will control many weeds simply by defoliation; sheep and goats are exceptional bio-control agents! Not all weeds are detrimental, and some weeds can be beneficial to livestock by having a high mineral content. There are commercial grazing varieties of some species such as chicory and plantain that once were considered weeds. Some weed problems can develop from overgrazing, treading damage, poor fertility or pH problems. Correcting these cultural aspects of pasture management

will frequently result in effective control. Occasional mowing helps reduce invasion by woody perennials. Clipping weeds in the bud to early bloom stage weakens them by depleting root reserves and preventing seed production.

Herbicides should only be used to control serious weed problems in pastures. Specific chemical weed control recommendations can be found in the *Weed Control Guide*, Extension Bulletin 789, available at all county Extension offices and online at: estore.osu-extension.org. Only poisonous, noxious and thorny weeds warrant specific control. If weeds are widespread, broadcast applications are needed; if weeds occur in patches, spot spraying is more appropriate and less costly. Because most broadleaf herbicides remove desirable legumes from pastures, minimize their use. Once weeds are controlled, avoid spreading manure contaminated with weed seeds, clean equipment after working in weed-infested pastures, and keep fence rows free of problem weeds.

Pasture Renovation

In many situations, introducing desirable legumes and productive, palatable grasses into pastures is worthwhile. Renovation techniques further improve pasture stands without completely destroying the existing sod. Newly renovated pastures should be grazed less frequently and less closely for 12 months, to prevent them reverting to their former state. More details on forage species adaptation, seeding rates for mixtures, and establishment guidelines are given in Chapter 7.

When renovating pastures, the existing sod must be suppressed sufficiently to allow new seedlings to become established. Three basic techniques of pasture renovation are outlined below. The success of these methods depends on adequate soil fertility and proper pH. Soil test a year prior to renovation and apply nutrients as needed to correct any deficiencies.

LIMITED TILLAGE. Disk or other tillage implement disturbs the sod enough to destroy 30 to 50 percent of the stand and expose the soil. When the tillage is performed in the fall, lime and fertilizers can be partially incorporated. Seed is broadcast or drilled on the pastures in late winter or early spring. Graze or mow the pasture to reduce competition from surviving pasture plants or weeds after seeding. Manage the stand so that seedlings can absorb plenty of sunlight. Mow just above the new seedlings. Control grazing and stocking rates during the establishment year to favor regrowth.

NO-TILL WITH CHEMICAL SOD CONTROL. Herbicides suppress the existing sod during establishment of introduced species. Close grazing the previous fall helps reduce spring vigor of the existing stand. If perennial or biennial broadleaf weeds are a problem, the pasture can be sprayed the previous fall with broadleaf herbicides (refer to Bulletin 789, *Weed Control Guide*). Then in the spring, use paraquat or glyphosate to burndown the sod

when 2 to 3 inches of new growth is present, and seed as soon as possible after applying the herbicide. Use a no-till drill designed to cut through the sod and place the seed shallow and in good contact with the soil.

FROST SEEDING. Sod control is essential; using heavy grazing the previous fall to weaken and open up the sod when tillage or chemical control of the sod is not used. Seed can be sown in late winter through early March, while the soil surface is still freezing and thawing. The freezing and thawing promotes good seed-soil contact. Germination occurs with warming soils. This technique is most successful with the clovers; red clover and ladino clover, in particular, are two of the easiest legumes to establish using this method. Frost seeding is less reliable for grasses, and should only be attempted for rapid establishing species such as ryegrass. Frost seeding is also more successful when pastures are dominated by bunchgrasses, such as orchardgrass, rather than by dense sod-formers, such as tall fescue and Kentucky bluegrass.

USE HIGH-QUALITY SEED. Plant high-quality seed of adapted cultivars at the recommended rates. Inoculate legumes with the proper nitrogen-fixing bacteria. Use one of the seeding methods described above to achieve good seed-soil contact and proper seeding depth. Many seedings fail because of poor seed placement and lack of timeliness in planting.

PEST CONTROL. Insecticide treatments may be beneficial, particularly when seeding alfalfa into old pastures. Refer to insect control guidelines for no-till seeding in Chapter 7.

First Year Management of Renovated Pastures

Manage the pasture carefully after seedling emergence to minimize competition from the established sod. Use light, periodic grazing to prevent the existing sod from overtaking the new seedlings. Grazing periods should be short (less than one week), and animals should be removed when the new seedlings begin to be grazed off. For example: graze closely when the existing sod has 3 to 4 inches of new spring growth, then graze again when regrowth is 6 to 8 inches. If tall, stemmy regrowth develops, mowing may be necessary. Throughout the summer, graze the pasture rotationally.

Pasture Species and Cultivar Selection

Many pasture species provide forage for grazing animals. In Ohio, we are fortunate to have diversity in adapted forage species. Species use should be based on suitability for the soil, animal enterprise, and the planned grazing management of the farm. Tables 7-1 and 7-2 in Chapter 7 outline the agronomic adaptation and characteristics of some of the more important forages grown in Ohio.

For many forage species there are now cultivars that are specifically bred for grazing systems. Most especially, alfalfa that is included in a grazing system should be one of the grazing tolerant varieties. For white clover, new varieties that are more branched and with smaller leaves are more persistent under grazing than the larger, ladino varieties. For orchardgrass, the smaller and more densely tillered varieties are sometimes preferred for grazing. Ask your seed supplier if grazing varieties are available and consult performance data under grazing currently being published by some Midwestern university forage testing programs.

Cool-Season Grass Species

Cool-season grasses begin growing early and produce considerable forage in the spring. In the summer, higher temperatures and moisture stress reduce production. Production increases slightly in the fall with normal moisture supply, and growth ceases by mid-October to mid-November (Table 9-1). If earlier spring grazing is desired, apply 50 pounds of nitrogen per acre in March. In most situations, early spring nitrogen should be applied to a very limited acreage, because it will make it even more difficult to manage the late spring flush of growth that occurs most years. Cows soon to freshen or with calves should have access to a magnesium-containing mineral supplement to help prevent grass tetany on pasture in the spring. Avoid application of potassium to pastures in the early spring to reduce this risk.

KENTUCKY BLUEGRASS usually volunteers over time in pastures. To hasten the establishment of bluegrass in pastures, seed may be planted in early spring or late summer and early fall. Kentucky bluegrass can withstand close, continuous grazing and tends to be more abundant under sheep and horse grazing. Although it tolerates poor fertility, its forage quality and production are greatly improved if pastures are limed and fertilized with phosphorus and potassium and rotationally grazed to favor companion legumes (Table 9-1).

MEADOW FESCUE is a cool season semi-bunch type grass that grows well under cool, moist conditions and reportedly tolerates wet and sometimes flooded conditions. It has recently gained renewed interest among grazing system managers because it produces palatable forage and is well suited to managed grazing systems. It is very winter hardy and yields more than perennial ryegrass, while being more palatable with higher fiber digestibility at equal stages of maturity than tall fescue and orchardgrass, resulting in higher animal performance. Meadow fescue has a fungal endophyte, which does not produce alkaloids that are harmful to animals. It is not currently known if the endophyte provides any benefit to the plant. Meadow fescue has good drought tolerance on shallow soils and populations of this grass on farms have been noted as growing in deep, consistent shade of remnant oak savannas in the Northcentral region. Leave a 3- to 4-inch residual after grazing and allow at least three weeks between summer grazings.

ORCHARDGRASS is well suited for grazing. In the spring, begin grazing when plants are 4 inches tall. Graze orchardgrass heavily and frequently (every 10 to 12 days) during the flush of spring growth. Leave 3- to 4-inch stubble so the grass can recover quickly. Harvest surplus pasture for hay or silage. Orchardgrass can tolerate continuous grazing if the plant is not grazed below 3 to 4 inches, but production will be lower than if rotationally grazed. Allow at least three weeks between summer grazings for best recovery.

PERENNIAL RYEGRASS is one of the highest quality grasses, and is excellent for use in creep grazing pastures for young animals. Initial spring grazing can begin when growth reaches a height of 3 to 4 inches and soils are dry enough to prevent excessive treading damage. Allow 6 to 8 inches of regrowth between grazings for improved yield and persistence. Established perennial ryegrass tolerates continuous grazing if a 2-inch stubble is maintained; however, rotational grazing improves production. Perennial ryegrass does not stockpile well in winter, and nitrogen applications in fall can reduce plant survival over winter. Ryegrass pastures should be grazed to a 3-inch stubble in late fall to prevent smothering and development of snow molds that can kill plants.

REED CANARYGRASS should be grazed hard in the spring. Maintain growth below a height of 12 inches during the rapid spring growth. Short duration rotational grazing with heavy grazing pressure will result in the best use and greatest animal gains per acre. Do not graze closer than 3 to 4 inches above the ground. Reed canarygrass can tolerate continuous grazing, but productivity will be much greater under rotational grazing that allows at least three weeks of recovery between summer grazings.

SMOOTH BROMEGRASS produces palatable, nutritious pasturage. Begin grazing in the spring before the stem elongates significantly. Loss of stand occurs when brome-grass is grazed off in the jointing stage (stem elongation) during stressful growing conditions and under high nitrogen fertilization. Best production in pastures is achieved with rotational grazing that allows three or more weeks of recovery. Smooth brome-grass tolerates moderate continuous grazing, but production is lower.

TALL FESCUE should not be grazed closer than 3 to 4 inches, and recovery periods between grazings will improve persistence and production. Tall fescue produces very palatable forage in the fall. It is the best grass for stockpiled forage for winter feeding. When stockpiling tall fescue, remove animals by early August, and apply 50 to 60 pounds of nitrogen per acre in August if increased yield and quality of stockpiled forage is desired (Table 9-1). There are new soft-leaved varieties that have improved palatability for livestock. Endophyte-free and non-toxic endophyte varieties are recommended in preference to varieties with ergovaline-producing endophytes.

TIMOTHY can be grazed if carefully managed, and it produces palatable, high-quality pasturage. Begin spring grazing when grass is 3- to 4-inches tall. Rotational grazing with at least three weeks of recovery results in good production and persistence. In the spring, timothy is relatively tolerant of grazing before stem elongation (jointing stage). It is adversely affected by harvesting or grazing during the jointing stage, as is smooth bromegrass.

FESTULOLIUM is a true hybrid between ryegrass and fescue. The hybrid has characteristics intermediate between the parent species. Festulolium has a dense ryegrass-like pasture growth habit that has better quality than fescue, and is hardier than ryegrass. The density of the sward is especially attractive for grazing. See Chapter 7 for more details about this species.

SMALL GRAINS provide late fall and early spring grazing. Refer to Chapter 7 for details.

Other forage resources can be used in a planned full-season grazing program. Examples include corn stalks grazed after grain harvest and hay stockpiled in pastures.

Legumes

Legume species are highly desirable components of productive, economical pasture systems. Alfalfa, clovers, and birdsfoot trefoil all provide high-quality forage for grazing and eliminate the need for nitrogen fertilizers. Many legume species are deep-rooted and more tolerant than grasses of summer moisture shortages. Legumes generally improve animal performance and increase carrying capacity of pastures.

Pasture systems containing legumes require more careful management than pure grass pastures. Most legumes will not persist under continuous grazing and must be grazed rotationally. Fertility requirements are higher for most legume species. Pasture management practices should favor legumes because of the difficulty of maintaining them in the system. Grazing must be managed carefully to prevent bloat when grazing pastures where legumes predominate. Exceptions are birdsfoot trefoil, sainfoin and annual lespedeza, which are all non-bloating.

ALFALFA should be rotationally grazed with short grazing periods (four to five days). Alfalfa can be grazed beginning in the late pre-bud stage in the spring if the stand is vigorous. Start grazing no later than the bud stage for improved utilization of the available forage. Allow recovery periods of 24 to 30 days between grazings under favorable growing conditions; therefore, four to five subdivisions (paddocks) are needed to provide adequate rest periods for this species. Less recovery time is required when grazing than for mechanical harvesting. By grazing at earlier stages of growth, the leaves remaining after grazing are still active and will support regrowth. Animals should be removed from alfalfa when soils are wet to prevent excessive crown damage.

RED CLOVER provides excellent animal gains and can be grazed beginning in the late vegetative stage in the spring. Rotational grazing management should be practiced, with short grazing periods (less than seven days) and recovery periods of 28 to 35 days. As red clover stands begin to thin out in the second or third year, pastures can be managed like pure grass stands. The red clover component in pastures can be maintained by reseeding (with a drill or frost seeding) every two to three years. Natural reseeding can be enhanced if stands are allowed to go to seed.

BIRDSFOOT TREFOIL can be grazed in the spring when it reaches the bud stage of growth. Best production and persistence is achieved with rotational grazing that allows 28 to 35 days of recovery after grazing. Close, continuous grazing damages the stand because regrowth of trefoil is dependent on sufficient leaf area being present to capture sunlight and produce energy. Because carbohydrate reserves are low in birdsfoot trefoil roots during the growing season, it should not be grazed shorter than 3 inches. In emergencies, it can tolerate several weeks of continuous grazing if a 3- to 4-inch stubble height is maintained. Grazing should be managed to allow birdsfoot trefoil plants to go to seed every two to three years to maintain its persistence in pastures. Individual plant persistence is poor because of susceptibility to *Fusarium*-type crown and root rotting organisms. Reseeding can be accomplished by stockpiling spring growth until July.

WHITE (LADINO) CLOVER can be grazed continuously or rotationally once established. Although it can be grazed to a 1- to 2-inch height, closely grazed plants need time to recover. If grown with tall-growing grasses and grazed rotationally, the pastures should be grazed at relatively short intervals (every 21 days) to prevent excessive shading by the grass.

ALSIKE CLOVER must be allowed to reseed itself to maintain its presence in pastures, otherwise it lasts only two years. If grown with tall grasses in pastures, the pastures should be grazed at short intervals to prevent excessive shading by grasses.

ANNUAL LESPEDEZA can be used effectively in pasture renovation to improve animal performance and late summer forage production, especially in endophyte-infected tall fescue pastures on acidic and low phosphorus soils. Do not graze after early September to allow sufficient seed production for stand regeneration.

Other Species

Switchgrass, big bluestem, Indiangrass, Caucasian blue-stem and eastern gamagrass are warm-season species that complement cool-season species by providing forage during the summer months when the cool-season grasses are less productive. Rotational grazing is necessary for good persistence of these species. They should not be grazed below 6 to 8 inches in height during the growing season and should be grazed less frequently than other forages to ensure recovery from a grazing. Overgrazing

of basal tillers jeopardizes the regrowth potential of these grasses. Caucasian bluestem tolerates closer grazing than the other species. In general, these warm-season species have low protein concentration and should be planted with clover to ensure livestock have sufficient protein intake.

Sudangrass, sorghum-sudangrass hybrids, pearl millet and teff are annual warm-season species that are ready for grazing about six weeks after seeding. They are well suited as supplemental forages during hot, dry periods when perennial cool-season forages are less productive. They must be grazed rotationally with short grazing periods (less than two weeks) to avoid prussic acid poisoning. Refer to Chapter 7 for grazing guidelines.

FORAGE CHICORY is a perennial plant suited to soils that are well drained to moderately well drained with medium to high fertility and a pH of 5.5 or greater. Chicory produces leafy growth that has high nutritive value and mineral content if managed properly, and animal performance on forage chicory has been excellent. Its large taproot provides drought tolerance and good growth from spring through summer for grazing animals. Chicory requires nitrogen fertilization for good production at rates similar to those used for cool-season grasses. Chicory production is optimized under rotational grazing management. The thick taproot of chicory can be exposed and damaged by overgrazing, excessive hoof traffic, and frost heaving. A stubble height of 1.5 to 2 inches should remain after grazing. After the seeding year, chicory grows vigorously and attempts to produce stems in late spring and early summer. Stubble heights greater than 1.5 inches and rest periods greater than 25 days allow stems to elongate rapidly (bolting). Sometimes grazing can keep stems below a 6-inch height in late May, but if this is not possible, a single mowing during July can keep the plant in a leafy state. There are several grazing varieties marketed throughout U.S.

FORAGE BRASSICAS are fast-growing, productive, and highly digestible annual crops. These crops offer great potential and flexibility for improving livestock carrying capacity from August through December. Spring-seeded brassicas boost forage supply in late summer. Summer-seeded brassicas extend the grazing season in late fall and early winter. Refer to Chapter 7 for details.

Mixtures

One unique aspect of livestock is their preference for pasture mixtures. Although livestock prefer some species over others (e.g., clover over grasses), when given the option, livestock will select a diet from a mixture of species. We call this the *buffet principle*, and when applied to humans, dietary intake is greatest when there is maximum choice (e.g., at a buffet). There is some evidence this principle also applies to livestock grazing mixtures.

Other benefits of mixtures are based on biodiversity theory. That is, when we use a mixture of species we can

increase the resilience and resistance of the resulting grassland when faced with variation in fertility, climate, and other stresses. For example, a mixture could include a combination of drought-hardy species that would be able to maintain some production during summer as well as species that provide early spring production when moisture is abundant. Research studies in Ohio and the northeastern U.S. have shown that mixtures of at least six species have more stable forage production over seasons, years and the pasture landscape than do single species or simple mixtures of two species.

The converse argument is that every species has a specialization that is best expressed in a simple pasture composition. A pasture manager might include a series of specialist pastures for particular purposes on their farm; for example, a field of tall fescue because it has superb characteristics for stockpiling in winter. Whether we employ mixtures of species within a single pasture, or mixtures of different pastures within the variable topography of a farm, we should use the benefits of species diversity wherever possible.

Toxicity

It is unfortunate that almost every forage species has some potential for toxicity. In the majority of cases toxicities occur in isolated instances, and can be treated and managed as they occur. Some of the most significant toxicities include:

- **BLOAT** Perhaps the most significant feed disorder for grazing. Bloat is caused by foam that is produced by saponins in most legume species. Unable to escape, the foam distorts the rumen and, if not treated, can result in death. There are many theories about causes of bloat, however there are many exceptions where animals graze legume-rich diets without event. The best guidelines are to be extra observant when grazing pastures with greater than 20 percent legume, restrict access to legume pastures on an empty stomach (especially during the main morning grazing—e.g., when dew might still be present), feed fibrous forage (rough pasture or hay) prior to grazing legumes, restrict grazing intervals on legumes to less than two hours. Anti-foaming detergents in water systems, applied to pasture or administered orally, can reduce the occurrence of bloat. Tannin-containing legumes, such as birdsfoot trefoil, do not cause bloat. Susceptibility to bloat is an inherited trait, and livestock that bloat should be culled and not used for breeding (including bulls).
- **ENDOPHYTE** is a fungus that is found in tall fescue, perennial ryegrass, and some other less common grass species. The fungus confers some benefits to the grass, such as drought tolerance and insect resistance, but also produces alkaloids (especially ergovaline) that are detrimental to livestock. The U.S. forage industry has adopted a standard of providing endophyte-free tall fescue and ryegrass varieties; however, these sometimes

have poor persistence, or can become re-infested with endophyte-infected tall fescue. Re-infestation of endophyte in pastures after seeding endophyte-free varieties can occur through natural reseeding of surviving infected plants in the pasture, through infected seed carried in by animals previously grazing infected pastures, and through feeding infected hay in the pasture. A revolution in the forage industry has been the discovery of new fungal races that do not produce ergovaline. These non-toxic endophytes seem to confer the benefits of regular endophytes, but without the toxic effects.

- **NITRATE TOXICITY** is largely a problem of warm-season annual species (sorghum-sudangrass), but has been reported for many other vigorous species. The problem is most likely to occur, when grazing the early flush regrowth following relief from drought, and when grazing frosted forage. Grazing by livestock during these risk periods should be restricted to one to two hours per day, after which livestock should be moved to safe feeds. The risk period usually passes after two weeks.

- **ALKALOIDS IN REED CANARYGRASS.** Varieties of reed canarygrass older than 20 years have the potential to accumulate alkaloids that are toxic to livestock. Modern varieties have had the active agents removed and are safe to graze. Old stands of reed canarygrass should only be grazed for short periods, and livestock intake diluted with safe forages.
- **HYPOMAGNESEMIA (tetany or staggers)** is a disorder resulting from an imbalance (deficiency) of magnesium, compared to calcium or potassium. This is most common in newly lactating dairy cows with a high forage intake. The condition occurs rapidly (as short as several hours after calving) and is most effectively treated by intravenous injections of magnesium. Forage conditions increasing the likelihood of staggers include low magnesium in forage (less than 0.2 percent), high calcium and potassium levels, and in rapidly growing forage (after nitrogen application or during spring)
- **SLOBBERS** is an uncommon disorder resulting from livestock ingestion of *Rhizoctonia* bacteria that can grow on legumes during warm moist conditions. The condition is not life-threatening, but is unsightly in show animals. Slobbers can be treated by removal from infected forage, and allowing free access to water.

Chapter 10 Considerations for Using Cover Crops

By Dr. Alex Lindsey, Dr. R. Mark Sulc and Dr. Ryan Haden



Cover crops are a growing topic of interest in modern cropping systems. Questions arise regarding how to include cover crops into existing rotations or how to modify management practices to improve cover crop success. The reasons for wishing to incorporate cover crops are very diverse, and can include (but are not limited to) reducing nutrient runoff, proving year-round ground cover, decreasing soil erosion, providing weed suppression, reducing soil compaction, and increasing biodiversity. However, two of the most common challenges identified with using cover crops include successful establishment and the time/labor associated with managing the cover crops. This chapter aims to address some practical concerns regarding cover crop implementation, establishment and termination.

Why are Cover Crops Needed, and What Species Should I Use?

Before proceeding with large-scale implementation of cover crop use, the first step that needs to be addressed is “what am I trying to achieve by using cover crops?” This answer may differ from farmer to farmer, as well as location to location. This is an important question to answer because it will impact how a grower will implement and manage the cover crop (species selection, when to establish, when to terminate, etc.). Cover crop species should be selected to meet the particular management objective of each grower. Some of the most successful species for cover cropping in Ohio are outlined in the NC-SARE publication *Managing Cover Crops Profitably* (2007), and Table 10-1 has been adapted from this resource.

If the goal for using cover crops is to reduce wind erosion in the fall, a quick-establishing cover that winterkills may be advantageous. Other goals, such as suppressing weed populations or providing an additional feedstock for grazing, may be achieved through a fast-establishing cover that survives the winter, or a slower establishing perennial cover that has limited competition with the cash crop. Each cover crop can have potential benefits and drawbacks. For instance, if the species overwinters then inadequate spring termination could result in the cover crop setting seed and becoming an ongoing weed issue in future years. Understanding the pros and cons from using cover crops will prepare producers to understand the new management challenges that could be incurred.

Table 10-1: Cover Crop Species Adapted for Use in Different U.S. Regions. Adapted from Chart 1 in *Managing Cover Crops Profitably* (2007, NC-SARE).

Cover Crop Type	Great Lakes Region	Midwest Corn Belt	Northeast
Grasses	Annual ryegrass Rye Sorghum-sudangrass Oats	Annual ryegrass Rye Barley Wheat Sorghum-Sudangrass Oats	Annual ryegrass Rye Sorghum-sudangrass Oats
Brassicacae	Forage radish Rapeseed	Forage radish	Forage radish Rapeseed
Legumes	Hairy vetch Red clover Berseem clover Crimson clover Sweet clover	Hairy vetch White clover Red clover Berseem clover Crimson clover Sweet clover	Hairy vetch Red clover Berseem clover Sweet clover Subterranean clover
Other Species	Buckwheat	Buckwheat	Buckwheat

Regardless of species and planting method, most of the benefits from cover crops are dependent on biomass production. The greater the establishment, the greater the chances for reaping a benefit from their use. Some example benefits and drawbacks of cover crop species are described in Table 10-2. One of the other major drivers of a species benefit is related to its tissue carbon to nitrogen (C:N) ratio. A higher C:N ratio (greater than 24:1) indicates the residue is slower to break down and may decrease short-term nutrient availability in the soil, whereas a lower C:N ratio (less than 24:1) will result in a more rapid breakdown and a net release of nutrients into the soil from the decomposing residue.

GRASS cover crops typically are fast establishing, produce dense fibrous root systems to help provide erosion control as well as alleviate compaction (Table 10-2). Growers should also consider that some grass species (i.e., oats) will winterkill while others will overwinter very well (i.e., annual ryegrass, cereal rye). However, these grass cover

Table 10-2: Relative Benefits and Drawbacks of Various Cover Crop Species in Ohio.

Cover Crop	Control Erosion	Add / Fix Nitrogen	Scavenge Nutrients	Build Organic Matter	Alleviate Compaction	Suppress Weeds	Livestock Forage	Potential Drawbacks
Grasses								
Annual ryegrass	●●●●	N/A	●●●●	●●●	●●●	●	●●●	Possible weed
Sorghum-sudangrass	●●	N/A	●●●	●●●●	●●●	●●	●●●	Warm season only, alternate virus host
Rye	●●●●	N/A	●●●●	●●●●	●●●	●●●	●●●	Cereal pest host
Wheat	●●●	N/A	●●●●	●●●	●●	●●	●●●	Cereal pest host
Oats	●●●	N/A	●●	●●●	●●	●●	●●●	Cereal pest host
Legumes								
Red clover	●●	●●●●	●	●●●	●	●●	●●●●	Soybean pest host
Crimson clover	●●	●●●	●	●●	●	●●	●●●●	Low winter survival
Berseem clover	●●	●●●	●	●●	●	●●	●●●●	Low winter survival
Balansa clover	●●	●●●●	●	●●	●	●●	●●●●	Soybean pest host
Winter pea	●●	●●●●	●	●●	●	●●	●●●●	Soybean pest host
Hairy vetch	●●	●●●●	●	●●●	●	●●	●●●●	Soybean pest host
Brassicas & Other Forbs								
Radish	●●	N/A	●●●	●●	●●●●	●●●	●●	No spring cover
Turnip	●●	N/A	●●●	●●	●●●	●●●	●●	No spring cover
Mustard	●●	N/A	●●●	●●	●●●	●●●	●●	No spring cover
Buckwheat	●●	N/A	●●●	●●	●●	●●	●●	No spring cover

Poor = ● Fair = ●● Good = ●●● Excellent = ●●●● N/A = Not Applicable

crops may serve as alternative host to diseases common in grass crops (i.e., winter wheat, corn, etc.) which may impact disease inoculum levels over time. If problems with Fusarium or Anthracnose are known perennial disease issues in a target field, use of a grass cover crop may lead to other management decisions during cash crop production (i.e., timing and frequency of fungicide application). Incorporation of green residue from cover crops can attract some pests, such as seed corn maggot, which may require the use of a soil insecticide or seed treatment to ensure adequate control. Living grass cover crops in the spring may increase the occurrence of lepidopteran larval pests, such as armyworm, stalk borer, and cutworm. Scouting for novel pests should be conducted to allow for early detection and management through implementing integrated pest-management strategies.

LEGUME cover crops which fix nitrogen from the air can potentially provide nitrogen credits to a grain crop grown the following year, but may also act as an alternative host to soybean pests in future years (i.e., soybean cyst nematode). Additionally, inoculation of the seed with a compatible rhizobial strain may be needed to ensure nodule formation and atmospheric nitrogen fixation. Legumes tend to have smaller, less robust root systems, but can contribute to the release of nitrogen due to lower C:N ratios (less than 20:1). However, the amount of nitrogen added can vary widely with the legume species, dry matter production, and management. In comparison, grass cover crops typically have a C:N ratio that exceeds 24:1 and do not provide a nitrogen credit to the subsequent crop. Additionally, the C:N ratio for most grasses tends to increase as the cover crop matures. Grass cover crop residues and may even tie up soil nitrogen for several weeks following termination and incorporation.

Estimation of nitrogen credits from legumes can be made using book values which approximate the nitrogen that will be available to the next crop based on the amount of vegetation incorporated into the soil. A general estimation is that every 6 inches of legume vegetation incorporated into the soil should provide approximately 40 to 50 pounds of nitrogen to the next crop. However, research from Ohio suggests the nitrogen credit from legumes may be more variable, ranging from zero to 45 pounds of nitrogen per acre. A rotational yield benefit not attributed to nitrogen was observed in corn when red clover was planted following wheat. If the legume is mixed with a grass, the estimated nitrogen credit should be reduced based on the fraction of legume in the mixed stand. More precise estimates of legume nitrogen credits can also be calculated by clipping vegetation samples to measure the dry matter production (pounds dry matter per acre) and submitting a plant sample to a lab for total nitrogen analysis. A fact sheet and Excel calculator, which provide detailed sampling methods and equations for estimating nitrogen credits, are available online via the following website from Oregon State University and the USDA-SARE program:

Nitrogen Credit Fact Sheet and Excel Calculator: westernsare.org/Learning-Center/SARE-Project-Products/Fact-Sheets/Estimating-Plant-Available-Nitrogen-Release-from-Cover-Crops (last accessed 24 June 2016).

BRASSICA Large taproots found in many Brassica species can help provide some compaction alleviation, as well as increase the macroporosity of a field after the tissue is decomposed. Brassica species can provide some weed suppression through large rosette production and also produce glucosinolate compounds that may contribute to pest control, but will generally winterkill, resulting in limited ground cover the following year. Multiple Brassica species have been identified as alternate hosts for plant parasitic nematodes, but depending on the timing of planting and termination, may help serve as a trap crop.

Another consideration for species selection is the use of cover crop mixtures. Planting cover crop mixtures has become more popular in recent years, with mixtures ranging anywhere from two species upwards of eight different species. Mixing two or more species may allow a producer to address multiple goals simultaneously through the unique services each species would provide. Combining cover crops into a single planting may also help reduce per acre seed costs of a more cost-prohibitive species without necessarily losing the benefits provided by the species. However, working to balance the seeding ratio of the species in the mixture to ensure both species are present is essential to try and preserve the balance of species and can be challenging. Other factors that need to be managed include minimizing seed separation during planting and optimizing seeding depth for the mixture. If successful cover is more important to the producer rather than multiple species, a mixture may be more advantageous because environmental conditions can vary from year to year. More species incorporated into a seeding mixture increases the likelihood that at least one of the species will establish in any given year.

Different varieties within each species can also vary in their specific growth characteristics, and more companies have begun screening their varieties for various growth characteristics. Please consult with your county Extension educator or agronomist when selecting a cover crop species and variety. More information regarding specific crop species and their relative ability to provide various services—such as speed of establishment, growth rates, ability to sequester or generate nutrients, residue decomposition and harvest value—can be found in resources such as the book *Managing Cover Crops Profitably* (NC-SARE, 2007) and the *Cover Crop Chart* generated by the USDA-ARS Northern Great Plains Research Laboratory. Both of these resources are available online for free:

Managing Cover Crops Profitably: sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition (last accessed 20 May 2016).

USDA-ARS NGPRL *Cover Crop Chart*: ars.usda.gov/Main/docs.htm?docid=20323 (last accessed 20 May 2016).

Economic Considerations

While cover crops may provide important soil quality and environmental benefits, their main goal is generally not to produce a harvestable and marketable commodity. As such, it is important that farmers accurately estimate the costs associated with establishing and terminating cover crops (e.g., seed, fuel, equipment, labor, herbicide). To this end, the USDA-NRCS has developed a free calculator tool designed to help farmers estimate and track the economic costs and benefits of their cover crops. A link to this Excel tool is provided below.

NRCS *Cover Crop Economics Tool*: nrcs.usda.gov/wps/portal/nrcs/detailfull/il/soils/health/?cid=stel-prdb1269028 (last accessed 12 July 2016)

As an incentive to encourage wider use of cover crops in the Midwest, many local soil and water conservation districts and the NRCS-EQUIP program offer cost-share programs for farmers. The amount of financial assistance for cover crops varies widely among conservation districts (ranging from zero to \$90 per acre), so growers will want to contact their local district conservationist for details on cost share programs in their area and how to apply.

Establishing a Cover Crop Stand

One of the biggest challenges associated with using cover crops is successfully establishing a cover crop stand. Successful establishment is dependent on multiple factors, including: species; seeding rate and method; timing of seeding; environmental conditions before, during, and after planting; and the duration of the growing period. This next section will address some of the considerations before planting to ensure maximum establishment of the cover crop.

Cover Crop Implementation

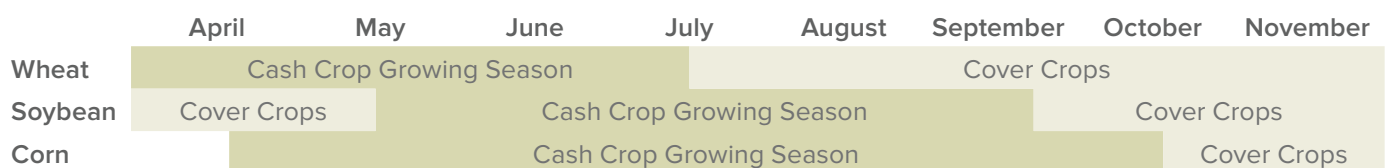
Once a species has been identified, a major consideration is when to insert the cover crop into a cropping sequence. Many grain producers in Ohio implement one of four common cropping sequences: corn-soybean, corn-soybean-wheat, continuous corn or continuous soybean. Incorporating a cover crop every year, every other year or every third year can also impact the timing of insertion into

the sequence (Figure 1). Growers with livestock may also have some of these crops in rotation, but may be interested in including a cover crop prior to pasture or forage crop establishment. A cover crop following wheat is typically the easiest to implement due to the long period allowed for establishment after wheat harvest. The second most common point of insertion for cover crops is following soybeans. Soybean harvest typically occurs in mid- to late September, which still allows up to two months of growing potential for a cover crop planted after soybean harvest. Incorporation during the corn sequence can be the most challenging due to the early plant dates (April to mid-May) and the late harvest dates (mid-late October). However, hybrid selection as well as harvest timing may increase the success of planting a cover crop in corn systems. Hybrids with a shorter relative maturity may allow for earlier harvest with limited impact on grain yield, and may be a viable option for growers interested in including cover crops with corn. Another area to increase success for corn is through harvest for silage or high-moisture purposes associated with livestock. Harvesting earlier (late August through September) creates a longer establishment window in corn production systems. However, these harvest methods may be limited where livestock production is low.

Another consideration for cover crop implementation is how cover crops will fit into a management operation using an herbicide rotation program. Multiple pre-emergence and post-emergence herbicides have varied degradation half-lives, which may impact their efficacy on both grain crops and cover crop species. The use of residual herbicides may impact the window for establishment, and consideration for current herbicide programs should be made to ensure this will not inadvertently limit cover crop establishment. Specific chemical weed control recommendations can be found in the *Weed Control Guide*, Extension Bulletin 789, available at all County Extension offices and online at CFAES publications at: estore.osu-extension.org/.

Incorporation of a cover crop into a livestock production system may also be of interest for multiple reasons. Current regulations in Ohio allow for surface manure application to a growing crop which can include a cover crop. Increasing establishment success can dramatically improve the cover crop's ability to reduce surface runoff in cases of manure application. Cover crops may also be grown as a supplemental forage source. Growing a cover crop for forage or grazing purposes should be approached using methods similar to those for grazing and pasture

Figure 10-1: Seasonal opportunities for inserting cover crops into Ohio crop rotations.



management as described in Chapter 9. Depending on the timing of establishment, reports of cover crop yields have ranged from 4 to 5 tons of dry matter produced per acre in a single-cut system in Pennsylvania when fertilized.

Planting Methods and Procedures

Planting method can also play a role with cover crop establishment. By far the most popular method of establishment is drilling the cover crops into the field after the cash crop has been harvested. As mentioned above, this is a fairly straight forward way to establish the cover crops in both a wheat and soybean system, but can cause challenges following a corn crop harvested for grain. Recommended seeding rates for drilling are located in Table 10-3, as well as information regarding winter hardiness. Typical seeding depth for most small-seeded cover crops (i.e., clovers, annual ryegrass) is shallow ($\frac{1}{4}$ to $\frac{1}{2}$ inch), but can be deeper (1 to 1.5 inches) for larger-seeded species (i.e., field pea, wheat, barley). One limitation of drilling cover crop seeds is that planting usually occurs with rows of the cover crop following the row pattern of the grain crop in a no-till scenario, which may impact the efficacy at slowing surface runoff if rows are not perpendicular to slope. Planned fall tillage may also impact cover crop establishment due to the time needed to complete the tillage event as well as plant the cover crop.

Alternative seeding methods include aerial broadcast application, which may be advantageous because seeding can occur two to three weeks earlier in the growing season as leaf senescence starts to occur in the cash crop (R5 in corn, R7 in soybeans), but seeding rates need to be increased due to poorer seed-soil contact. Late-season broadcast seeding can also be facilitated with the use of a high-clearance seeder. An additional difference in this method is the cover crop plants are more randomly distributed in the field compared to the rows achieved with a grain drill. Similar results of plant randomization may be achieved through broadcast seed application followed by light incorporation.

The topic of interseeding cover crops into grain crop stands has also been gaining traction, especially during the corn sequence of a crop rotation. Interseeding is planting cover crops using a high-clearance drill or broadcast applicator after the weed-free period is completed in corn but prior to canopy closure. In the eastern Corn Belt, this period is between V4 and V6 stages. The cover crop will germinate and emerge, but will remain in a dormant-like state until leaf senescence in the grain crop begins to occur. After grain crop harvest, the cover crop is already present and can resume growth allowing for greater fall establishment. Seeding rates are similar using the interseeding method as those used for establishment after harvest. There are a few inherent challenges with producing grain crops and cover crops concurrently. Competition for nutrient resources and water may occur if the cover crop is seeded too early. Additionally, if a pre-emergent herbicide is used in the corn sequence the active ingredients

Table 10-3: Common Seeding Rates and Winterkill Properties for Various Cover Crop Species.

Cover Crop Type	Species	Seeding Rate ¹ lb/ac	Winterkill
Grass	Annual ryegrass	20-25	No
	Rye	80-110	No
	Barley	60-90	No or Yes ²
	Wheat	100-120	No or Yes ²
	Sorghum-sudangrass	20-25	Yes
Brassicas	Oats	70-90	Yes
	Forage radish	5-10	Yes ³
Legumes	Rapeseed	5-10	No or Yes ²
	Hairy vetch	30-45	No
	Red clover	8-10	No
	White clover	5-7	No
	Berseem clover	10	No
Other Species	Crimson clover	10	No
	Sweet clover	10-15	No
	Subterranean clover	15-20	No
	Buckwheat	60	Yes

¹Seeding rates were determined using the Ohio Agronomy Guide forage chapters, as well as the University of California Division of Agriculture and Natural Resources for drilled planting.

²Winter versions will typically overwinter, whereas spring versions will not.

³Mild winters may not kill all radishes.

may be prohibitive to cover crop survival. Herbicides with a shorter residual period will be more conducive to cover crop interseeding, but should not be used at the expense of adequate weed control. Increased residue distribution and smaller residue size may also improve fall recovery of an interseeded cover crop.

Regardless of species and planting method, the success of cover crop is often dependent on soil and weather conditions. Adequate moisture is needed to germinate and maintain cover crop growth, and warmer temperatures can promote biomass production and growth. Additionally, a prepared seedbed will increase establishment success in most years, but time and weather may restrict these activities. Use of irrigation may help to improve germination in a dry year but may also impact soil crusting in tilled fields.

The use of inoculant for novel legume species should be considered prior to planting if the objective is to rely on

the legume residue as a nitrogen source for future seasons. Inoculating the legume cover crop with a compatible nitrogen-fixing bacteria will enable the cover crop to fix atmospheric nitrogen which will help contribute nitrogen to the system in a natural state. As the legume residue decomposes after termination, the nitrogen that was fixed biologically is released and made available for crop uptake and utilization. Inadequate inoculation may result in poor-to-no nodulation, lower than expected nitrogen contributions from the cover crop, and slower residue degradation due to an elevated C:N ratio. Each legume species will only form associations with specific rhizobial strains, so it may be worth the investment to purchase a coated legume seed with a pre-applied inoculant or an inoculant that is added prior to planting. Using coated seed should not impact the targeted seeding rate for the cover crop, and some coatings are on the market that are certified organic if this is a concern. Be sure to consult with your seed representative or agronomist to ensure the proper inoculant strain is available for use with the legume species selected.

Terminating a Cover Crop Stand

The final step in cover crop management is the termination procedure. Adequate timing of termination is necessary to ensure cash crop survival and minimize cover crop competition. Inadequate termination may result in flowering and seed set of the cover crop, which may result in the current year cover crop becoming a future weed problem. However, termination too soon or with specific methods may result in limited benefits from cover crop utilization or difficulties in planting next year's crop. When identifying a termination method, a producer should be mindful of the purpose for implementing the cover crop into the system.

In the Eastern Corn Belt, the NRCS termination guidelines recommend termination at or within five days after planting, but prior to crop emergence. However, termination prior to planting is also a viable option for spring cover crop management. In a dry spring, a large amount of living cover crop biomass may be detrimental to establishment of a grain crop due to excessive moisture use. Early termination (two weeks prior to planting) may be necessary to ensure adequate cash crop establishment. Conversely, in a spring with adequate moisture, planting into a lush green stand may be an acceptable practice. Allowing the green tissue to survive will help the soil dry more rapidly due to transpiration by the plants in addition to evaporation from the soil. However, this may result in a thick mat of residue after termination which may retain water and inhibit cash crop growth. Considerations for timing, biomass, and weather should all be made prior to selecting a termination method.

Multiple methods are available to help terminate cover crops. One of the most surefire ways to terminate cover crops is to plant an annual species in the fall that will winterkill. This will provide living cover in the fall, but will not typically need to be killed in the following spring. The

winterkill probability of the recommended species for the Eastern Corn Belt is listed in Table 10-3. If the objective is to have a living cover that survives the winter, this species will need to be terminated in the spring in most instances to limit competition with the cash crop.

The most popular and effective methods to terminate the cover crop are through tillage, herbicides or a combination of the two. Tillage can effectively break up cover crop stands prior to planting, and can help incorporate the biomass produced by the cover crop into the soil. If a burndown herbicide is not used prior to tillage, the breakdown of green plant tissue may attract pests such as seed corn maggot. Additionally, spring lepidopteran pests, such as black cutworm and stalk borer incidence, may increase with the use of cover crops that overwinter. Utilization of a seed insecticide treatment or soil-applied insecticide at planting may be needed to help ensure grain crop survival. Tillage can also influence residue breakdown and mineralization of nutrients. Cover crops with higher C:N ratios will tend to break down slower than those with lower C:N ratios, but tillage will accelerate the decomposition process regardless of the C:N ratio. If one of the objectives for using a cover crop is to scavenge for nutrients and allow them to be made available during the next growing season, then the use of tillage and its effect on the rate of residue decomposition should be considered. If the breakdown of the residue and release of nutrients coincides with crop uptake and utilization, this may be a preferred termination method. However, for a cover crop with a lower C:N ratio this may cause decomposition to occur too quickly, causing asynchronous nutrient release and grain crop uptake.

In Ohio, no-till production is a very common practice and tillage may not be a viable option for cover crop termination. Depending on the cover crop species, mowing or rolling/crimping may be adequate to either kill the cover crop or delay its development to allow the cash crop to establish. These activities can be completed prior to planting, but may result in elevated levels of residue that can make planting more difficult. Often it will be easier to plant into a lush green stand and terminate the cover crop after planting in a no-till system.

Another method for termination is through herbicide use. Broad-spectrum herbicides with limited residual are preferred because they will effectively control the cover crop stand with limited impact on the planted cash crop. The spectrum of herbicides available are diverse with varying efficacy on each species, so each program should be tailored for the species, timing, and cash crop of interest. Resources for herbicide options are available through the Agronomic Crops Network. One advantage of using a burndown program is that pre-emergence herbicides planned for use in the grain crop may be tank-mixed and applied at the same time to reduce application passes. However, the soil residue degradation rates should be considered when selecting a cover crop species and planting method.

While tillage and herbicides are the two most popular termination methods, they are not the only methods that can be used to terminate a cover crop stand. Additionally, using one method exclusively may not provide adequate termination success. Use of two or more methods may increase the success of termination, and may be the appropriate method for control depending on the cover crop species, the timing of termination and the following cash crop for implementation.

Summary

Cover crops are a tool that can help producers address production and stewardship goals, but not every cover crop is created equal. Careful planning and implementation can greatly increase success in achieving the goals from using cover crops. Implementation and experience on farm can help producers gauge what specific practices should be used for successful cover crop incorporation. Please consult with your agronomist or Extension educator about incorporating cover crops into your operation if this is a topic of interest.

Chapter 11

Conducting On-Farm Research

By Dr. Alex Lindsey, Dr. David J. Barker and Dr. R. Mark Sulc



New products and farming practices related to agricultural production are coming to market every season. Regionally or locally specific (and non-biased or objective) data for many of these techniques or products is often limited or non-existent, and questions do arise if research conducted at select locations using specific practices will still be applicable in other environments with different production practices (i.e., tillage, soil type and fertility levels, cropping sequence). Because each farm (and field) is unique, it may be difficult to make large-scale management decisions for many acres based on the available information. One of the options open to producers is conducting on-farm, large-plot strip trials to evaluate a new improved agricultural product or practice side-by-side with the conventional practice. The advantage of these experiments is that the data generated is locally specific, can be tailored to address specific questions, and may be used to help inform farmers and industry professionals prior to making a management decision that might impact a large acreage. The objective of this chapter is to introduce some basic concepts for on-farm experimental design and basic analysis tools to help industry professionals and growers correctly produce locally or regionally specific data to evaluate new products and production practices.

Determining Your Goal, Research Question and Treatments

Before establishing a research trial, you or your client must identify the goal or purpose for conducting the trial. Often, there is a question that you wish to answer such as:

- Will using product “X” increase my yield?
- Will production practice “Y” impact my plant date next spring?
- What rate of product “Z” will give me the best result?
- How does product “A” compare to product “B”?
- Will an application of product “C” pay for itself in yield gain at the end of the season?

Once a goal or a question has been identified, a treatment list can be designed to address the research question. A treatment can be defined as any imposed factor (i.e., seed treatment, growth regulator, variety, seeding rate, fungi-

cide application) that will potentially impact the answer to the question asked. One treatment in every trial likely will be some sort of control (i.e., current production practice) to allow for assessment of the new practice to the current practice. Additionally, the goal can determine what data should be collected during and after the season to answer the question (i.e., emergence, disease level, yield).

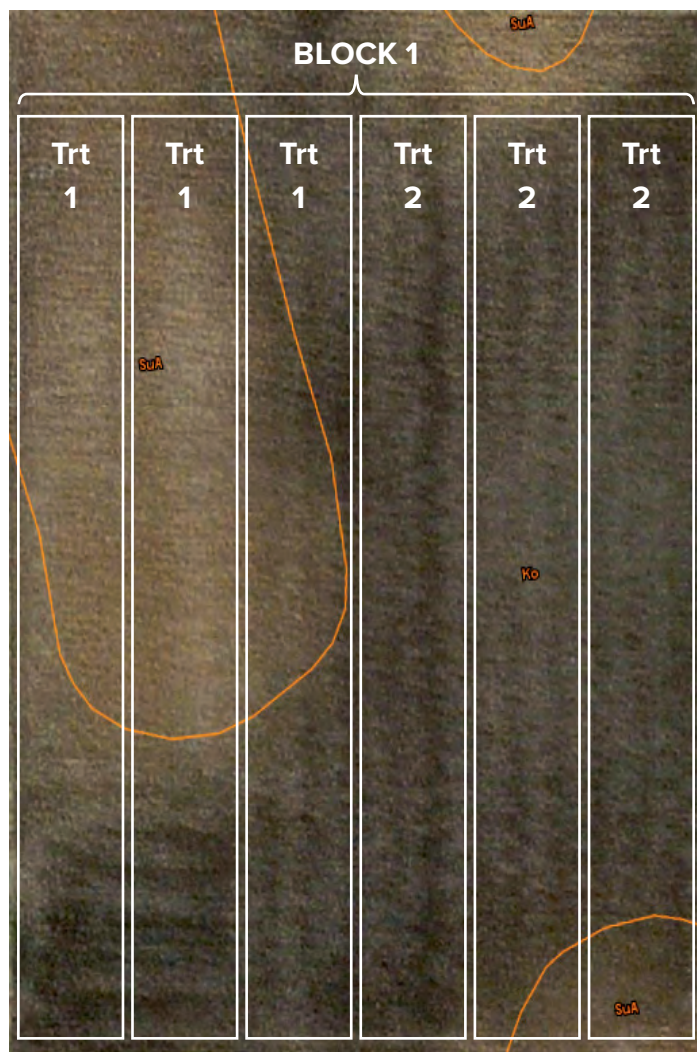
Typically, two to three treatments are adequate to answer the question of interest for most on-farm trials, but more treatments may be necessary depending on the question. For example, determination of the optimal application rate of a new product may require four or five treatments (control plus three to four different product rates). All other management factors for the trial should be kept constant to maximize your ability to detect the treatment effect. Multiple factor designs are more complex and can require more complex analysis methods. Manipulation of too many factors can also confound the results and make treatment effects more difficult to detect. Please consult with your local Extension agricultural educator or agronomist prior to implementation to ensure your trial and treatment design is adequate to address your question.

Trial Design and Replication are Key

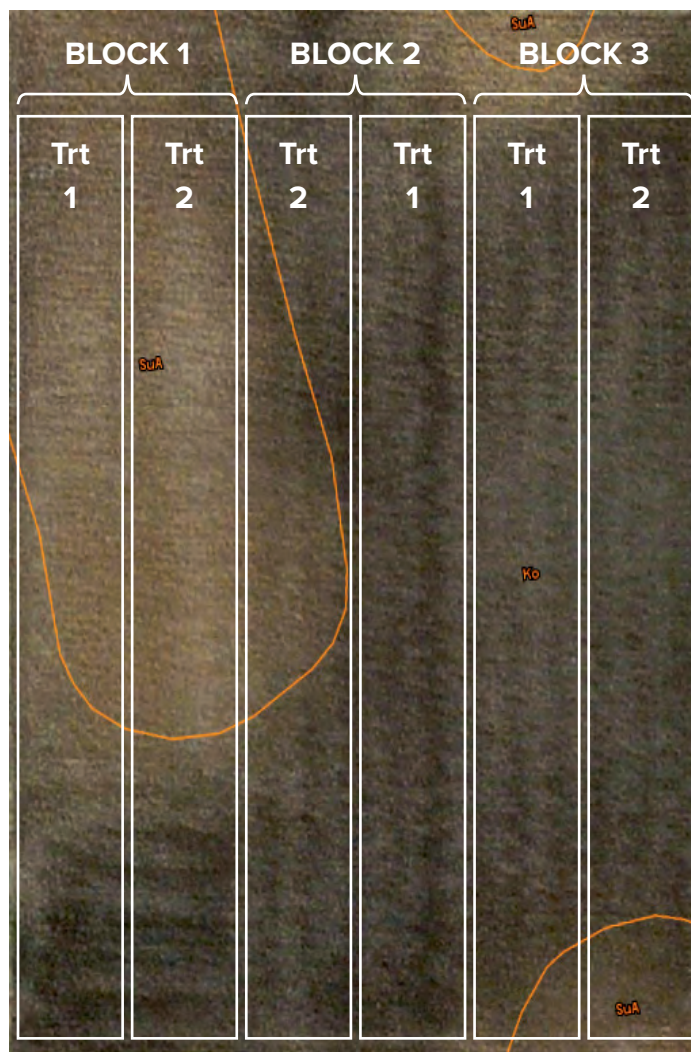
To be a valid study, the treatments need to be compared side-by-side within the same field (randomization) and repeated multiple times within the study (replication). Often it is helpful to have a baseline or control treatment, which is typically the current practice for comparison to the new proposed practice. Splitting a field in half and applying the same treatment in adjacent strips may be tempting, but this does not provide true randomization or replication (Figure 11-1A). Repeating a treatment within the same field half provides pseudo-replication, and each strip acts as a subunit within a larger treatment unit. Inherent differences within the field (i.e., slope, texture, cropping history) could also give one treatment a yield advantage that may be due to field variability rather than a true treatment effect. Randomizing your treatment passes within the same field will decrease the likelihood that unseen, or unplanned, factors such as environmental variability will affect your ability to detect true treatment differences (Figure 11-1B).

Figure 11-1. Each design contains three passes of each treatment (Treatments 1 and 2), but have major differences in the power of the data collected. **A)** Applying a treatment in adjacent strips may be easier, but inherent differences in the environment may give an advantage (bias) to one of the treatments. In this example, Treatment 1 was planted in an area with lighter soil and Treatment 2 was planted in a darker soil. Any differences between the treatments may be due to the soil properties rather than a treatment effect. This design provides **pseudo-replication** because there is one large group of each treatment made of three smaller passes, and is incorrect because it only provides one true block (field replication). **B)** Randomizing strips of each treatment within the same field reduces bias, and increases the likelihood of detecting treatment differences. Each treatment pair is a block or replicate.

A) An incorrect treatment layout. Each box represents one pass.



B) A correct treatment layout. Each box represents one pass.



Each group of treatments can be called a block in the field (Figure 11-1B). One of the most common designs implemented in field research is the Randomized Complete Block design (or RCBD), which means: each block (or replicate) contains a full set of treatments; the treatment order within each block is randomized; and the differences within the block between treatments is expected to be less than the differences between the blocks. Blocking also allows for some control of the environmental variability, which can increase the discernment of treatment differences. Each block should be planted at least three times to ensure adequate replication of each treatment. Replicating the blocks in multiple areas of the field will

allow you to evaluate the treatments in different microenvironments, and can increase your ability to use the information to make management decisions. In Figure 11-1B, Block 1 allows both treatments to be evaluated in the lighter soil type, and Block 3 allows for the same comparison in the darker soil type. The position of each treatment within each block is also randomized to decrease bias in the trial. Flipping a coin to determine treatment order in each block is a simple way to randomize your treatments in a two-treatment study. Additionally, there is an app that has been developed by researchers at The Ohio State University designed to help establish a randomized and replicated treatment design, organize on-farm trial data and allow

for real-time data entry, as well as perform some basic statistical analysis for an RCBD trial. The app is called Ohio State Precision Led On-Farm Trial Support, or Ohio State PLOTS for short, and is available for both iOS and Android devices (see “Chapter 12, Precision Agriculture,” for more information).

Designing your plot width to align with your treatment applicator (i.e., planter, tillage implement, sprayer) and harvester (combine swath, planter width) is an easy way to design a strip trial with minimal adjustments come evaluation time. Plot length should be predetermined and uniform across treatments. Differences in plot length can influence yield from that harvest pass, which could impact your results. Keeping strip length consistent will minimize this error. If the field is variable in its width due to a non-conventional shape, it is better to make the plot length of each strip the same as the smallest pass length to allow for fair comparisons. The increased use of georeferencing tools, such as GPS and yield mapping, may enable producers to maintain and mark plots without needing to physically mark them in the field.

So How Do I Make Sense of the Data?

Conducting on-farm research is most helpful when you can compare the treatments and make management decisions based on the results from the trial. Analyzing the data can help provide confidence that any observed differences are truly due to the treatment and not just chance. For more information regarding statistical terminology, as well as more information on why statistics can be used to help interpret data in agricultural research, please consult the 2016 Ohio State University fact sheet *Statistics and Agricultural Research* available at: **ohioline.osu.edu**. A spreadsheet tool such as Excel can be used to organize trial data as well as run some basic statistics, but the analysis capability of Excel is typically limited to a single trial in a single year. Completing multiple years of a trial across multiple fields can test a new product in a wide range of environments in a relatively short amount of time, but the analysis for this type of dataset is more complex.

Prior to conducting data analysis, please consult with your Extension agricultural educator or agronomist to ensure you are conducting the correct tests for the research goals and treatment design.

Excel can be used to calculate basic statistics, such as averages (mean), paired t-tests, variance and standard deviation. Additionally, the statistical values calculated by Excel can be used to determine the least significant difference (LSD) value for a trial. In versions of Excel 2003 and later, there is an Add-in option for Excel that enables you to conduct simple statistics using the Analysis ToolPak. In order to load the ToolPak into your specific version of Excel, search a phrase similar to “installing data analysis toolpak in Excel” in a search engine for step-by-step instructions. For newer versions of Excel, this can typically be achieved by going into the File >> Options >> Add-Ins; within the Add-Ins menu in the “Manage” box, select “Excel Add-ins” from the drop-down menu, and click “Go.” In this menu, select the “Analysis ToolPak” box and click “OK.” A new button should appear in the Data tab of toolbar within Excel (Figure 11-2).

Performing the Data Analysis—A Few Examples

The following example on-farm field trial will be used to demonstrate the use of Excel for analysis:

“Your trusted agricultural chemical salesperson in your area asked you to consider applying a new foliar product (Treatment B) this year to see if it increases the yield on your farm. He suggests you compare it to your current production practice (using Treatment A) to see if the new product will improve your yield beyond current levels. To do this, you alternate your passes with the sprayer to contain the treatments of interest (Figure 11-3). Sometimes the new product is on the north side, other times the new product is on the south side compared to the control (achieving randomization). At the end of the season, you harvest each pass separately and obtain the results presented in Table 11-1.”

Figure 11-2. The new “Data Analysis” ToolPak (circled) should appear in the Data tab of the toolbar.

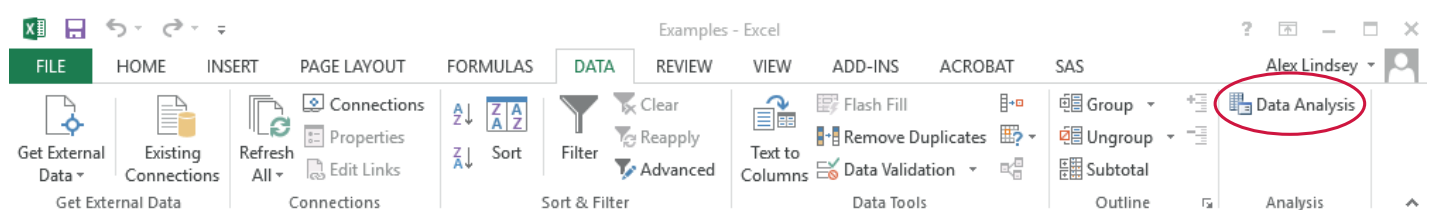


Figure 11-3. The test plot arrangement for comparison of a new foliar treatment (Trt B) to the known practice (Trt A) using a randomized complete block design.

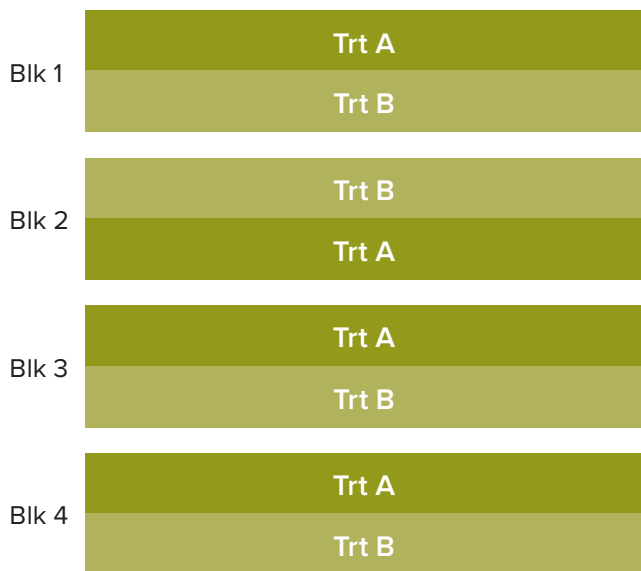


Table 11-1: Yield Data Obtained from an On-Farm Trial with Two Treatments and Four True Replications.

Block	Treatment A (control)	Treatment B
	Yield (bu/ac)	
1	47	45
2	46	50
3	51	60
4	48	57

Example 1: Paired t-Test Analysis

Step 1: Data Entry

Organizing your data is key to analyzing the data efficiently. For Excel, entering the values as seen in Figure 11-4 is a good way to manage the data and compare the results. In this example, each cell is the yield from one individual plot or strip from the field. Each row contains the yield from each block (or replicate) from the field, and each column contains the yield from each tested treatment.

Figure 11-4. Data entered into Excel for analysis.

	A	B	C
1	Yield (bu/a)		
2	Block	Trt A	Trt B
3	1	47	45
4	2	46	50
5	3	51	60
6	4	48	57

Step 2: Data Analysis

The next step is to use the correct analysis procedure to best interpret the results of the trial. For this research question, the objective was to determine if there was a yield difference between Treatment A and Treatment B. The first step is to calculate the average (or mean) yield of each treatment, which can be calculated using the equation shown in the top-right of Figure 11-5. In this example, a 5 bushels per acre yield difference was recorded between the two treatments. However, it is not clear if this difference is due to the application of Treatment B or if another uncontrolled factor like environmental variability was contributing to the yield difference. More statistical analysis can be conducted to determine the probability that the difference in yield was caused by a true treatment difference (rather than environmental variability).

Figure 11-5. The mean or average yield for the treatments in Example 1. The formula used for calculation of the average of Treatment A shown in the upper right.

	A	B	C	D
1	Yield (bu/a)			
2	Block	Trt A	Trt B	
3	1	47	45	
4	2	46	50	
5	3	51	60	
6	4	48	57	
7	Average	48	53	

A paired t-test can be used to calculate the probability that the yield difference observed was truly due to an imposed treatment. This test is available in the Data Analysis ToolPak described earlier in the chapter. To conduct a paired t-test, click the “Data Analysis” button in the “Data” tab shown in Figure 11-2. This should open a window with multiple statistical analysis choices, but the option of interest in this example is called “t-Test: Paired Two Sample for Means.” Select this option and click “OK” as shown in Figure 11-6A.

Figure 11-6. **A)** Select the “t-Test: Paired Two Sample for Means” option from the Data Analysis ToolPak. **B)** Complete the fields as shown to conduct the paired t-test analysis.

A)

	A	B	C	D	E	F	G	H	I
1		Yield (bu/a)							
2	Block	Trt A	Trt B						
3	1	47	45						
4	2	46	50						
5	3	51	60						
6	4	48	57						
7	Average	48	53						
8									
9									
10									
11									

The Data Analysis dialog box is open, showing a list of analysis tools. The option "t-Test: Paired Two Sample for Means" is highlighted at the bottom of the list. The OK button is being clicked.

B)

	A	B	C	D	E	F	G	H	I	J
1		Yield (bu/a)								
2	Block	Trt A	Trt B							
3	1	47	45							
4	2	46	50							
5	3	51	60							
6	4	48	57							
7	Average	48	53							
8										
9										
10										
11										
12										
13										
14										
15										

The t-Test: Paired Two Sample for Means dialog box is open. The fields are filled as follows:
 Variable 1 Range: B2:B6
 Variable 2 Range: C2:C6
 Hypothesized Mean Difference: (empty)
 Labels
 Alpha: 0.05
 Output Range: E1
 New Worksheet Ply:
 New Workbook

Once selected, a window will appear asking for cells to be selected for analysis (Figure 11-6B). In “Variable 1 Range” box, select the name of the first treatment and all the data for that treatment (in this case, Treatment A is cells B2-B6). Do the same for the “Variable 2 Range” box (Treatment B would be cells C2-C6). Be sure to check the box called “Labels” as well since the names of the treatments were selected. The “Alpha” value listed is the significance level for the trial, and defaults to a value of 0.05. A significance level (or alpha) of 0.05 indicates acceptance of a 5 percent probability that the differences observed are due to chance. Similarly, a significance level of 0.1 would indicate a 10 percent probability the differences observed were due to chance. Some research requires a low (conservative) probability of less than 0.05, especially if the treatment (new product or practice) cost is high. On-farm

research is sometimes less conservative, and a probability of less than 0.1 is considered acceptable. Certain studies, such as those with a low treatment cost are considered acceptable with a probability less than 0.2. For the following example, the Alpha level of 0.05 will continue to be used. In the “Output Range” box enter “E1” (Figure 11-6B), click “OK,” and the results of the paired t-test will appear within the same worksheet beginning in cell E1 (Figure 11-7).

The mean values shown in row 4 of Figure 11-7 are identical to the averages calculated in Figure 5. The probability generated by the paired t-test is shown in cell F13 in Figure 11-7. The two-tailed test probability should be considered because this simultaneously tests if yield increased and if yield decreased with the application of Treatment B. The probability using a one-tailed test shown in cell F11 only

allows you to determine if the yield after using Treatment B was greater than the control, but does not allow you to test if Treatment B decreased yield. The probability or P-value of 0.152 indicates there is a 15.2 percent chance the 5 bushels per acre yield difference between treatments was due solely to chance. Alternatively, the result could be stated that there is an 84.8 percent chance the yield difference observed was due to a true treatment difference. This 15.2 percent uncertainty could indicate that other factors, like environmental variability, contributed to the observed 5-bushel yield difference.

Figure 11-7. Results of the paired t-test analysis for Example 1.

	E	F	G
1	t-Test: Paired Two Sample for Means		
2			
3		<i>Trt A</i>	<i>Trt B</i>
4	Mean	48	53
5	Variance	4.667	46
6	Observations	4	4
7	Pearson Correlation	0.796	
8	Hypothesized Mean Difference	0	
9	df	3	
10	t Stat	-1.913	
11	P(T<=t) one-tail	0.076	
12	t Critical one-tail	2.353	
13	P(T<=t) two-tail	0.152	
14	t Critical two-tail	3.182	

Table 11-2: Yield Data Obtained from an On-Farm Trial with Two Treatments and Four True Replications.

Block	Treatment A (control)	Treatment B
Yield (bu/ac)		
1	45	50
2	47	52
3	52	56
4	48	54

Figure 11-8. Paired t-test analysis for the data presented in Table 2.

	E	F	G
1	t-Test: Paired Two Sample for Means		
2			
3		<i>Trt A</i>	<i>Trt B</i>
4	Mean	48	53
5	Variance	8.667	6.667
6	Observations	4	4
7	Pearson Correlation	0.965	
8	Hypothesized Mean Difference	0	
9	df	3	
10	t Stat	-12.247	
11	P(T<=t) one-tail	0.001	
12	t Critical one-tail	2.353	
13	P(T<=t) two-tail	0.001	
14	t Critical two-tail	3.182	

Using the same approach with the data shown in Table 11-2, the 5 bushel per acre yield difference still exists between Treatment A and B. However, there is less intrinsic variation among the replications (Figure 11-8). The paired t-test resulted in a probability value of 0.001 (cell F13), indicating there is only a 0.1 percent probability that the differences in treatment yield were due to chance. Although the same yield difference was observed between treatments in both Tables 11-1 and 11-2, the lower variance of the data in Table 11-2 resulted in greater confidence to say there was a true treatment difference. The paired t-test allows for more in-depth analysis of the results to provide additional information to help with future recommendations.

Example 2: Calculation of an LSD from an Experiment Using Randomized Complete Block Design

For a trial with three or more treatments, calculation of an LSD may help make comparisons among the treatment means. If the chemical salesperson asked you to try two new treatments against your known treatment, an LSD would enable you to compare the treatments to one another. For this example, we will use the data shown in Table 11-3.

Table 11-3: Yield Data from On-Farm Trial with Three Treatments and Four True Replications.

Block	Treatment A (control)	Treatment B	Treatment C
Yield (bu/ac)			
1	47	50	60
2	45	53	64
3	52	49	59
4	48	54	57

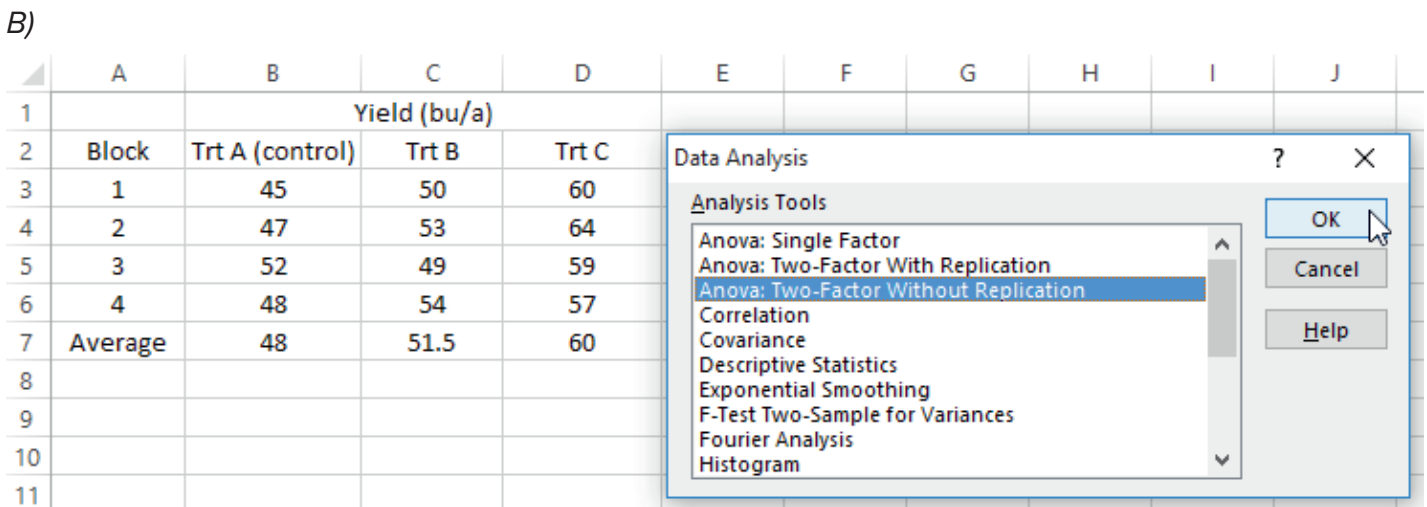
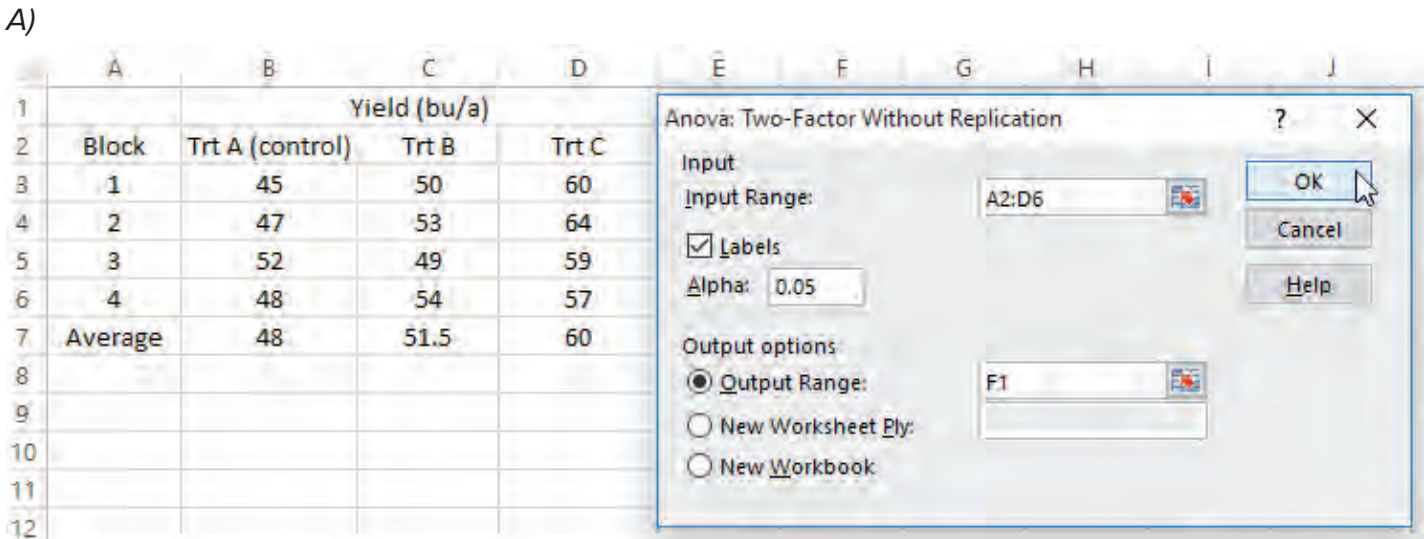
Step 1: Enter Data into Excel

Enter the data into Excel, as has been done in the previous example, using the rows as each block (or replicate) and the columns as each treatment.

Step 2: Conduct a Two-Way Analysis of Variance (ANOVA) Test

Once the data is entered, click the “Data Analysis” option shown in Figure 11-2. A box should appear showing multiple options of statistical tests to conduct, and for this example, select the option called “Anova: Two-Factor Without Replication” (Figure 9A). This option is appropriate for a RCBD because the “Two-Factor” refers to two factors of interest, which are block and treatment for this design. The “Without Replication” refers to “without replication in time or space,” which also means the data was collected from a single site in a single year. Once this option has been selected, click “OK.”

Figure 11-9. **A)** Select the “Anova: Two-Factor Without Replication” option. **B)** Input the values as shown for the “Input Range,” “Alpha” and “Output Range” boxes to generate an ANOVA table based on these results.



In the prompt window shown in Figure 11-9B, place the cursor in the “Input Range” box and select all cells from A2 through D6. Once completed, make sure the box next to the word “Labels” is checked. The Alpha denoted describes the significance level, and it defaults to 0.05. In the Output options, enter the “Output Range” as F1 to ensure the ANOVA table appears within the same worksheet. Once all this has been entered, click “OK,” and Figure 11-10 should be present in the Excel worksheet beginning in cell F1.

Figure 11-10. Results of the Two-Way ANOVA analysis given the data in Table 3.

	F	G	H	I	J	K	L
1	Anova: Two-Factor Without Replication						
2							
3	SUMMARY	Count	Sum	Average	Variance		
4	1	3	155	51.667	58.333		
5	2	3	164	54.667	74.333		
6	3	3	160	53.333	26.333		
7	4	3	159	53	21		
8							
9	Trt A (control)	4	192	48	8.667		
10	Trt B	4	206	51.5	5.667		
11	Trt C	4	240	60	8.667		
12							
13							
14	ANOVA						
15	Source of Variation	SS	df	MS	F	P-value	F crit
16	Rows	13.667	3	4.556	0.494	0.700	4.757
17	Columns	304.667	2	152.333	16.518	0.004	5.143
18	Error	55.333	6	9.222			
19							
20	Total	373.667	11				

The first table in Figure 11-10 shows the data from each row summarized (the four blocks for this example) followed by the data from each column summarized (the treatments for this example). The second table generated shows the results of the ANOVA analysis. In our data set, the “Source of Variation” called Rows is the blocks or replications, and the Columns represent the treatments evaluated. Contained in the “P-value” column of the second table is the probability that the differences recorded are due to chance. In this case, there is approximately a 70 percent probability that the differences between replications were caused by chance. Conversely, there was only a 0.4 percent probability the differences we observed in treatment were caused by chance. This gives us confidence that it is acceptable to calculate an LSD to compare the treatment means based on our trial results.

The final process is a step-by-step procedure to calculate the LSD for the trial:

1. **Locate the Mean Square for the Error (MSE) term from cell I18 (9.222) in Figures 11-10 and 11-11A.**
2. **Calculate the Standard Error of the Difference (SED) between two treatment means (Figure 11A).** This is completed by (1) multiplying the MSE by 2; (2) dividing by the number of blocks or replications (in this example 4); and (3) taking the square root of the entire value. This can be achieved with the formula “=SQRT(I18*2/4)” in this example, resulting in an SED of 2.147 (cell I22).
3. **Determine the Critical t-Value to use for the calculation (Figure 11B).** The critical t-value is different than the paired t-test conducted in Example 1 because it is not a direct probability measurement. A t-value is determined by two main components: the significance level; and the degrees of freedom (df) of the error term (found in cell H18 in Figure 11-10). The significance level can vary based on the trial type and desired confidence, and the degrees of freedom are determined by the number of plots, treatments, and replicates used in the trial. Because the research question is related to yield differences, the critical t-value from a two-tailed distribution is needed (tests for yield increase and decrease simultaneously). For this example, the significance level is set as 0.05, and the degrees of freedom value is 6. Entering the formula “=T.INV.2T(0.05,6)” results in a Critical t-Value of 2.447 (cell I23).
4. **Multiply the SED by the Critical t-Value to produce the LSD for the trial (Figure 11C).** Multiplying the SED (2.147, cell I22) by the Critical t-Value (2.447, cell I23) produces the LSD for the trial (5.25 bushels per acre, cell I24). The “(0.05)” following the LSD denotes the significance level for the trial. The value of 5.25 bushels per acre indicates the treatments that produced yield within 5.25 bushels per acre of one another are not statistically different. In this case, Treatment A and Treatment B produced similar yield to one another (48 and 51.5 bushels per acre, respectively), but Treatment C produced greater yield (60 bushels per acre) than both A and B.

Figure 11-11. **A)** Calculation of the SED between two treatments means using the ANOVA results. The formula used to calculate this value is shown in the formula bar in the upper right. **B)** Determination of the Critical t-Value using a two-tailed distribution with a significance level of 0.05 and the degrees of freedom (df) for the error from the ANOVA table. **C)** Calculation of the LSD at the 0.05 significance level by multiplying the Critical t-Value by the SED. The units of the LSD are the same as for the treatment means (in this case, bushels per acre).

A)

I22 : \times \checkmark f_x =SQRT(I18*2/4)

	F	G	H	I	J
1	Anova: Two-Factor Without Replication				
2					
14	ANOVA				
15	Source of Variation	SS	df	MS	F
16	Rows	13.667	3	4.556	0.494
17	Columns	304.667	2	152.333	16.518
18	Error	55.333	6	9.222	
19					
20	Total	373.667	11		
21					
22	Standard Error of the Difference (SED)			2.147	

B)

I23 : \times \checkmark f_x =T.INV.2T(0.05,6)

	F	G	H	I	J
1	Anova: Two-Factor Without Replication				
2					
14	ANOVA				
15	Source of Variation	SS	df	MS	F
16	Rows	13.667	3	4.556	0.494
17	Columns	304.667	2	152.333	16.518
18	Error	55.333	6	9.222	
19					
20	Total	373.667	11		
21					
22	Standard Error of the Difference (SED)			2.147	
23	Critical t-Value			2.447	

C)

I24 : \times \checkmark f_x =I22*I23

	F	G	H	I	J
1	Anova: Two-Factor Without Replication				
2					
14	ANOVA				
15	Source of Variation	SS	df	MS	F
16	Rows	13.667	3	4.556	0.494
17	Columns	304.667	2	152.333	16.518
18	Error	55.333	6	9.222	
19					
20	Total	373.667	11		
21					
22	Standard Error of the Difference (SED)			2.147	
23	Critical t-Value			2.447	
24	LSD (0.05)			5.25	

Summary

On-farm research can be extremely valuable to generate regionally or locally specific data, but each trial needs to be designed with a specific question in mind. Implementing randomization and replication is necessary to be able to interpret and use the data generated from on-farm trials. Additionally, blocking can help differentiate treatment effects from environmental variability during analysis. On-farm data can also be used to compare the locally generated data to other trials available (i.e., local demonstration plots, university data) to look for consistent trends and help validate any claims being made. Conducting basic statistical analysis will provide valuable information to help a producer or consultant make a local recommendation using data from on-farm research trials. The statistical analysis processes outlined here can be conducted using Excel to quickly analyze the data without purchasing a new software program, and can help provide more detailed information beyond an average value. Even if the trial is replicated and produced reliable data, the analysis procedures outlined are limited to specific trial designs and single site-years. Testing at multiple locations across multiple years may be a more reliable method to ensure detection of a treatment effect, but requires more complex analysis techniques. Please consult with your agronomist or Extension agricultural educator about conducting on-farm research if this is a topic of interest.

Chapter 12

Precision Agriculture

By Dr. John Fulton



PRECISION AGRICULTURE is a farming management concept based on observing, measuring, and responding to variability in crops. These variabilities contain many components that can be difficult to compute and quantify, as a result, technology has advanced to offset these challenges. Precision agriculture technology can generally be grouped into two categories: those which ensure accuracy, and those meant to enhance farming operations. Both technology categories can be used to efficiently aid in crop production. By combining accuracy and enhancement technologies, farmers are able to create a decision support system for an entire operation, thereby maximizing profits and minimizing excessive resource use.

Some of the crop production benefits being utilized by farmers today include:

- Reduced overlap areas leading to cost savings on seed.
- Improved overall machine and implement efficiency.
- Reduced operator fatigue.
- Increased operator visibility during harvest (able to see rows clearly) leading to increased field efficiency (especially at night).
- As-applied maps for field documentation, record keeping, and use in farm management information systems (FMIS) or other agricultural data management services.

In addition to cost cutting and energy consumption (both human and machine), precision agriculture technologies reduce environmental impacts of nutrient runoff which negatively affect water quality.

Precision Agriculture Technologies

Precision agriculture technologies provide multiple benefits to producers through input savings, improved time, labor and equipment management, and environmental benefits. Automatic-section control (ASC) technology, available for use on sprayers, planters, spreaders, and other application equipment, works by turning sections of application equipment on and off in areas where application has already occurred or off in unwanted areas (e.g., environmentally sensitive areas such as grassed waterways) (Figure 12-1).

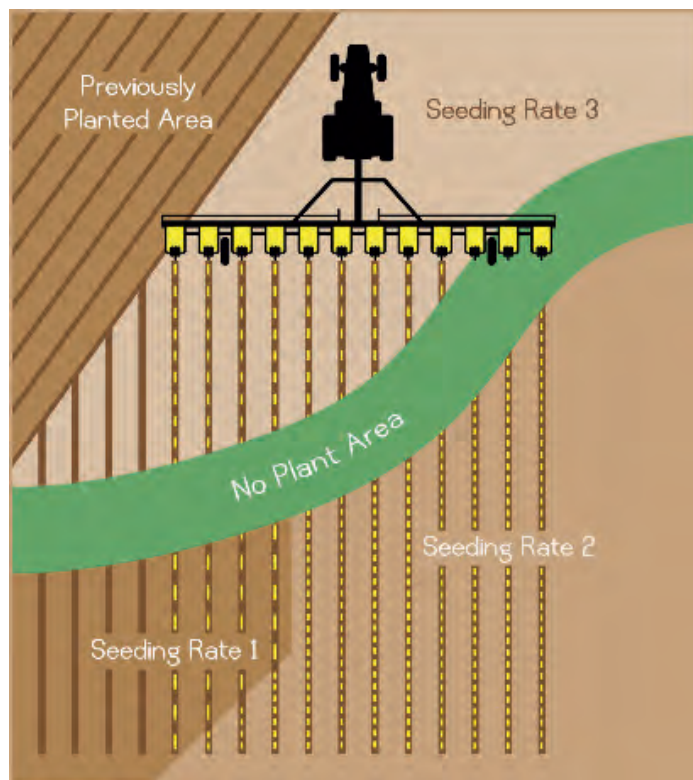


Figure 12-1. ASC technology on a planter.

Guidance systems, which reduce overlap and input usage, can on average save approximately 10 percent on input savings. Additional benefits of auto-guidance systems include reducing the concentration time needed during driving, leading to less fatigue and an increased ability to focus on other tasks.

Technologies such as autoguidance and autoswath provide quick, tangible benefits while other precision technologies (and site-specific practices) can offer paybacks but should be evaluated over several years. It can take time to evaluate and determine the value of particular practices such as variable-rate nitrogen and seeding.

Yield maps can be used not only to evaluate current and new management practices, but also as a data source for development of site-specific management strategies (e.g., management zones, variable-rate seeding and nutrient prescription maps, etc.). Further, the adoption of variable-rate technology to vary inputs can provide additional savings and yield benefits to producers.

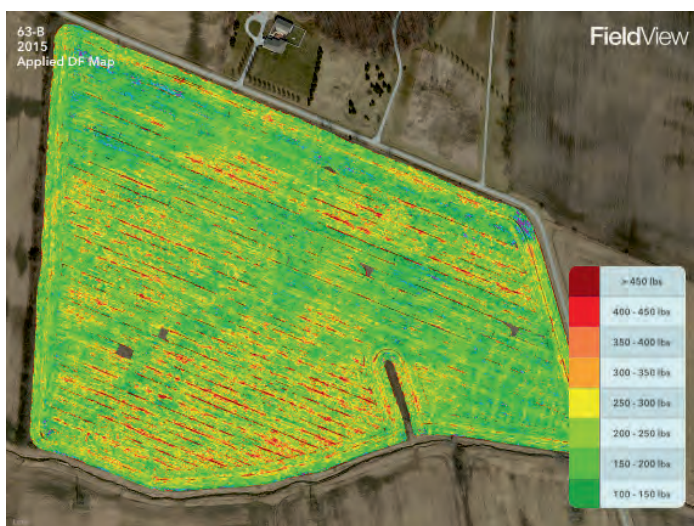
As-applied and as-planted maps are helpful in tracking input placement as well as input rates. Data can be used to determine, on a row-by-row feedback, down to a single seed, where inputs are being placed. Using singulation data, an operator can determine how seeds are being placed and if they are being placed accurately (Figure 12-2). Other forms of as-applied/as-planted data include downforce, planter speed, and multi-hybrid placement (Figure 12-3).

These analyses can be used to monitor input use which can help limit excessive placement of seeds, nutrients, and other inputs, but can also trigger the farmer to monitor or adjust equipment if needed to continue operating in an efficient manner.

Figure 12-2. A singulation map that shows where skips, multiples and good placement of seeds took place during planting.



Figure 12-3. An applied downforce map showing how much downforce is being applied to the ground from the planter at a given time.



Today, precision technologies enable farmers to conduct on-farm research more easily providing the ability to evaluate inputs, practices and other management strategies in order to determine value and most profitable return for

their operation. Specifically, the increased development and use of apps have become a useful tool to many farmers. By utilizing apps designed for on-farm data logging, note taking, and research, farmers have the ability to take their data and results into their own hands, making decisions based on hard numbers rather than guessing and hoping for better yields next year. One example of an app designed to aid in on-farm research is Ohio State PLOTS (Figure 12-4). In addition to Ohio State PLOTS, apps like Precision Planting's FieldView assist the grower in smart scouting by allowing the user to log, store, and map data collected on a field-by-field basis (Figure 12-5).

Figure 12-4. Ohio State PLOTS, an all-in-one on-farm research support app.

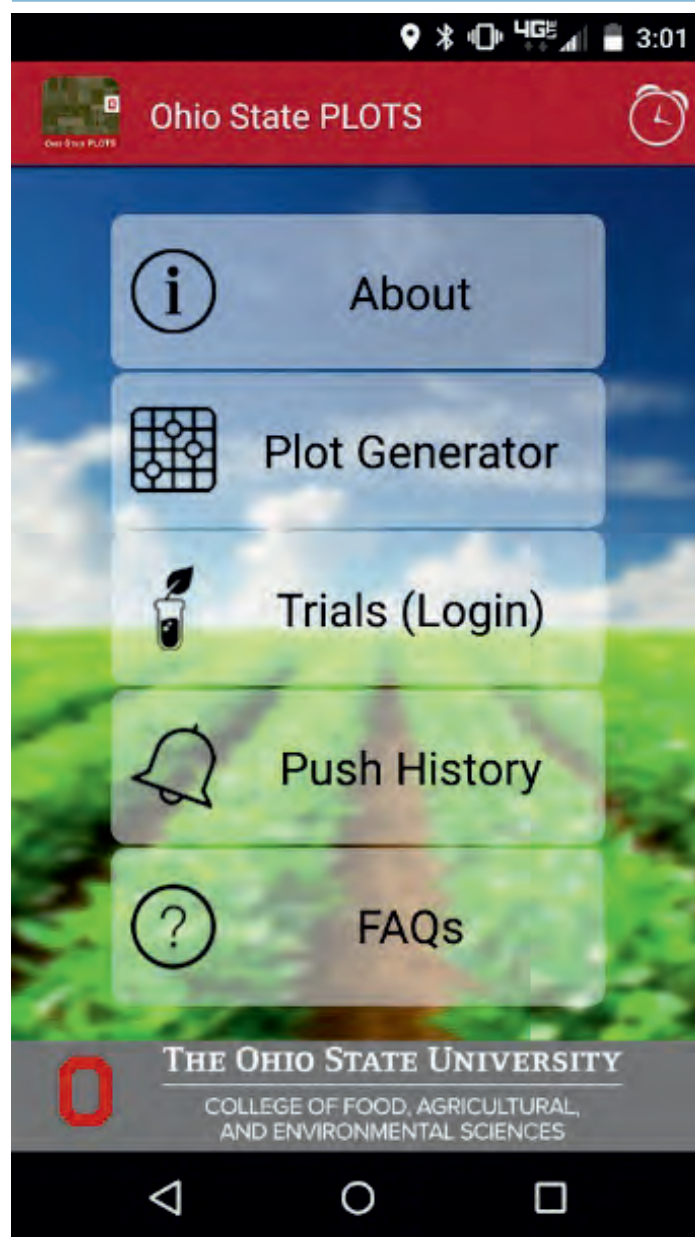
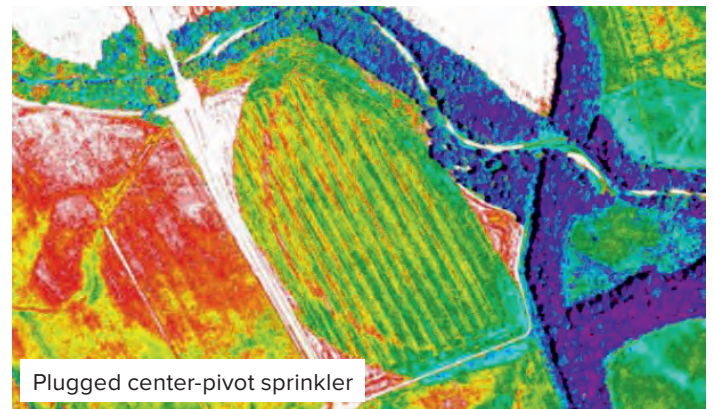


Figure 12-5. FieldView note-taking screen, allows the user to place georeferenced pins within a field and take scouting notes at each location.



Another precision agriculture technology that aids growers in crop production is the use of aerial imagery for decision making. Imagery options that include thermal, bare soil imagery, NDVI, and ADVI can be used alone or collectively to support on-farm decisions. For example, Figure 12-6 shows how NDVI imagery was used to remedy an in-field problem midway through the growing season. By looking at various images of fields throughout the growing season, growers can make real-time management decisions, or decisions that will have an impact on subsequent cropping seasons.

Figure 12-6. NDVI image from midseason shows a clogged center pivot irrigation system. Upon noticing the heavy red streaking (low vegetative density) in the field, the grower was able to assess the situation and remedy the problem.



Precision agriculture technologies provide a means to simply setup and execute on-farm research, providing valuable feedback to the farm operation. While PA technologies and practices can feel overwhelming and time consuming to adopt, newcomers should take it slow and adopt new technologies at a comfortable pace.

Benefits of Precision Agriculture

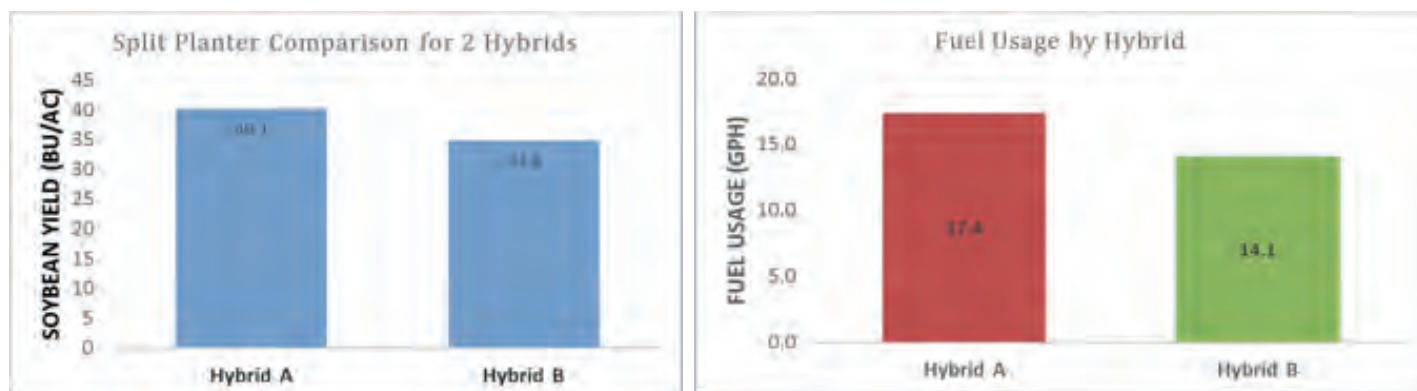
Auto-swath technology provides an average overlap reduction of 4.3 percent. When autoswath is coupled with autoguidance, overlap reduction can range from 3 to 35 percent (on a per field basis). These savings are dependent upon field size and shape with higher benefits occurring in large, irregularly shaped fields or fields containing conservation management structures such as grass waterways and terraces. Further, implementing autoswath or row-by-row On/Off control on planters can further provide yield and harvest loss advantages in corn. Average yield loss across double-planted areas can be 17 percent less in corn with a harvest loss factor of 8.7X in those same double planted areas. A properly adjusted combine will nominally have a loss of 1 bushel per acre so double planted areas could have an 8.7 bushels per acre harvest loss.

Additionally, machine data combined with yield data can be used to make crop production decisions, especially in subsequent cropping years.

Bringing the agronomic and machine data together could change decisions about hybrid selection (Figure 12-7). According to the above information, Hybrid A demonstrated about a 5 bushels per acre advantage; it was a green stem variety requiring more fuel and engine load to harvest. When determining which Hybrid (A or B) was a better choice, it is important to consider additional costs, such as fuel and engine load. While Hybrid A showed the higher yield, after factoring in additional costs, Hybrid B may have been the better choice for maximum return on investment.

Capturing machine data today through precision agriculture technology makes this type of analysis much easier and begins to provide a richer decision-making environment. This example also shows how precision agriculture data could begin to help farmers with decisions and thereby add value back to their farm.

Figure 12-7. A comparison of two hybrid soybean varieties and their respective fuel use, engine load and field capacity information during harvest.



	Moisture Content (%)	Ground Speed (mph)	Fuel Usage (gallons per acre)	Mean % Engine Load	Mean Field Capacity (ac/hr)
Hybrid A	14.8	2.8	1.71	86	10.2
Hybrid B	14.3	5.2	0.86	44	18.9

Appendix

English and Metric Conversion



English to Metric

Acres	X 0.405	= Hectares (ha)
Acres	X 4047	= Square meters
Cubic inches	X 16.39	= Cubic centimeters (cc)
Cup	X 236.5	= Milliliters (ml)
Feet	X 0.3048	= Meters (m)
Feet	X 30.48	= Centimeters (cm)
Fluid ounce	X 29.57	= Milliliters (ml)
Gallons	X 3,785	= Cubic centimeters (cc)
Gallons	X 3.785	= Liters (l)
Grains	X 0.0648	= Grams (g)
Inches	X 2.54	= Centimeters (cm)
Miles	X 1.69093	= Kilometers (km)
Ounces (dry)	X 28.3495	= Grams (g)
Ounces (liquid)	X 29.573	= Cubic centimeters (cc)
Pints	X 473	= Milliliters (ml)
Pints (liquid)	X 0.4732	= Liters (l)
Pounds	X 453.5924	= Grams (g)
Pounds	X 0.45359	= Kilograms (kg)
Pounds per acre	X 1.12	= Kilograms/hectare (kg/ha)
Quarts	X 946	= Milliliters (ml)
Quarts (liquid)	X 0.9463	= Liters (l)
Tablespoon	X 15	= Milliliters (ml)
Teaspoon	5	= Milliliters (ml)
Ton	X 907.1849	= Kilograms (kg)
Yards	X 0.9144	= Meters (m)

English to English

Acres	X 43,560	= Square feet
Acres	X 160	= Square rods
Acres	X 4,840	= Square yards
Bushels	X 2,150.42	= Cubic inches
Bushels	X 4	= Pecks
Bushels	X 1.25	= Cubic feet
Bushels	X 32	= Quarts
Cord (4' x 4' x 8')	X 8	= Cord feet
Cord foot (4'x4'x1')	X 16	= Cubic feet
Cubic foot	X 1,728	= Cubic inches
Cubic foot	X 0.03704	= Cubic yards
Cubic foot	X 7.4805	= Gallons
Cubic foot	X 29.92	= Quarts (liquid)

Cubic yards	X 27	= Cubic feet
Cubic yards	X 46,656	= Cubic inches
Cubic yards	X 0.7646	= Cubic meters
Cubic yards	X 202	= Gallons
Cubic yards	X 807.9	= Quarts (liquid)
Cup	X 8	= Fluid ounces
Cup	X 0.25	= Quarts
Cup	X 16	= Tablespoons
Cup	X 48	= Teaspoons
Degree Celsius +18	X 1.8	= Degree Fahrenheit
Degree Fahrenheit -32	X 0.5555	= Degree Celsius
Fathom	X 6	= Feet
Feet	X 12	= Inches
Feet	X 0.33333	= Yards
Feet per minute	X 0.01667	= Feet per second
Feet per minute	X 0.01136	= Miles per hour
Fluid ounce	X 2	= Tablespoons
Fluid ounce	X 6	= Teaspoons
Furlong	X 40	= Rods
Gallons	X 0.1337	= Cubic feet
Gallons	X 231	= Cubic inches
Gallons	X 128	= Ounces (liquid)
Gallons	X 4	= Quarts (liquid)
Gallons of water	X 8.3453	= Pounds of water
Hundred wt (cwt.)	X 100	= Pounds
Inches	X 0.08333	= Feet
Inches	X 0.02778	= Yards
Miles	X 5,280	= Feet
Miles	X 320	= Rods
Miles	X 1,760	= Yards
Miles per hour	X 88	= Feet per minute
Miler per hour	X 1.467	= Feet per second
Miles per minute	X 88	= Feet per second
Miles per minute	X 60	= Miles per hour
Ounces (dry)	X 0.0625	= Pounds
Ounces (liquid)	X 1.805	= Cubic inches
Ounces (liquid)	X 0.0078125	= Gallons
Ounces (liquid)	X 0.03125	= Quarts (liquid)
Ounces	X 16	= Drams

Pecks	X 0.25	= Bushels
Pecks	X 537.605	= Cubic inches
Pecks	X 8	= Quarts (dry)
Pints	X 28.875	= Cubic inches
Pints	X 2	= Cups
Pints	X 0.125	= Gallons
Pints	X 32	= Tablespoons
Pints (dry)	X 0.015625	= Bushels
Pints (dry)	X 33.6003	= Cubic inches
Pints (dry)	X 0.0625	= Pecks
Pints (dry)	X 0.5	= Quarts (dry)
Pints (liquid)	X 28.875	= Cubic inches
Pints (liquid)	X 0.125	= Gallons
Pints (liquid)	X 16	= Ounces (liquid)
Pints (liquid)	X 0.5	= Quarts (liquid)
Pounds	X 7,000	= Grains
Pounds	X 16	= Ounces
Pounds	X 0.0005	= Tons
Pounds of water	X 0.01602	= Cubic feet
Pounds of water	X 27.68	= Cubic inches
Pounds of water	X 0.1198	= Gallons
Quarts (dry)	X 0.03125	= Bushels
Quarts (dry)	X 67.20	= Cubic inches
Quarts (dry)	X 0.125	= Pecks
Quarts (dry)	X 2	= Pints (dry)
Quarts (liquid)	X 57.75	= Cubic inches
Quarts (liquid)	X 0.25	= Gallons
Quarts (liquid)	X 32	= Ounces (liquid)
Quarts (liquid)	X 2	= Pints (liquid)
Rods	X 16.5	= Feet
Square feet	X 0.0000229	= Acres
Square feet	X 144	= Square inches
Square feet	X 0.11111	= Square yards
Square inches	X 0.00694	= Square feet
Square miles	X 640	= Acres
Square miles	X 27,878,400	= Square feet
Square miles	X 3,097,600	= Square yards
Square yards	X 0.0002066	= Acres
Square yards	X 9	= Square feet
Square yards	X 1,296	= Square inches
Tablespoon	X 3	= Teaspoons
Tablespoon	X 0.5	= Fl. ounces
Teaspoon	X 0.17	= Fl. ounces
Ton	X 32,000	= Ounces
Ton (long)	X 2,240	= Pounds
Ton (short)	X 2,000	= Pounds
Yards	X 3	= Feet

Yards	X 36	= Inches
Yards	X 0.000568	= Miles

Metric to Metric

Centimeters	X 0.01	= Meters
Centimeters	X 10	= Millimeters
Grams	X 0.001	= Kilograms
Grams	X 1,000	= Milligrams
Kilogram	X 1,000	= Grams
Liters	X 0.001	= Cubic centimeters
Meters	X 100	= Centimeters
Meters	X 0.001	= Kilometers
Meters	X 1,000	= Millimeters
Square meters	X 0.0001	= Hectares
Cubic meters	X 1,000,000	= Cubic centimeters

Metric to English

Centimeters	X 0.3937	= Inches
Cubic centimeter	X 0.061	= Cubic inches
Cubic meters	X 1.308	= Cubic yards
Cubic meters	X 35.31	= Cubic feet
Cubic meters	X 61,023	= Cubic inches
Cubic meters	X 264.2	= Gallons
Cubic meters	X 1,057	= Quarts (liquid)
Grams	X 15.43	= Grains
Grams	X 0.0353	= Ounces
Grams/liter	X 1,000	= Parts per million
Hectares	X 2.471	= Acres
Kilograms	X 2.205	= Pounds
Kilograms/hectare	X 0.8929	= Pounds per acre
Kilometers	X 3,281	= Feet
Kilometers	X 0.6214	= Miles
Kilometers	x 1,094	= Yards
Knot	X 6,086	= Feet
Liters	X 1,000	= Cubic centimeters
Liters	X 0.0353	= Cubic feet
Liters	X 61.02	= Cubic inches
Liters	X 0.2642	= Gallons
Liters	X 1.057	= Quarts (liquid)
Liters	X 0.908	= U.S. dry quart
Meters	X 3.281	= Feet
Meters	X 39.37	= Inches
Meters	X 1.094	= Yards
Milliliter	X 0.034	= Fluid ounces

Useful Tables: Adjustments and Conversions

Soybean Moisture Conversions

% Moisture	Pounds per Bu	% Moisture	Pounds per Bu
7.0	56.13	14.0	60.70
7.5	56.43	14.5	61.05
8.0	56.74	15.0	61.41
8.5	57.05	15.5	61.77
9.0	57.36	16.0	62.14
9.5	57.68	16.5	62.51
10.0	58.00	17.0	62.89
10.5	58.32	17.5	63.27
11.0	58.65	18.0	63.66
11.5	58.98	18.5	64.05
12.0	59.32	19.0	64.44
12.5	59.66	19.5	64.84
13.0	60.00	20.0	65.25
13.5	60.35		

lbs dry = [(100 percent - wet percent) / (100 percent - dry percent)] x pounds of wet grain.

EXAMPLE: Convert 3,000 pounds of 18 percent moisture beans to 13.0 percent moisture:

$[(100\% - 18\%) / (100\% - 13\%)] \times 3,000 \text{ lbs} = 82/87 \times 3,000 \text{ lbs} = 0.942 \times 3,000 \text{ lbs} = 2827.5 \text{ pounds at 13 percent.}$

Atomic Weights of Nutrients

Element		Atomic Weight
N	Nitrogen	14.01
P	Phosphorus	30.98
K	Potassium	39.10
Ca	Calcium	40.08
Mg	Magnesium	24.31
S	Sulfur	32.06
Cu	Copper	63.54
Fe	Iron	55.85
Mn	Manganese	54.94
Zn	Zinc	65.37
B	Boron	10.82
Cl	Chlorine	35.46
Mo	Molybdenum	95.94
O	Oxygen	16.00
C	Carbon	12.01
H	Hydrogen	1.01

Water = H₂O = 2 * 1.01 + 16.0 = 18.1

	Percentage
Boron Materials	
Borax	11
Boron Frits	2–6
Boric Acid	17
Fertilizer Borate-46	14
Fertilizer Borate-65	21
Solubor	20
Zinc Materials	
Zinc Sulfate	35
Zinc Oxide	78–80
Organic Zinc Complexes	5–12
Zinc Chelates	9–14
Zinc Frits	Varies
Manganese Materials	
Manganese Sulfate	25–28
Organic Manganese Complexes	5–12
Manganese Chelate	5–12
Manganese Frits	10–25
Iron Materials	
Ferrous Sulfate	19–21
Ferric Sulfate	23–27
Iron Chelates	5–15
Organic Iron Complexes	5–12
Iron Frits	30–40
Copper Materials	
Copper Sulfate	13–53
Cupric Oxide	75
Cuprous Oxide	89
Copper Chelate	9–13
Copper Frits	40–50
Organic Copper Complexes	5–7
Molybdenum Materials	
Ammonium Molybdate	54
Sodium Molybdate	39
Molybdenum Frits	2–3

Bushels, Test Weights and Calculations

How and why grain test weight is used in the grain market and how producers can assure acceptable test weights from their crop production program are explained here.

Bushel is a volume measurement for grain created many years ago by Celtic peoples (Scotland, Wales, Brittany, Ireland) to facilitate fair grain trade. The bushel measurement was not defined in terms of cubic feet, but it is currently considered to be about 1.25 cubic feet in volume. Although grain is referred to in terms of bushels in the United States, it is referenced and traded on the basis of weight (tons or metric tons) throughout the rest of the world. To facilitate the trading of grain, the USDA created weight standards for each grain so that grain could be weighed to determine the number of bushels rather than trying to make volume measurements. Corn was assigned a bushel weight of 56 pounds, while soybeans and wheat were assigned bushel weights of 60 pounds. Some other examples are rye = 56 pounds per bushel, barley = 48, oat and fescue = 32, etc.

The **test weight** concept was developed many years ago by the grain trade as a means of accounting for the varying densities of grain caused by weather and/or production practices. When grain density is lower than the accepted standard (low test weight), more volume is needed to store and transport a given weight of grain, thus increasing storage and transport costs. Different grades of each grain have different standard test weights. No. 2 yellow corn has a standard of 56 pounds per bushel, while No. 3 yellow corn has a lower weight. Test weight is determined on each load of grain sold by weighing a known volume of the grain. If the weight is lower than the acceptable range, the sale is docked on a percentage basis. The seller of grain with test weight greater than the acceptable range is usually not rewarded for a superior product.

Varieties of a crop often vary in their inherent test weight. Two common causes of low test weights are:

- Grain is prevented from filling completely and/or maturing and drying naturally in the field due to a killing frost, hail, or insect damage.
- When this happens, the starch molecules inside the grain are prevented from the natural process of shedding absorbed water molecules that allows the grain to shrink to a normal size. Artificial drying with heat removes this excess water, but the starch molecules do not shrink, and grain size does not change appreciably, so test weight (density) remains low.
- Grain matures and dries naturally in the field but is re-wetted by rainfall, dew or fog, causing the grain to initiate the germination process (precocious germination) before harvesting.

During germination, oil, starch and protein are digested to provide energy and molecules to produce a new seedling. This process leaves small voids inside the grain. Although the grain may again dry in the field, the seed size does not change, and the small voids inside the seed result in a decreased test weight. Maximum test weight is achieved when grain is harvested on the first dry-down and also at higher moisture. For example, the ideal harvest moisture for soybeans and corn is 16 to 19 percent moisture and 20 to 25 percent moisture, respectively.

Grain is seldom sold at the standard moisture content (soybean = 13 percent, corn = 15.5 percent). When grain moisture content is greater than the standard, the grain weight is discounted to account for the extra moisture ac-

ording to the formula: (100 percent - wet percent) divided by (100 percent - dry percent). For a sample of soybeans at 18 percent moisture, the calculation would be: $(100 - 18)$ divided by $(100 - 13) = 82/87 = 0.94$. Multiplying the weight of the wet grain by 0.94 will give the weight of the grain at 13 percent moisture. For example: 6,000 pounds of soybeans at 18 percent grain moisture would become 5,640 pounds of grain at 13 percent moisture ($6,000 \times 0.94 = 5,640$).

If grain is dryer than the standard, that same equation can be used to calculate the increased weight that should be credited the seller, although that calculation is seldom made, and the seller is not usually rewarded for the low-moisture content. This calculation works for any grade of any grain for which the standard moisture content is specified.

Ohio State University Websites

General Agronomy

General agronomic information from the Ohio State University AgCrops Team can be found at agcrops.osu.edu.

Timely Updates—C.O.R.N. newsletter

For timely updates regarding agronomic crops in Ohio, subscribe to the free digital C.O.R.N. newsletter. The newsletter is available at: corn.osu.edu.

Crop Performance Trials for Corn, Soybean, Wheat and Alfalfa can be found at: u.osu.edu/perf.

Soil Fertility

Information about soil testing and analysis, developing nutrient recommendations and other general soil fertility information can be found at: agcrops.osu.edu/FertilityResources.

Corn Production

General corn production information can be found at: agcrops.osu.edu/specialization-areas/corn.

Soybean and Wheat Production

General soybean and wheat production information can be found at: stepupsoy.osu.edu.

Forage Production

General forage production information can be found at: agcrops.osu.edu/specialization-areas/forages.

Ohioline Fact Sheets

Ohio State University Extension fact sheets about various agronomic crops topics can be found at: ohioline.osu.edu.

Ohio Field Crop Insects

Information on corn, soybean, wheat and alfalfa insects and insecticides can be found at: www.oardc.ohio-state.edu/ag/.

Weed Science

Information on weed identification, control and other recommendations can be found at: u.osu.edu/osuweeds/.

Ohio Field Crops Precision Ag

Information on precision ag can be found at: fabe.osu.edu/programs/precisionag.