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Cropping Systems

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Two crops—corn and soybeans—have come to dominate the cultivated area of Illinois over the past 60 years, moving from 60% of cropped acres in 1950 to more than 90% in recent years (**Figure 5.1**). Wheat acreage declined by about half during this period, to about 1 million acres, while the number of acres used to produce livestock feed—oats and hay—has declined by almost 90%, down to less than 750 thousand acres. These shifts were due largely to the reduction in livestock numbers in Illinois. Much of the corn and soybeans produced in Illinois is exported to other states and to other countries.

Soybean acreage reached current levels during the 1970s, and though corn acreage has remained slightly higher than soybean acreage, most fields in Illinois have been managed as a 2-year corn–soybean rotation. In the past few years, corn acreage has increased at the expense of soybean acreage, and as a result there is more corn following corn in Illinois. Although there is little evidence to suggest that the 2-year rotation common in Illinois is less stable than cropping systems common elsewhere, some producers are interested in trying alternatives in an attempt to spread risks and to learn about other possible uses of the land they farm. So far, few alternatives have proven themselves to be economically viable, at least on large acreages.

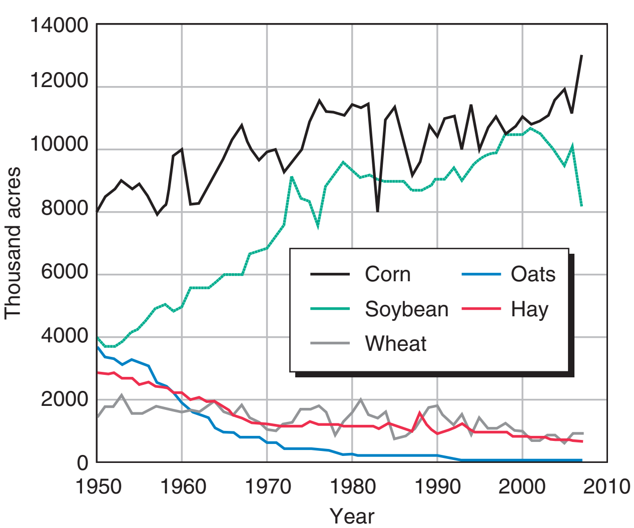

Figure 5.1. Crop acreage in Illinois, 1950 through 2007. Source: National Agricultural Statistics Service.

Cropping System Definitions

The term *cropping system* refers to the crops and crop sequences and the management techniques used on a particular field over a period of years. This term is not a new one, but it has been used more often in recent years in discussions about sustainability of our agricultural production systems. Several other terms have also been used during these discussions:

- **Allelopathy** is the release of a chemical substance by one plant species that inhibits the growth of another species. It has been proven or is suspected to cause yield reductions when one crop follows another of the same family—for example, when corn follows wheat. Technically, damage to a crop from following itself (such as corn following corn) is referred to as *autotoxicity*. In many cases the actual cause of such yield reduction is not well understood, but it is generally thought that the breakdown of crop residue can release chemicals that inhibit the growth of the next crop. So keeping old-crop residue away from new-crop roots and seedlings should help to minimize such damage.
- **Double-cropping** (also known as sequential cropping) is the practice of planting a second crop immediately following the harvest of a first crop, thus harvesting two crops from the same field in one year. This is a case of *multiple cropping*, which requires a season long enough and crops that mature quickly enough to allow two harvests in one year.
- **Intercropping** is the presence of two or more crops in the same field at the same time, planted in an ar-

rangement that results in the crops competing with one another.

- **Monocropping,** or **monoculture,** refers to the presence of a single crop in a field. This term is often used to refer to growing the same crop year after year in the same field; this practice is better described as *continuous cropping*, or continuous monocropping.
- **Relay intercropping** is a technique in which different crops are planted at different times in the same field, and both (or all) crops spend at least part of their season growing together in the field. An example would be dropping cover-crop seed into a soybean crop before it is mature.
- **Strip cropping** is the presence of two or more crops in the same field, planted in strips such that most plant competition is within each crop rather than between crops. This practice has elements of both intercropping and monocropping, with the width of the strips determining the degree of each.

Crop rotations, as a primary aspect of cropping systems, have received considerable attention in recent years, with many people contending that most current rotations are unstable and (at least indirectly) harmful to the environment and therefore not sustainable. Many proponents of "sustainable" agriculture point to the stability that accompanied the mixed farming practices of the past, in which livestock played a key role in utilizing crops produced and in returning manure to the fields. Such systems can still work well, but reduced livestock numbers, fewer producers, and increased crop productivity have meant that such systems are likely to work well for a relatively small segment of Illinois agriculture.

Corn and Soybean in Rotation

The corn–soybean rotation (with only one year of each crop) is still by far the most common one in Illinois. This crop sequence offers several advantages over growing either crop continuously. These advantages have been affected by the development of glyphosate-tolerant corn and soybean (which has tended to lessen the advantages of rotation with regard to weed control) and by the development of Bt-rootworm hybrids in corn (which has lessened the disadvantage in cost of control, and possibly in loss of yield, historically tied to rootworm control in continuous corn). The rotation with soybean reduces nitrogen fertilizer rate compared to continuous corn, but today the perceived disadvantage for continuous corn is less of an incentive to rotate than it has been in the past.

Even with the shifts in management options, most current data continue to suggest that yields of corn following

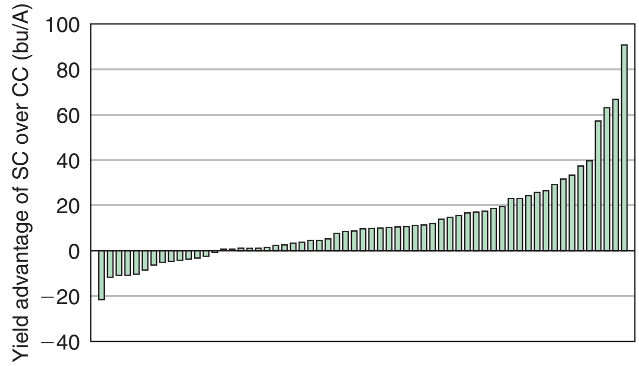

Figure 5.2. Yield advantage of corn following soybean over corn following corn in 62 trials in Illinois from 1999 through 2007.

soybean (SC) tend to be higher than yields of corn following corn (CC). **Figure 5.2** shows the yield difference between SC and CC over some 60 trials conducted over the past decade in different Illinois locations. While there is considerable variation over years and environments, CS averaged about 8% more yield than did CC. The four large yield differences in favor of SC on the right side of the figure are from locations where CC did relatively poorly, for reasons that might have included inadequate control of corn rootworm and a particular pattern of dryness. Such yield differences have diminished in the past four years, and it is possible that the use of Bt for rootworm, or of hybrids improved in other ways, will mean much less incidence of such loss. Without those four sites, SC yielded only about 5% more than CC.

Considerable effort has gone into trying to explain the yield increases found when corn and soybean are grown in sequence instead of continuously. One factor is the effect of residue on nitrogen (N) supply. Corn crop residue (stalks, leaves, and cobs) has low N content, so microbes take up N from the soil as they break down this residue from the previous crop, thus tying up some soil N and reducing the amount available to the next crop. Soybean residue is lower in quantity than corn residue, and it has a much higher N content. The breakdown of soybean residue, therefore, ties up little or no N, leaving more for the following corn crop.

Trials in which residues of previous crops have been removed or added back in different amounts have generally shown that removing corn residue after harvest partially removes the negative effects of corn as the crop that precedes corn (**Figure 5.3**). Removing the soybean residue before planting corn did not affect yield, and adding corn residue back after removing soybean residue decreased yield somewhat. Much of the positive effect of soybean on corn in the corn–soybean rotation seems to be related to the fact that soybean residue is low in quantity and, as measured by its relatively low C:N ratio, higher in quality

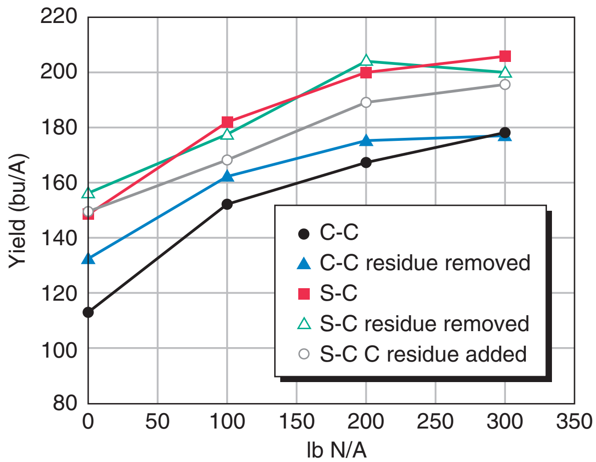

Figure 5.3. Effects of the previous crop and crop residue on corn yield and response to N rate. Data are from a 2-year study at Urbana.

than the residue from corn. Low amounts of residue mean less effect on soil temperature and moisture in the spring, and low C:N ratio means less tie-up of N as the residue breaks down. It is also likely that corn residue carries diseases to the following corn crop while soybean residue does not. Attempts to prove this with individual diseases, however, have not been very successful.

Soybean is usually grown following corn, but because of relatively better income expected from soybean or because of unusual circumstances such as very late planting or application of the wrong herbicide, soybean occasionally is grown following itself. In the rotation and residue study just described, soybean following soybean yielded 45 bushels per acre, while soybean following corn yielded 47, or about 2 bushels per acre more. Removing soybean residue increased the yield of the following soybean crop by less than 2 bushels per acre, but removing corn residue decreased yield of the following soybean crop slightly, as did adding corn residue back to soybean residue before planting soybean following soybean. From these results, we can only conclude that the causes of the "rotation effect" are complex, making it difficult to assign parts of the effect to specific causes.

Regardless of the mechanisms involved, the corn–soybean rotation has worked well during the time it has prevailed in much of the Midwest. From a standpoint of stability and optimal fit within a complex cropping system, a rotation as simple and short-term as this may not be ideal in the long run. Some contend that the growth requirements and other features of corn and soybean crops are so similar that the 2-year corn–soybean rotation does not constitute a crop rotation, at least in the normal sense of the word. Given the clear influence of each crop on the other, it is difficult to accept that conclusion. The corn–soybean rotation is, however, much less complex than are the multiple-crop rotations seen in many parts of the world. But most cropping systems develop problems over time, and there is little evidence that the corn–soybean system is more prone to problems than are longer-term, more complex rotations, especially rotations that do not include extended periods of forage legumes in the field.

The corn–corn–soybean (CCS) rotation represents one way for producers to increase corn acreage but still retain some benefits of the corn–soybean rotation. In fact, some research has shown that soybeans tend to yield more if they follow more than a single year of corn; in a study over three locations in Minnesota and Wisconsin, soybean following 5 years of corn yielded about 10% more than soybean rotated with corn in a 2-year sequence, which in turn yielded about 10% more than continuous soybean. **Table 5.1** gives the results of a 4-year study over six locations in Illinois. The second corn crop in the CCS rotation yielded 5 to 6 bushels per acre more than continuous corn, while the first year of corn in CCS yielded about the same as corn in the soybean–corn (SC) rotation in the northern locations, and due perhaps to variation among years, a little less than SC in southern Illinois. Soybean following 2 years of corn yielded about 3 bushels more than soybean following a single year of corn. As a result, the CCS rotation outperformed the SC rotation, at least at prevailing prices.

One frequent question is whether input costs can be reduced by using longer-term, more diverse crop rotations. Studies into this question have compared continuous corn and soybean and the corn–soybean rotation with rotations lasting 4 or 5 years that contain small grains and legumes either as cover crops or as forage feed sources. Like the

Table 5.1. Yields of corn and soybean in a study comparing continuous corn with corn–soybean and corn–corn–soybean rotations.

Crop and rotation	Yield (bu/A): 12 northern Illinois sites	Yield (bu/A): 7 southern Illinois sites
Corn		
Continuous corn	178	139
Corn–soybean	197	149
1st-yr corn in corn–corn–soy	196	144
2nd-yr corn in corn–corn–soy	184	145
Significance	*	NS
Soybean		
Corn–soy	54.9	53.0
Corn–corn–soy	58.3	56.0
Significance	*	NS

Data are from 2004 through 2007.

corn–soybean rotation, certain longer rotations can reduce pest control costs, while including an established forage legume can provide considerable nitrogen to a succeeding corn crop. At the same time, most of the longer-term rotations include forage crops or other crops with smaller, and perhaps more volatile, markets than corn and soybean. Lengthening rotations to include forages will be difficult unless the demand for livestock products increases. Such considerations will continue to favor production of crops such as corn and soybean.

Continuous Corn

With recent trends of corn yields increasing faster than soybean yields and with the price tending to favor corn slightly, the number of acres of corn following corn has risen in Illinois, and some producers have most, if not all, of their fields in corn every year. Though corn yields tend to be lower following corn than following soybean, many producers believe that they can manage continuous corn to produce yields as high as those of corn rotated with soybean. This is especially true in areas with the corn rootworm variant that lays eggs in soybean fields; in east-central Illinois, for example, many producers report yields of continuous corn as high as, or higher than, yields of corn following soybean.

To see whether increasing input levels might produce higher yields of continuous corn, we ran a study over several sites and several years on continuous corn. **Table 5.2** has data over years for these sites. In most cases, increasing the depth or amount of tillage had little effect on yield, though at Monmouth, where we used the modified mini-moldboard plow, it produced a yield increase. Added fertilizer sometimes increased yields, but seldom by enough to pay the added cost. And increasing the plant population from high (32,000) to very high (40,000) often decreased yield and seldom increased it. These results suggest that continuous corn, while it needs adequate inputs, does not typically respond very much to raising inputs to very high levels or to combinations of high inputs.

Corn residue can represent a challenge to corn that follows corn. With the possibility that corn residue might be harvested to produce cellulosic ethanol or other energy forms in the future, we initiated a study on the effects of residue removal on the response to tillage and N rate. **Figure 5.4** shows results averaged over 8 site-years in northern Illinois. Yields and the response to N rate were nearly identical in conventionally tilled plots, regardless of how much residue was removed. If all of the residue was left on and plots were no-tilled, then yields were reduced by about 10%, and it took some 20 pounds more N to reach the highest yield. Removing about half of the residue followed by no-till lowered the N requirement, but yields were still 4% (10 bushels per acre) less than yields of tilled plots. When complete residue removal was followed by no-till, yields were only about 2% less than in tilled plots, and N requirements were about the same. While it is not yet clear what will happen to soils if corn residues are removed for a number of years, it is clear that in the short term, removing some or even all of the residue will not decrease yields, and it may even increase yields under no-till.

Table 5.2. Effect of changing tillage, fertilizer amounts, and plant population on yield of continuous corn at four Illinois sites.

			Yield (bu/A)			
Tillage	Fertilizer	Plant population	DeKalb 2005–07	Monmouth 2003–07	Urbana 2003–06	Perry 2004–07
Normal	Normal	Normal	199	175	223	182
Normal	Normal	High	202	159	208	175
Normal	High	Normal	205	181	223	186
Normal	High	High	207	175	224	193
Deep	Normal	Normal	205	186	215	180
Deep	Normal	High	205	182	206	182
Deep	High	Normal	211	192	226	176
Deep	High	High	209	189	225	184
Significant effects ($P < 0.1$)			None	T, F, P	Fert	FxP

Normal and deep tillage used chisel plow and deep ripping or mini-moldboard plow, respectively. Normal and high fertilizer were normal P and K and 220 lb of N and additional N-P-K amounts of 100-80-120 lb per acre. Normal and high plant populations consisted of 32,000 and 40,000 plants per acre, respectively.

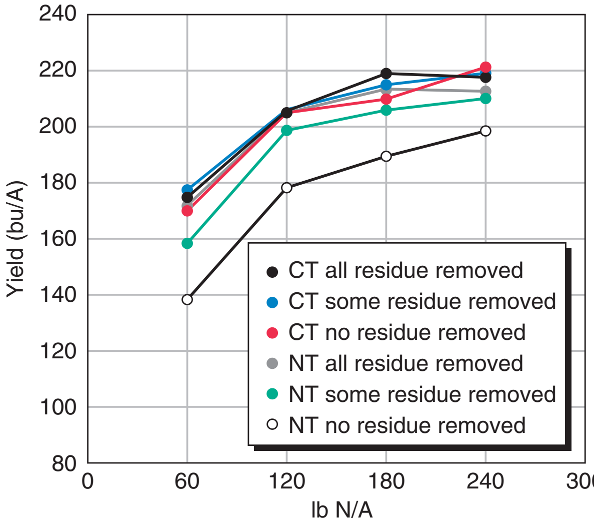

Figure 5.4. Effect of full and partial residue removal, tillage, and N rate on yields of continuous corn. Data are averaged over 8 site-years in northern Illinois from 2006 to 2008. CT = conventional tillage (chisel plow) and NT = no-till.

Corn–Soybean–Wheat Cropping Systems

While corn and soybean remain the primary crops of choice for most Illinois producers, there is still great interest in finding other combinations of crops that can provide similar or greater profits, more stability of yield and income, and some reduction in risks that corn and soybean crops share. One such system is a 3-year rotation that includes wheat along with corn and soybeans. While the double-cropping system in southern Illinois often includes these three crops, questions remain unanswered about the extent to which the wheat–soybean double-crop represents one or two crops, from a standpoint of effects on the next season's crop.

Over the past decade we have been conducting experiments at three sites in Illinois to see how adding winter wheat into the corn–soybean rotation affects yields and profitability. This experiment includes corn, soybean, and wheat grown in either of their two possible sequences (C–S–W or S–C–W), corn–soybean, continuous corn, and, at two of the sites, continuous soybean. Each crop is present in all possible phases each year. Double-crop soybean follows winter wheat harvest at the Brownstown site, but not at Monmouth and Perry, which are north of the normal double-cropping area in Illinois.

Results from the past three years of this study are presented in **Table 5.3**. Continuous corn yielded only 3% to 5% less than corn following soybean, and including wheat in the rotation improved corn yields by 3% to 7% at all locations. The sequence of corn, soybean, and wheat has had little effect on corn yield, though corn following soybean yielded slightly more than corn following wheat.

Continuous soybean yielded 4% and 2% less than soybean rotated with corn at Monmouth and Perry, respectively. Adding wheat into the rotation increased soybean yields by about 4% at Monmouth and 6% at Brownstown, but for some reason it tended to decrease soybean yields at Perry. Over 3 years of favorable double-crop conditions, double-crop soybean yielded about 90% of full-season soybean yields at Brownstown. Along with good wheat yields and good corn yields, the three-crop/double-crop system at Brownstown was highly productive and profitable. Wheat yields were little affected by crop sequence, though at Monmouth the wheat yield was about 4% higher when wheat followed soybean compared to wheat following corn.

Economic returns for these systems depend, of course, on crop prices and input costs. But results of this research indicate that three-crop rotations including wheat can be economically competitive at current crop price ratios. Drawbacks to the inclusion of winter wheat in northern Illinois include the occasional difficulty in getting the wheat crop planted on time following harvest of corn or soybean. The sequence in which the crops are grown does not affect yields much in most years, but it can be easier to plant wheat following soybean, both because of earlier harvest and because of less crop residue.

Table 5.3. Yields of corn, soybean, and wheat in cropping system trials at three Illinois sites (2006–2008).

	Yield (bu/A)		
Crop and sequence	**Monmouth**	**Perry**	**Browns-town**
Corn			
Continuous corn	197	180	146
Soybean–corn	208	188	151
Soybean–wheat–corn	217	192	160
Wheat–soybean–corn	220	196	161
Soybean			
Continuous soybean	68	45	—
Corn–soybean	71	46	35
Wheat–corn–soybean	74	45	37
Corn–wheat–soybean	74	42	37
Corn–soybean–wheat/ doublecrop soybean	—	—	31
Soybean–corn–wheat/ doublecrop soybean	—	—	22
Wheat			
Corn–soybean–wheat	90	75	67
Soybean–corn–wheat	86	76	69

Alternative Crops in Illinois

Many crops other than corn, soybean, and small grains will grow in Illinois, and many will grow quite well, but most have not been produced commercially. A few such crops have been produced on a limited scale and sold in limited quantities, either to local markets or for transportation to processing or export facilities. Many alternative crops are associated with high market prices and high potential income per acre, and thus they catch the attention of entrepreneurial producers who might hear about them. But such crops may have requirements (especially for quality) that can be difficult to meet under Illinois conditions, have high labor costs or other costs of production, or have very limited or inconsistent markets due to unpredictable production elsewhere.

Even though some alternative crops may grow quite well in Illinois, they may not enjoy a *comparative advantage* under Illinois conditions. If a crop is less profitable than other crops that grow or that could grow, then it is not economically advantageous, even if it grows well. For example, various types of edible dry beans grow well in Illinois, but these crops usually enjoy a comparative advantage elsewhere in the United States. This is not necessarily because they grow better elsewhere, but because they produce more income than most other crops in those areas. Some of this can be due to the proximity of processing facilities, which provides a large economic advantage in terms of transportation costs.

The most important consideration when deciding whether to produce a novel crop is its agronomic suitability. In some cases, the crop grows in areas with similar soils and weather, so we can easily learn about potential yields and problems. In other cases, the crop might not well grow in similar areas for very good reasons, and in most cases risks of growing such untested crops are very high. As an example, field (dry) pea was promoted as a crop in Illinois in 2004, with no prior production in most of the state. Thousands of acres were planted, using expensive seed imported from Canada. Field pea is a crop of dry areas, and it was basically destroyed by wet weather, with many fields abandoned and most of the rest yielding little. Illinois producers lost a great deal of money on a crop that was both untested and unsuitable, despite warnings about this.

After agronomic considerations, market availability, demand, and growth potential for any alternative crop need to be considered. Crops with relatively small, inflexible markets (that is, markets that require fixed quantities of only that crop, with the crop not readily used for other purposes) can easily become surplus in supply, quickly driving down prices or even making the crop impossible to sell. Unless alternative crops are desired by large populations, potential market expansion is limited. Delivery to a local market is desirable, but local markets often grow only slowly and with considerable expense, such as for advertising of "locally grown" products.

Some alternative crops can be used on-farm, perhaps substituting for purchased livestock feed. If production cost is sufficiently low, it may be possible to increase overall farm profitability with such a crop. The feeding value of the alternative crop should be included in such a consideration; while some crops can perhaps substitute for protein supplements, they may not result in equal animal gain or performance if protein quality is lower.

If specialized equipment and facilities or a large supply of inexpensive labor is needed to produce an alternative crop, the crop may not be very profitable or even feasible. Unless equipment or special facilities are used across many acres of a crop, the cost will be prohibitive. Large seasonal labor supplies are usually unavailable or are expensive in the Corn Belt; thus crops that require intensive hand labor, such as hand harvest, are typically not grown here.

Web Resources on Alternative or New Crops

There is a very good resource on alternative crops at the website www.hort.purdue.edu/newcrop. Here you can find information on virtually every crop that one would ever consider for Illinois, plus many crops that only grow elsewhere due to climatic restrictions in Illinois.

A research project at the University of Illinois resulted in a website (www.isws.illinois.edu/data/altcrops) that provides some estimates of suitability of crops, including many that are not grown in Illinois. Some of the data provided are incomplete, but the site provides information on a very large number of crops, and it does give some idea about production potential in Illinois.

Sunflower

Sunflower is an alternative crop that some Illinois farmers have produced profitably. Sunflower usually grows in areas of low humidity, and Illinois weather is often more humid than is ideal.

Two kinds of sunflowers can be produced in Illinois: the oil type and the confectionery type. Production practices are similar, but end uses of the grain differ. Oilseed sunflower produces a relatively small seed with an oil content of up to 50%. The hull on the grain is thin and dark colored and adheres tightly to the kernel. Oil from this type of sunflower is highly regarded for use as a salad and frying oil. Meal from the kernel is used as a protein supplement in livestock rations. Because sunflower meal is deficient in lysine, it must be supplemented for nonruminant animals.

Due to the distance to sunflower oil processors (most are in the upper Great Plains), most of the oil-type sunflowers produced in Illinois are used for products other than oil. In recent years, some producers have been producing sunflower as a double-crop following wheat harvest. While it is possible to get good yields in this short season, sunflower quality, as measured by oil content, is usually lower than industry standards. This, coupled with the low density (weight per bushel or per cubic foot) common in the Illinois crop, makes it prohibitive to ship out of state for oil extraction. Instead, most sunflowers produced in Illinois are packaged and used for birdseed.

Confectionery sunflowers usually have larger seeds and a striped hull. They are processed for use as snack foods, and some are used in birdseed mixtures to provide color. Tall plants with very large heads, often planted in gardens, are usually the confectionery type. Birds like all types of sunflower, and they will often eat seeds from the head with great enthusiasm.

Sunflower planting coincides with corn planting in Illinois. Many hybrids offered for sale will reach physiological maturity in only 90 to 100 days, so they can usually mature when planted following harvest of small grain crops. Use of sunflower as a double-crop may be a good choice if soybean cyst nematode is a pest, because sunflower is not attacked by cyst nematode.

Populations of 20,000 to 25,000 plants per acre are suitable for oilseed sunflower types produced on soils with good water-holding capacity. Coarser-textured soils with low water-holding capacity may benefit from lower stands. The confectionery-type sunflower should be planted at lower populations to help ensure production of large seed. Planting of seed should be at 1-1/2- to 2-inch depth, similar to placement for corn. Performance will tend to be best in rows spaced 15 to 30 inches apart.

A seed moisture of 18% to 20% is needed to permit sunflower harvest. Once physiological maturity of seed occurs (at about 40% moisture), a desiccant can be used to speed drying of green plant parts. Maturity of kernels occurs when the backs of heads are yellow, but the fleshy head and other plant parts take considerable time to dry to a level that permits combine harvest. A conventional combine head can be used for harvest, with losses reduced considerably by using special panlike attachments that extend from the cutter bar. Long-term storage of sunflower is feasible, but moisture levels of less than 10% need to be maintained.

Locating a market for sunflower is important before producing the crop. Because the head containing seed is exposed at the top of the plant, insects, disease, and birds can be pest problems. The location of sunflower fields relative to wooded areas will have an impact on the extent of bird damage.

Canola (Oilseed Rape)

Rapeseed, a member of the mustard family, is a crop that has been used as an oilseed in many countries for centuries. Canola is rapeseed that was genetically improved by Canadian scientists (hence, the "can" in "canola"), resulting in low erucic acid content in the oil and low levels of glucosinolates in the meal produced from the seed. These developments improved the quality of both edible oil and protein meal used in animal feed.

Types of canola with spring and winter growth habits are available, but the winter type is more likely to succeed in Illinois; when spring types are grown, hot weather occurs during seed production. Winter-hardiness and disease resistance under Illinois conditions have proven to be problems for the winter types, which are planted in the fall several weeks before winter wheat is planted.

Site selection is critical to successful production of canola because this crop cannot tolerate waterlogged soil. Only fields with good surface drainage should be used, and good internal drainage will help yields.

Planting 2 to 3 weeks before the normal wheat planting time is adequate for plant establishment, provided that cold temperatures do not arrive unusually early. The very small seeds need to be planted shallowly with a grain drill at a rate of only 5 to 6 pounds per acre. Canola needs adequate time to become established before fall temperatures decline, but it does not need to develop excessively. Plants with 6 to 10 leaves, with a lower stem about the diameter of a pencil, are considered adequate for winter survival. A taproot 5 to 6 inches deep generally develops with desired levels of top-growth in the fall.

Soil fertility needs for canola are similar to winter wheat, with a small amount of nitrogen applied in the fall to stimulate establishment and a larger topdress application in the early spring to promote growth. Too much nitrogen available in the fall can delay the onset of dormancy, putting the crop at greater risk for winter injury. Excessive amounts of nitrogen can increase lodging problems.

Growth of canola resumes early in the spring, with harvest maturity reached about the same time as that of winter wheat. Harvest needs to be done as soon as the crop is ready to reduce the amount of seed shatter. Only the top portion of the plant containing the seedpods is harvested.

Combining works well when seeds reach 10% moisture, but further drying of seeds (to 9% moisture or less) and occasional aeration are needed for storage. The tiny, round seeds tend to flow almost like water, so wagons, trucks, and bins used for transportation and storage need to be tight, with all cracks sealed.

There is no canola processing in Illinois, so locating a nearby delivery site is currently a problem. Problems with disease (especially *Sclerotinia*) and winter survival have also been common, and acreage of canola in Illinois is currently very low.

Buckwheat

Nutritionally, buckwheat is very good, with an amino acid composition superior to that of any cereal, including oats. Producing the crop as a livestock feed is possible, but markets for human consumption tend to be small. An export market exists in Japan, where noodles are made from the grain. This market requires large, well-filled seeds, which can be difficult to produce when the weather is hot and dry.

Buckwheat has an indeterminate growth habit; consequently, it grows until frost. Growth is favored by cool, moist conditions. In a short period (75 to 90 days), it can produce grain ready for harvest. High temperatures and dry weather during flowering can seriously limit grain formation. Little breeding work has been done to enhance yield potential; buckwheat is naturally cross-pollinated and cannot be inbred because of self-incompatibility. There are not many varieties available.

Because it produces grain in a short time, buckwheat can be planted as late as July 10 to 15 in northern Illinois and late July in southern parts of the state. Rapid vegetative growth of the plant provides good competition to weeds. Fertility demands are not high, so buckwheat may produce a better crop than other grains on infertile or poorly drained soils.

With the exception of those that can use the crop for livestock feed, producers should determine market opportunities before planting buckwheat. A few grain companies in the Midwest handle the crop for export, but buckwheat produced from late planting may often have small seeds and thus limited potential for the export market.

Specialty Corn and Soybean Production

Corn and soybeans with unique chemical or physical properties can perhaps be viewed as alternative crops, though production of these types is generally little different than production of "conventional" crops. Typically corn and soybean varieties with these special characteristics are used in the manufacture of food products, although some offer feeding advantages for livestock as well. A considerable portion of specialty soybeans is exported to Asian countries to be used in foods.

Organic production. Some of the fastest growing specialty markets are for organic corn and soybean. Companies are manufacturing increasing numbers of consumer food products based on organic grains, and demand for organic meat, milk, and other products is increasing rapidly. The USDA has produced a set of rather complex rules that govern the production of organic crops and the labeling of foods that contain such crops. These rules are much too extensive to list here, but persons interested in organic production can locate rules and other information at the USDA Agricultural Marketing Service (www.ams.usda.gov/AMSv1.0). In order to have products labeled as organic, producers need to have an agency certify that they are in compliance with the rules.

It takes three years without the use of prohibited inputs for a field to be certified as organic. Prohibited inputs include, among other things, manufactured forms of fertilizer, all synthetic pesticides, and genetically modified seed. Certain rotational sequences and intervals between crops must also be maintained. While it is neither simple nor easy to gain certification, organic crops often command prices that are much higher than those of nonorganic crops, so organic crops can be profitable even if production costs per unit are high. In a general sense, organic production that involves livestock tends to be easier than that which produces only grain crops. This is because forages in rotations can be grown for ruminants, and manure from livestock can be used to provide nutrients.

Special-use corn and soybean. Markets for specialty corn and soybeans domestically are often smaller than those for commodity corn and soybeans, but for some producers, growing specialty grains may be a means to enhance income. Specialty grain is usually produced under contract with a grain buyer, and the requirements for grain delivered may differ considerably from the requirements for that delivered to a local elevator.

One of the largest current specialty markets is for non-GMO corn and soybean. Other than needing to manage weeds and insects using conventional techniques and keeping harvested grain separate from that produced using GM seed, these are not generally difficult to produce. Many GM traits have strip tests that can be run at receiving points (elevators or terminals) to see if the grain meets the standard for presence of low levels of GM grain.

As the market for GM corn and soybean seed has grown, however, finding top-yielding varieties of these crops can be challenging. In the University of Illinois variety trials, conventional soybeans are tested in separate trials, while corn hybrids are in the same trial but identified as having no genetic (Bt or herbicide resistance) traits. Recent results confirm that most of the GM varieties that companies currently enter into these trials tend to yield more than conventional entries. However, the premium for non-GMO crops can make them still profitable.

Most specialty types of corn differ from conventional corn by having altered protein, oil, or starch in their grain. Some of these are described in Chapter 2. Specialty soybeans are also nutritionally altered, mostly by having different-than-normal types or ratios of fatty acids in their oil. Some demand for these products stems from the current health concerns regarding trans fats.

Biofuel Sources and Crops

Due to high petroleum prices and government mandates for production of "renewable" fuel (not from fossil fuel sources), interest in growing crops to convert to liquid fuel has been very high in recent years. By far the most common liquid fuel produced from renewable sources is ethanol, which can be produced by yeast grown in vats and fed by sugar. Sugar to feed this process is available in some countries from sugarcane, which is highly productive in terms of gallons of ethanol per acre. In the United States, where we grow limited acres of sugarcane due to limitations of temperature (it needs warm temperatures for at least 8 months to produce a crop), most of the sugar for ethanol production is produced by breaking down cornstarch into sugars in a process that uses enzymes. The byproduct is the non-starch parts of the kernel—protein, oil, and minerals, which together make up a useful livestock feed. In 2008, the U.S. will use about 30% of the corn crop to produce about 10 billion gallons of fuel ethanol. There are about a dozen ethanol plants in Illinois, and more than 130 plants in the U.S., most using corn grain as their major feedstock. Corn grown for grain is, and will remain for some time, our primary "biofuel" crop.

Increasing demands for ethanol and eventual limitations of corn supply and price will increase the production of ethanol using sources of sugar besides corn grain. Most experts believe that the real growth potential is in the production of *cellulosic ethanol*, which uses sugars produced by the breakdown of plant-based materials like wood waste, newspaper, cornstalks, and forage-type (non-grain) crops. Cellulose is a complex carbohydrate much like starch, and it is in nearly pure form in cotton fiber. It is more difficult to break cellulose down into sugars than to break down starch. But the real challenge is that cellulose in most plant materials is mixed with other chemical constituents that are not good sources of sugars, and extracting cellulose is difficult and expensive. While enterprises are under development to use plant materials such as cornstalks to produce ethanol, it will be some years before this is a major part of the supply. Compared to corn grain, cellulosic ethanol production creates not valuable livestock feed, but instead large quantities of sludgelike material that will present a disposal challenge.

In the event that cellulosic ethanol production becomes commercially viable, markets for crops and crop materials to be used as feedstocks will develop. One prominent source is likely to be corn crop residue, including stalks and cobs. There is about 1 ton (dry weight) of residue in the field after harvest for each 40 bushels of grain yield. So harvesting half of the corn residue in Illinois (12 million acres at 180 bushels per acre) would produce some 2.7 million tons, which at 80 gallons of ethanol per ton (such yields are not yet certain, but estimates range from 60 to 100 gallons per ton) would produce more than 2 billion gallons of ethanol. It is not yet clear what producers would be paid for such residue, but harvest, transportation, processing, and waste disposal costs will be high, and the replacement of nutrients removed in the residue will also represent a cost to the producer. As noted, removal of some of the corn residue should not present a problem, and it may even make it possible to do less tillage. The large challenges with this source may well turn out to be logistics of getting the residue harvested and transported, and then storing enough of the material to allow a plant to operate throughout the year, including during the growing season, when there would be no residue to harvest.

Corncobs make up about 20% of the weight of the ear, so a 200-bushel corn crop produces a little more than a ton of cobs. Efforts are under way to find ways to harvest cobs at the same time that grain is harvested. Cobs break down slowly and do less to protect the soil compared to stalks, so they may represent less loss to producers than would the loss of stalks. Challenges include getting cobs harvested without disrupting grain harvest, getting them dry enough to store (cob moisture may be similar to grain moisture at the time of harvest, unless harvest is delayed), and the fact that cobs may not be ideal sources of cellulosic ethanol due to their hardness and chemical composition.

While production of liquid fuel (ethanol, and perhaps a few others) is part of the renewable fuel mandate, it is also possible to burn various plant products directly to produce heat for generating electricity or for heating buildings. Direct burning is a less expensive way to extract energy than is the production of liquid fuel. It also means less waste, though ash—mineral content that doesn't burn—still has to be disposed of. Grass crops and other biological materials have been burned along with coal in power plants and have been compressed into pellets for burning in heating devices. Such material needs to be dry enough to burn well, and it is typically an advantage if it has low levels of nitrogen and other plant nutrients. This reduces the need to replace nutrients removed from the soil where the plant material grew, helps reduce pollution, and minimizes the amount of ash that needs to be disposed of after burning.

Dedicated Biofuel Crops

The amount of crop residue will, once processing is commercially viable, provide a great deal of material from which to make ethanol. If dry weight is the only important measure of value as a feedstock for ethanol production or burning, then it is possible that roadsides, interstate highway medians, waterways, and other unfarmed areas might become viable sources, to the extent that prices more than cover harvest and transportation costs. Wood processing wastes, recycled paper (paper has a high cellulose content), and other materials currently available at low cost might take on value as feedstock.

A great deal of effort is under way to find and develop crops that produce large quantities of harvestable dry matter that can be used as a source of cellulose. We call these "dedicated" biofuel crops because they typically aren't much good for anything else. Some such plants could be used as forages if harvested early, but getting maximum dry weight yields is possible only if the crop is grown to near maturity, when forage quality is not good.

The biofuel crop on which the most research has been done over the past two decades in the U.S. is *switchgrass* (**Figure 5.5**). This is a warm-season, perennial grass species native to the prairies of North America. It has very small seed and establishes somewhat slowly. Yields of more than 10 tons per acre have been reported from research, but yields of whole fields are likely to be less than that, perhaps 3 to 6 tons. Switchgrass can be used as a forage crop for livestock grazing, though its quality decreases as it matures.

Miscanthus, specifically the sterile natural cross called *Miscanthus* x *giganteus* (**Figure 5.5**), is being promoted as a biofuel crop based on high dry matter yields that have been reported in Illinois and other places. It is a perennial that can grow up to 13 feet tall, and it has underground stems called rhizomes that store materials to enable the plant to grow back quickly in the spring. Yields of more than 15 tons per acre have been reported from research trials. There is at present not enough grown in fields in the U.S. to be able to know what yields might be over years. Warm weather with relatively high rainfall and moderate soil drainage tend to improve yields, so it is possible that this plant will do well in some southern Illinois locations.

Figure 5.5. Switchgrass (foreground, left) and *miscanthus* x *giganteus* (right).

There is no established market and not enough seed stock to plant large acreages, so most plantings over the next few years will likely be for research and demonstration.

One of the major drawbacks to growing miscanthus is that, as a sterile plant that produces no seed, it has to be propagated vegetatively. This is usually done by planting pieces of rhizome harvested from an existing stand, typically using wide spacing between plants (3 ft in both directions) to minimize planting costs. Rhizome pieces sometimes fail to produce a viable plant from their buds, and so some may need to be replanted. Weed control during establishment is an issue as well. So establishing a stand is costly. After establishment, the plant needs to grow for three years before it reaches maximum productivity, and even then the stand may not be completely filled out. There is evidence that the plant responds to N fertilizer, at least after depletion of soil N supplies starts to limit growth.

Harvest of miscanthus plants as biofuel takes place in late fall or winter, after the leaf material has dried up and blown away and stems have dried. It can be harvested using forage equipment, either baled or chopped. Until cellulosic ethanol production begins, most harvested miscanthus will likely be burned directly. It is very coarse plant material, and so it has few if any uses other than as a fuel. The economics of miscanthus production are currently uncertain, given that no real market exists for the product and that yields in different field situations are largely unknown.

Cover Crops

Rye, wheat, ryegrass, hairy vetch, and other grasses and legumes are sometimes used as winter cover crops in the Midwest. The primary purpose for using cover crops is to provide plant cover for soil to help reduce erosion during the winter and spring. Winter cover crops have been shown to reduce total water runoff and soil loss by 50% or more, although the actual effect on any one field will depend on soil type and slope, the amount of cover, planting and tillage methods, and intensity of rainfall. A cover crop can protect soil only while it or its residue is present, and a field planted after cover crop residue has been displaced or buried by tillage may lose a great deal of soil if there is intense rainfall after planting. The use of winter cover crops in combination with no-till corn may reduce soil loss by more than 90%. Cover crops are promoted as a way to improve soil tilth, and they sometimes contribute nitrogen to the following crop.

The advantages of grasses such as rye as cover crops include low seed costs, rapid establishment of ground cover in the fall, vigorous growth, recovery of residual nitrogen from the soil, and good winter survival. Most research has shown, however, that corn planted into a grass cover crop often yields less than when grown without a cover crop. In one study at the University of Illinois research center near DeKalb, the negative effect of wheat and rye cover crops killed at different times before planting was closely related to the amount of cover crop dry matter that was present (**Figure 5.6**).

There are several reasons why grass cover crops might reduce yields of the following corn crop. Residue from grass crops, including corn, has a high carbon-to-nitrogen ratio, so nitrogen from the soil is tied up by microbes as they break down the residue. Second, a vigorously growing grass crop such as rye can dry out the surface soil rapidly, causing problems with stand establishment under dry planting conditions. When the weather at planting is wet, heavy surface residue from a cover crop can also cause soils to stay wet and cool, reducing emergence. Finally, chemical substances released during the breakdown of some grass crops have been shown to inhibit the growth of a following grass crop or of grass weeds. This is an example of allelopathy.

While grass cover crops can reduce yields of the following corn crop, most research has shown little or no effect of cover crops on a following soybean crop. In one Illinois study, rye cover crop was allowed to grow to reach a weight of about 2 tons per acre, and there was no effect of the cover crop on soybean yield. In that study, the rye took up as much as 100 pounds of N per acre. One cover crop grass that has gotten attention recently is annual ryegrass, especially for planting before soybean. It tends to grow fairly deep roots, which might improve soil structure some as they decay. But as with all cover crops, benefits to growing ryegrass need to be greater than the cost of planting and controlling it.

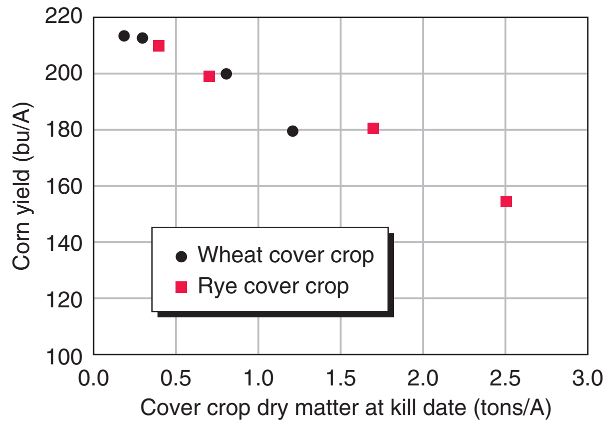

Figure 5.6. Effect of fall-seeded cover crop wheat and rye on the yield of corn. The cover crops were killed at 3, 2, and 1 week before planting using herbicide, and 2 days before planting with tillage. Earlier kill dates produced lower cover crop weights, and wheat produced about half the dry matter of rye by each date. Data are over three years (2007-2007) and are from a study conducted by Jim Morrison and Lyle Paul at the University of Illinois Northern Illinois Agronomy Research Center near DeKalb.

Figure 5.7 shows that in a 2-year study at Urbana, Illinois, using the legume hairy vetch as a cover crop resulted in higher yields than did using no cover crop or using rye or the combination of rye and vetch, at least at lower N rates. There are several reasons why legumes might be better cover crops than grasses. Legumes can fix nitrogen, so, providing that they have enough time to develop this capability, they may provide some "free" nitrogen—fixed from the nitrogen in the air—to the following crop. Most leguminous plant residues have a lower carbon-to-nitrogen ratio than those from grasses, so breakdown of their residue ties up little or no soil nitrogen. On the negative side, early growth by legumes may be somewhat slower than that of grass cover crops, and many of the legumes are not as winter-hardy as grasses such as rye. Legumes seeded after the harvest of a corn or soybean crop thus often grow little before winter, resulting in low winter survivability, limited nitrogen fixation before spring, and ground cover that is inadequate to protect the soil, particularly in northern Illinois.

Hairy vetch, at least in the southern Midwest, has often worked well as a winter cover crop. It offers the advantages of fairly good establishment, good fall growth, and vigorous spring growth, especially if it is planted early (during the late summer). When allowed to make considerable spring growth, hairy vetch has provided as much as 80 to 90 pounds of nitrogen per acre to the corn crop that follows. One disadvantage to hairy vetch is its lack of sufficient winter-hardiness; severe cold without snow cover will often kill this crop in the northern half of Illinois, especially if it has not made at least 4 to 6 inches of growth in the fall. The seed rate is moderately high, at 20 to 40

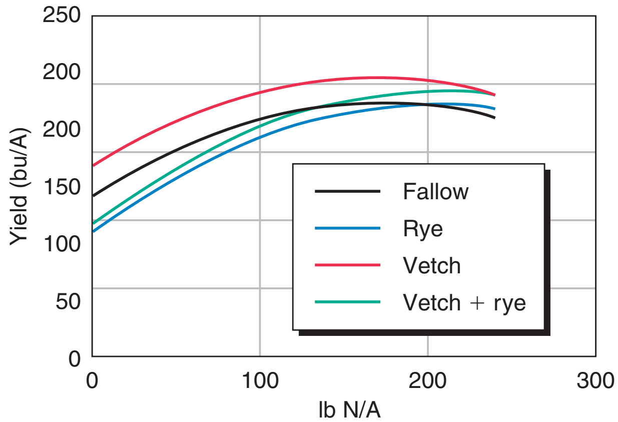

Figure 5.7. Effects of no cover crop, hairy vetch, rye, or hairy vetch plus rye on yield and N response of no-till corn grown following soybean. Data are from a 2-year study at Urbana, published by Fernando Miquez and Germán Bollero in *Crop Science* 46:1536–1545 (2006).

pounds per acre, and seed is currently priced at more than $2 per pound, so seed costs alone can be $50 to $80 per acre. The value of the nitrogen fixed under good conditions and provided to the next crop may return more than half of the seed cost, but there clearly need to be other benefits besides nitrogen supply to make the use of vetch profitable as a cover crop. Some producers grow their own seed to reduce the expense. Hairy vetch can also produce a considerable amount of hard seed, which may not germinate for 2 or 3 years, at which time it may become a serious weed in a crop such as winter wheat. Other legume species that may be used as winter cover crops include mammoth and medium red clovers, alfalfa, and ladino clover.

To get the maximum benefit from a legume cover crop, it must be planted early enough to grow for 6 to 8 weeks before the onset of cold weather in the late fall. The last half of August is probably the best time for planting such cover crops. They can be aerially seeded into a standing crop of corn or soybean, although dry weather after seeding may result in poor stands of the legume. Some attempts have been made to seed legumes such as hairy vetch into corn at the time of the last cultivation. This practice may work occasionally, but a good corn crop will shade the soil surface enough to prevent growth of a crop underneath its canopy, and cover crops seeded in this way will often grow very poorly or die during periods of dry weather. All things considered, the chances for successfully establishing legume cover crops are best when they are seeded into small grains during the spring or after small-grain harvest, or when they are planted on set-aside or other idled fields, well before the time of corn or soybean harvest.

There is some debate as to the best management of cover crops before planting field crops in the spring. A trade-off of benefits usually exists: Spring planting delays will allow the cover crop to make more growth (and to fix more nitrogen in the case of legumes), but this extra growth may be more difficult to kill, and it can deplete soil moisture. As discussed above, killing a grass cover crop several weeks before planting—or even earlier if cover crop growth is heavy—is preferable to killing it with herbicide or tillage just before planting the main crop. Legumes can also create some of the same problems as grass cover crops, especially if they are allowed to grow past the middle of May.

Research at Dixon Springs in southern Illinois has illustrated both the potential benefits and possible problems associated with the use of hairy vetch. In these studies, hairy vetch accumulated almost 100 pounds of dry matter and about 2.6 pounds of nitrogen per acre per day from late April to mid-May (**Table 5.4**). The best time to kill the cover crop with chemicals and to plant corn, however, varied considerably among the 3 years of the study. On average, corn planted following vetch yielded slightly more when the vetch was killed 1 to 2 weeks before planting (**Table 5.5**). Also, corn planted in mid-May yielded more than corn planted in early May, primarily due to a very wet spring in 1 of the 3 years, in which vetch helped to dry out the soil. Vetch also dried out the soil in the other 2 years, but this proved to be a disadvantage because moisture was short at planting. The conclusions from this study were that vetch should normally be killed at least a week before planting and that corn planting should not be delayed much past early May because yield decreases due to late planting can quickly overcome benefits of additional vetch growth.

Although the amount of nitrogen contained in the cover crop may be more than 100 pounds per acre, the rate applied to a corn crop following the cover crop cannot be reduced 1 pound for each pound of nitrogen contained in the cover crop. One study in Illinois showed that the economically optimal nitrogen rate dropped by only about 20 pounds per acre when a hairy vetch cover crop was used, even though the hairy vetch contained more than 70 pounds of nitrogen per acre. In the results shown in **Figure 5.7**, vetch cover crop increased yield over that without a cover crop, but the nitrogen response lines are nearly parallel to one another, meaning that the nitrogen rate required for maximum or optimum corn yield was not changed by the cover crop.

Whether to incorporate cover crop residue using tillage is debatable, with some research showing no advantage and other results showing some benefit. Incorporation may enhance the recovery of nutrients such as nitrogen under some weather conditions, it may offer more weed-control options, and it can help in stand establishment, both by reducing competition from the cover crop and by providing a better seedbed. On the other hand, incorporating cover crop

Table 5.4. Dry matter and N content of hairy vetch killed at different times using herbicide.

Kill date	Dry matter (lb/A)	Nitrogen (lb/A)
Late April	1,300	55
Early May	2,509	85
Mid-May	3,501	115

Data are from a 3-year study conducted by Steve Ebelhar at Dixon Springs.

Table 5.5. Corn yields from different corn planting dates and hairy vetch cover crop kill dates.

	Yield (lb/A)	
Corn planting date	Vetch kill 1–2 wk before planting	Vetch kill at the time of planting
Early May	1,300	55
Mid-May	2,509	85
Late May	3,501	115

Data are from a 3-year study conducted by Steve Ebelhar at Dixon Springs.

residue removes most or all of the soil-retaining benefit of the cover crop during the time between planting and crop canopy development, a period of high risk for soil erosion caused by rainfall. Tilling to incorporate residue can also stimulate the emergence of weed seedlings, and incorporated residue can cause problems in seed placement.

The danger of allelopathy caused by the release of chemical substances during the breakdown of cover crop residues can be minimized by physically moving cover crop residue from the crop row. This is difficult to do if tillage is used to kill the cover crop and to incorporate residue. If the cover crop is killed chemically long enough before crop planting, dried residue can usually be moved safely off the row by trash-moving planter attachments. This also helps with crop seed placement.

Cropping Systems and the Environment

In recent years a number of scientists have been studying the effects of cropping systems on the soil, water, and other natural resources located in and near fields where crops are grown. The approach to such studies is grounded in ecological sciences, and the general term *agroecology* has been coined to refer to this blend of ecology and agricultural sciences. *Ecological services* are means by which cropping systems can be shown to have positive effects on things like water quality or soils. Many ecological studies begin with the idea that unfarmed, unsettled, unused natural areas represent the most stable and resilient ecological systems. From that standpoint, any managed agricultural system represents an ecological negative. Thus ecological services from agricultural systems are usually considered in comparison with other agricultural systems, not with natural areas.

Carbon Sequestration

Crops take up carbon dioxide (CO_2) from the air and release oxygen (O_2). Because the continuous rise of atmospheric CO_2 concentration from the burning of fossil fuels (which started out as plant material, and before that as atmospheric CO_2 millions of years ago) has been blamed as a cause of global warming, there has recently been a lot of interest in claiming credit for growing crops as a means of removing carbon from the air, hence “sequestering” carbon. One visible example of carbon sequestration by plants is in forests, where the carbon in the woody part of trees has been removed from the air, at least until the wood burns or trees fall down and decay. In fact, the global atmospheric CO_2 concentration goes down during the northern hemisphere summer because photosynthesis removes it from the air.

While crop dry matter is indeed a store of sequestered carbon, most such carbon is sequestered only for a short time. Nearly all of the carbon in the grain used to feed livestock and people is respired to release its energy. Crop residue on or incorporated into the soil can take a long time to decay, but much of it eventually returns back to the atmosphere as CO_2. One form of carbon that remains sequestered, though, is the carbon in the stable fraction of soil organic matter. Soil organic matter is about 50% carbon, and 1 acre of topsoil 10 inches deep weighs about 3 million pounds, so if the topsoil has 4% organic matter it contains about 30 tons of carbon per acre. Though many soils are not this deep or do not have such high levels of organic matter, world soils contain huge quantities of carbon.

Illinois soils lost as much as half of their organic matter during the first 100 years or so of producing cultivated crops. Measurements indicate that this loss has slowed or stopped, and it may be possible, depending on crops and how they are grown, that soils could be made to gain *stable* soil organic carbon again. Organic matter is said to be stable only after it is in a chemical form that does not break down any further. Crop residue returned to the soil is not stable organic matter; in fact, 99% or more of it will disappear during the breakdown process in most soils, leaving less than 1% as added organic matter. Evidence is that roots break down more slowly and contribute considerably more to soil organic matter than do crop residues from above ground.

The breakdown process takes decades to complete, so changes in stable organic matter cannot be measured accurately after only 10 or 20 years of cropping. It is clear that cases where people claim that soil organic matter has increased by 1 percentage point or more over a few years do not reflect changes in stable organic matter, but rather changes in organic crop material or crop residues in various stages of breakdown. We also know that each percentage point of stable soil organic matter contains about 1,000 pounds of nitrogen per acre, so the long-term buildup of soil organic matter will require nitrogen above the needs of the crop.

While studies on carbon sequestration continue, it is in the best interest of most producers to keep crop residues in the field but perhaps not to drastically alter cropping practices. Proponents of sequestering carbon with annual crops often suggest that continuous corn is the best crop to use for this and that no-till is required, though strip-till is now often allowed as a variant of no-till. Continuous no-till corn is difficult to manage, especially in northern Illinois, due to buildup of large amounts of crop residue on the soil surface. Power companies may even pay for carbon "credits" if certain rules are followed. Because they can be easily monitored, it is likely that agronomic practices, not measured increases in soil carbon, will be the basis for such payments if they occur in the future. Early indications are that the amount of such credit payments may not be enough to cover added expenses or any crop losses that might occur from some of the practices that might be required.

Water Quality

Water quality in agricultural systems is associated with the amount of soil lost as runoff into surface water and with the amount of plant nutrients and pesticides that reach surface waters. A cropping system thus affects water quality to the extent that it keeps soil in place, releases little pesticide, and takes up nutrients that would otherwise leave fields in drainage or runoff water. Perennial cropping systems such as permanent pasture that are managed without use of excess nutrients or pesticides generally excel at preserving water quality. More common systems such as the corn–soybean rotation, even if managed well by using appropriate amounts and forms of nitrogen fertilizer, only those pesticides needed, and little or no tillage, will still in many cases lose more nitrogen to surface water than will perennial crops. Tile drainage, by making it possible for water to move out of a field to a stream or river, often increases nutrient loss from a field. But with proper care it is possible to produce crops with minimal effects on water quality.

Air Quality

Because higher CO_2 levels mean higher rates of photosynthesis, an increased atmospheric CO_2 level is itself a positive factor in crop production. Photosynthetic rates of well-managed crops are generally higher than those of natural systems, though the fact that forests and some perennial systems have active leaf area much longer during the growing season than do crops means that seasonal carbon uptake might be higher in some natural systems, even if the highest daily rates are less. Recent studies have shown that as the CO_2 level continues to rise, productivity of some crops will increase moderately, unless the increase in CO_2 is associated with hotter, drier conditions and so more stress.

The idea that plants, including crops, help to "restore" the air by taking in CO_2 and releasing oxygen for animals to breathe is a popular one, and it might be considered by some to be one of the ecological services provided by crops. Of course, natural systems do this as well. All photosynthesis is accompanied by release of large amounts of water vapor—each corn plant in a field loses about 5 gallons of water from its leaves over the course of a season, and the more a crop or system yields, the more water it uses. Some have linked crop production with increases in humidity levels, and even to the occurrence of thunderstorms. Another, more indirect link between cropping systems and air quality stems from the fact that engines that power farm equipment, as well as tillage and harvest operations, release particulate matter that can affect air quality.

Besides affecting air quality to some extent, plants can also be affected by the presence of pollutants in the air from sources such as automobile engines and factories. One such pollutant is ozone, a form of oxygen that is produced by the action of sunlight on engine exhaust gases. Ozone has been found in experiments to severely reduce yields of crops such as soybean. Because levels of such pollutants vary so much depending on windspeed and other conditions, it is difficult to know how much yield loss actually occurs. When plants take up ozone, there is presumably less for people and animals to breathe in, which might be a benefit.

Species Diversity

To many ecologists, any system with limited species diversity has low stability. Many thus see a corn field with low weed numbers and few insect or disease problems as lacking diversity, and hence a system with very low stability. According to principles of ecology, which generally deals with stability of systems left alone in nature, a corn field certainly is unstable: It will not stay a corn field unless people intervene to keep it as a corn field the next year. And this will require the use of extensive inputs such as new seed, methods of weed control, and nitrogen, all of which are not "natural" products or processes.

While the diversity within a corn field may not be very visible, there is a considerable amount of diversity in insects, disease organisms, and species that inhabit the soil. In general, though, the reason agronomists and ecologists would view the stability (and desirability) of a well-managed corn field quite differently is that the ecologist generally looks toward the long-term stability based on known principles, while the agronomists is looking at productivity in that year, without trying to predict whether such a crop will be possible in 10 or 20 years, or how things might need to be changed to maintain productivity. There is no good evidence that a corn field that produced a high yield in 2008 will be unable to do that in 2030, nor is there evidence that introducing more diversity through strip-intercropping or more diverse crop rotation will make it more productive over the long run.

Will Cropping Systems Need to Change?

Some who look at cropping systems in terms of ecological principles contend that current cropping patterns are so unstable that changes must be made soon to prevent disaster. There is historical evidence that some cultures have been destroyed as a consequence of depending too much on a single crop or a few crops, though it is not clear that the methods of production were the problem as much as lack of means to adequately manage insects and diseases. Yields of some major crops in major growing areas of the world have stagnated in recent years, in some cases without a clear cause, even as genetic potential of these crops continues to increase. Thus the answer to the question of whether cropping systems will need to change is "probably," though there is very little evidence pointing to specific changes that will have to be made. As long as crops are produced using sound agronomic principles, with a minimum of pesticides, and with awareness of the need to preserve the soil and minimize effects on the environment, we will stay flexible enough to meet challenges to current crops as they come.