Kansas Rural Center
SUSTAINABLE AGRICULTURE
MANAGEMENT GUIDES

NON-CHEMICAL WEED MANAGEMENT FOR ROW CROPS

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Weeds are second only to soil moisture as a factor limiting crop production in Kansas (Ham, 1989). Farmers wishing to eliminate pesticide use generally find weed control the greatest hurdle. To clear this hurdle, farmers need to: 1) understand the relationships between weeds and crops; 2) adopt cropping and tillage systems that reduce overall weed pressure; and 3) develop non-chemical techniques for weed control within crops.

A Weed/Crop Primer

Nature works to cover the land. Natural phenomena such as fires, floods, earthquakes, and animal activity have always created bare soils. Green plants require air, water, nutrients, light and space to grow. A patch of bare soil that contains these resources quickly becomes occupied by plant species evolved to colonize disturbed soils. Through the ages, these aggressive, colonizing species have played an important role in soil conservation.

Today, the agricultural and construction activity of humans has become the dominant source of soil disturbance. Pre-adapted colonizer species were the forerunners to today's weeds and many of today's crops. The evolution of weeds often parallels the evolution of crops, and many crop species with their weed relatives form crop-weed complexes (Harlan, 1992). An example is sorghum, with its truly wild races in Africa that are far removed from human disturbance, the domesticated forage and grain sorghums, and the shattercane that farmers recognize as the premier weed problem in sorghum fields. Both weeds and crops thrive on habitats disturbed by people.

Some agricultural weed species, such as field bindweed, have such a long history of living with humans that they are seldom found in the wild. Other species have evolved to mimic the crops in which they grow. In California, barnyard grass has been selected by hand weeders in rice fields to look exactly like rice. Some weed species have developed resistance to herbicides used for weed control.

Many of the major weeds in the United States were brought over by European immigrants. Often this was done through use of soil as ballast for stability in sailing ships. The soil was then dumped in Eastern port cities in order to carry valuable cargo back to Europe. Velvetleaf was brought from Europe and used by colonists as a fiber crop. Pigweed, a member of the amaranth family, was cultivated for its grain in pre-Colombian South America. Hemp provided fiber for rope in the Civil War. Johnsongrass was imported from Africa for forage. Morning glory and some types of thistles were brought over as ornamental plants.

Even today, the distinction between weeds and crops is sometimes blurred. Large crabgrass and kochia (fireweed) are notorious weeds to grain farmers, but are sometimes planted for cattle grazing.

Characteristics of Weeds

Weed species have several characteristics not shared by crops that contribute to their success (Baker, 1974). Most weeds have indeterminate flowering. They begin flowering very early, and continue to flower as they grow, as long as resources permit. This results in great size variability (plasticity) among plants of the same species. A Palmer pigweed germinating at the same time as a sorghum crop will overtop the sorghum, producing over a half million seeds, while another pigweed seedling, emerging under the sorghum canopy in August, may reach a height of only a few inches and produce but a few dozen seeds. The size difference is due simply to differences in available resources. Both have succeeded in perpetuating the species.

Another characteristic important to weed species is their seed dormancy mechanisms. For example, common ragweed seed is dormant when shed by the parent plant. A winter cold treatment breaks the dormancy, readying them for germination in the cool moist soils of spring. Those that do not germinate in spring, for whatever reason, lapse into secondary dormancy that requires another winter cold treatment to break (Bazzaz, 1979). Thus, the seeds “avoid the mistake” of germinating in fall when there is little time left for warm-season growth.

Weeds may grow rapidly, according to the availability of nutrients and light. Thicker populations will result in smaller weeds. Weeds are generally self-pollinated, allowing them to reproduce in isolation. Long distance weed seed dispersal is achieved by special characteristics such as the hooks of cocklebur fruits, the "parachute" of marestail (horseweed) that sails in the wind, and the fins that allow curly dock seed to float on water. Weeds may absorb fertilizer faster and in relatively larger amounts than crops, thereby deriving more benefit from the fertilizer than the crop does (Alkamper, 1976).

A square yard of soil may contain as many as 25,000 weed seeds of various species. Each species of seed needs the proper stimulus for germination. Three important stimuli are influenced by tillage: light, soil atmosphere, and changes in soil temperatures. Soil tillage stimulates germination, thereby reducing the seed bank. If seed near the soil surface is depleted and the soil remains undisturbed, seedling numbers decline. However, seeds at lower depths can persist for much longer. Seed longevity is often enhanced by deep burial, oxygen deficiencies, moderately moist soil, and low temperatures (Aldrich, 1984).

Each weed species has its preferred germination window, which may be as narrow as several weeks. In Kansas croplands, the first weeds to germinate in spring include wild buckwheat, Pennsylvania smartweed, kochia, common ragweed, giant ragweed, and velvetleaf. As soils warm up, pigweed, cocklebur, and morning glory germinate. Among the grassy weeds, fall panicum and the foxtails tend to germinate earlier, in cooler soils, than crabgrass and shattercane. As might be expected, the most formidable weeds in agriculture tend to have a longer emergence period, giving them more chances to avoid the farmer's management practices. Tillage dates will influence which weeds will dominate the following crop.

Rainfall is an important factor determining weed germination. It is common for a flush of shallow-germinating weeds to emerge after each tillage operation, as soon as surface soil moisture is adequate. In more arid regions, fields with a dust mulch may remain weed-free for weeks or months. Large-seeded broadleaf weeds, such as velvetleaf, morning glory, sunflower, and cocklebur, germinate from two to four inches below the soil surface, where soil moisture is often adequate even during dry weather.

Light will influence how crops and weeds compete. For example, foxtail that emerges with soybeans may reduce yields by over twice as much as it will in corn. Foxtail is able to overtop the beans and continue its growth. But if the crop is given a head start on the foxtail, soybeans compete more aggressively with grass weeds than corn since soybeans provide a complete canopy more quickly (Aldrich, 1984).

Weed Life Cycles

Summer Annual Weeds: Germinate mainly in spring, sometimes in summer; produce seed by fall; mature and die by fall, or freeze

Summer annual grasses: crabgrass, foxtails, grassy sandbur, shattercane, barnyardgrass, fall panicum, witchgrass

Summer annual broadleaf weeds: wild buckwheat, Pennsylvania smartweed, kochia, lambsquarters, ragweeds, pigweeds, velvetleaf, venice mallow, sunflower, cocklebur, devilsclaw, morning glory

Winter Annual Weeds: Germinate mainly in late summer and fall; overwinter as vegetative rosettes; bolt in spring, flower, set seed, and die by early summer

Winter annual grasses: cheat, downy brome, Japanese brome, jointed goatgrass

Winter annual broadleaf weeds: henbit, field pennycress, tansy mustards, flixweed, horseweed (marestail), prickly lettuce, evening primrose

Short-Lived Perennial Weeds: Persist up to several years; form taproot, reproduce by seed and not via underground rhizomes Examples: curly dock, dandelion.

Perennial Weeds: Germinate at various times of year, according to species; often persist for many years, spreading through fragmentation in tillage operations; accumulate food reserves in underground roots and rhizomes

Perennial grass weeds: Johnsongrass, windmillgrass

Perennial broadleaf weeds: field bindweed, swamp smartweed, climbing milkweed, common milkweed, hemp dogbane, burragweed, smooth groundcherry.

Cropping and Tillage Systems to Reduce Weed Pressure

Crop Rotations

The starting point for successful weed management by non-chemical methods is crop rotation. For any given crop, weed species with life cycles similar to the crop tend to increase. Weed species that pose problems in summer row crops include broadleaf weeds like pigweeds, velvetleaf, cocklebur, sunflower, and grass weeds like foxtails, crabgrass, and shattercane. Adding a winter crop such as wheat to the rotation, along with the summer tillage that follows wheat harvest, helps to disrupt the normal growth pattern of the summer annual weeds.

Adding perennial crops to annual crop rotations steps up pressure on weeds. Once established, a healthy stand of alfalfa is extremely competitive with annual weeds. Repeated alfalfa harvesting for forage is detrimental to perennial weeds such as johnsongrass and milkweed, as well as annual weeds. Smooth brome is a widely used crop on marginal lands. When properly managed, it is extremely competitive and will crowd out most weeds.

"You cannot simply use a corn/soybean rotation and expect to have a strategy of non-chemical weed control work satisfactory," explains Jim Bender, who operates a 650-acre Nebraska farm without the use of herbicides. Ninety percent of Bender's cropland is highly erodible with conventional terraces and waterways. Non-chemical weed control becomes easier with experience, claims Bender. But, he cautions, "farmers using this method must be willing to give attention to details."

Oren Holle, an organic farmer near Bremen, KS, agrees. "You must take more than a windshield approach to weed management," says Holle. "You need to get out of the pickup and walk your fields." The Holles' rotation includes alfalfa spring seeded with oats into soybean stubble. The alfalfa is hayed for two years and then rotated either to wheat or corn. Such a rapid rotation of alfalfa prevents the stand from becoming thin and leaving an opening for weeds. Corn is followed with a soybean-corn-soybean rotation of crops. As with most organic farmers, this rotation is flexible and is based upon soil fertility needs and weed pressure. A problem in either soil fertility or weed pressure will shorten the rotation back to a perennial legume, usually alfalfa.

Leguminous crops, including deep-rooted clovers and alfalfas, summer annual soybeans, and winter annuals such as hairy vetch and Austrian winter peas, have a particularly good effect on other crops in the rotation. When legume seed is properly inoculated at planting time, symbiotic bacteria associated with these crops fix atmospheric nitrogen that may benefit the following crop. The winter annual legumes can fit the narrower windows between cash crops, adding soil organic matter and improving soil tilth. Red clover provides forages for livestock and a rotation between crops.

Crop and Weed Competition Principles

- All green plants require the same resources: light, water, nutrients, and space.
- The plants that first occupy a site with these resources will have a distinct competitive advantage over plants that come later.
- There is usually a fixed amount of plant dry matter production on a given soil surface, irrespective of the species (weed or crop) composition.
- Weeds should be prevented from growing with the crop during the first few weeks, or removed within the first few weeks, to protect crop yields.
- Weeds that emerge after about one-third of the life cycle of annual crops usually do not reduce crop yields.
- Broadleaf weeds tend to reduce crop yields more than grassy weeds, on a "per plant" basis.

Allelopathy

Allelopathy, where toxic chemicals produced by one crop suppress other plants, is another consideration in planning crop rotations. Smaller seeded crops planted into rye mulch appear to be more suppressed than larger seeded crops. Smooth crabgrass and common purslane were particularly suppressed by residues of sorghums and oats (Putman, 1988). Recent KSU research suggests that allelopathic effects may be reduced by tillage.

Tillage Between Crops

Weeds invariably get started in any crop. Farmers committed to non-chemical weed management will find it necessary to terminate weed growth with tillage soon after crop harvest and throughout fallow periods. Primary tillage with moldboard plows, disk plows, and twisted-shank chisels may be used, however these implements bury a high percentage of plant residues, which is not consistent with good soil conservation. Deep tillage requires high horsepower and results in soil drying. Furthermore, it must be followed by multiple shallow tillage trips to firm up the seedbed.

Undercutters and field cultivators with high residue clearance are alternative implements which stir the soil and eliminate growing weeds, while sacrificing only about 15 percent of surface residues with each pass. Such field cultivators typically have four or more rows of widely spaced sweeps for maximum residue clearance. Sweeps are typically 18 to 24 inches wide, with six inches of overlap. They can operate shallowly with minimal residue incorporation and minimal oxidation of soil organic matter. Leaving a soil surface that is reasonably rough and somewhat cloddy is detrimental to weed establishment during fallow periods.

Tillage encourages seed germination. The timing of tillage operations affects which weed species will later dominate. Moldboard plowing suppresses perennial weeds and buries surface seeds. Shallow tillage stimulates more weed germination than plowing. Early spring tillage in April will stimulate more weed seed germination than later operations in June. Reduced tillage may increase perennial weeds, small-seeded annual grasses and broadleaves at the expense of larger seeded annuals such as velvetleaf. For farmers dependent on mechanical cultivation, extra effort to restrict weed seed banks by maintaining clean fields is a wise management strategy. Large seed banks can later haunt the farmer when wet weather disrupts timely field operations (Regnier and Janke, 1990).

Establishing a Good Seedbed for Row Crops

The condition of the seedbed at planting and the timing of precipitation, can make or break a non-chemical approach to row-crop farming. Jim Bender, an organic farmer near Omaha (Bender, 37), cautions that a farmer must wait for fields to dry out properly before beginning tillage in the spring. He describes the optimum seedbed as one where the surface is dry with adequate soil moisture at seed depth. This allows the crop to germinate immediately while weed seed germination is delayed until after the next rain. The longer the delay until the next rain, the better the competitive edge of the crop.

Bender times his preplant tillage to manipulate soil moisture conditions. On wetter soils, he may allow up to 36 hours of natural drying between final tillage and planting. Or, a field may be worked twice to eliminate problem weeds and dry out the soil more quickly. During dry weather, soil moisture may be conserved by shortening the time period between the last tillage operation and planting. This might necessitate one person working the field with another person immediately following with a planter.

Wet seedbeds create compaction problems. Shallow germinating weeds such as grasses and pigweeds germinate readily where surface soils are compacted. The soil is too wet if the planter's furrow-closing wheel leaves a visible soil track.

Seedbeds that are too dry may result in uneven crop germination, or in no germination at all before the next rain. In either case, the crop will not have the height advantage needed for later weed control practices.

Preplant tillage should be kept shallow, leaving a field surface that is slightly, but not excessively, rough and cloddy. Field cultivators with leveling harrow attachments achieve this condition most closely. Tandem disk harrows tend to leave the surface excessively smooth and subject to erosion by wind and water.

Optimize Planter Effectiveness

Farmers have been able to adapt a variety of planters and tillage practices to their non-chemical systems. Modern surface planters are designed to drop the seeds into a slit and then squeeze the soil firmly around the seed. Dry soil stays on top and moist soil remains under the surface. This is a good combination for weed control.

Ridge till planters may be used to shave the top of ridges, pushing residue and weed seeds into the row middles. KSU research at the Ottawa Experiment Field has demonstrated the management advantages of ridge tillage has demonstrated the management advantages of ridge tillage to reduce or eliminate herbicides (Janssen and Regehr, 1990). Preplant cultivation of furrows between the undisturbed ridges may be necessary to control early spring weeds where no burndown herbicides are used.

Some farmers use a lister-type planter that ridges soil between the rows. Such planters can place seed in moisture even when topsoils are excessively dry. Soil in the ridge can later be moved back into the row with cultivation. A drawback of lister planters is they leave the crop vulnerable to drowning and they bury crop residue.

Leaving the area dry and loose between rows discourages the germination of small seeded weeds such as pigweeds and grasses. Larger seeded weeds, such as velvetleaf and cocklebur, germinate from greater depths, and therefore, are more difficult to control. Generally weed control with tillage is easier in drier years.

Every tool has strengths and weaknesses. A fiscally conservative approach is to learn how to adjust the mechanical tools you currently have to control weeds. As farm profits allow, consider upgrading your tillage steel later.

Sharpen Your Non-Chemical Weed Management Skills with Soybeans

Weeds in soybeans are generally more easily managed without herbicides than weeds in corn or sorghum. Under Kansas conditions, soybeans may be planted up to the end of May without yield penalties. Soybean seeding rates are often increased to more quickly shade the row. Such increased seeding is not detrimental to yields.

Soybeans are more competitive against weeds than corn. Research at the University of Minnesota revealed that soybeans can withstand a far greater stand loss than corn before significant yield reductions are experienced (Gunsolus, 1990). Grain sorghum stubble appears to provide some allelopathic suppression of weeds, giving soybeans planted into sorghum stubble an additional competitive edge on weeds.

Optimize the Relationships Between Soil Temperature and Germination

Corn planted in 55 degree Fahrenheit soils at the 2-inch depth may take two weeks or longer to emerge, whereas corn planted at a constant 60 degrees will emerge in seven to ten days. Mechanical weed control is less effective when crop emergence is delayed. Ridge-till planted corn benefits from warmer temperatures earlier than corn on level surfaces.

For rapid germination of soybeans, soil temperatures should be 55 to 60 degrees because cooler soil temperatures hinder germination. A soybean seedling will emerge in five to seven days after planting when the soil temperature reaches the middle sixties. Soybeans should not be planted when the soil temperature is high unless sufficient moisture for rapid germination is present or assured. Soybean seeds lose vigor when subjected to high temperatures and humidity.

Grain sorghum germinates quickly when the soil temperature is a consistent 65 degrees and the planting depth should be 1- 1½ inches.

Plant Later to Speed Crop Germination

Summer annual weeds such as foxtails, lambsquarters, and redroot pigweed begin germination in late April, peak in mid-May, and taper off into early June. These weeds tend to have a peak germination flush followed by diminished flushes.

Farmers should consider planting later in the season to take advantage of these germination cycles, and to till out extra flushes of weeds. As the soil warms up later in the season, the crop will germinate quicker and grow faster. Staggering planting times also stretches the farmer's workload over a longer period of time so that timely post-plant cultivation can be performed during the busy summer season.

The importance of timeliness in cultivation creates physical limits on the number of acres that can be successfully managed with non-chemical weed control. A farmer will likely not be able to manage as many acres as mechanical cultivation is substituted for herbicides. For this reason, it is important for farmers to transition slowly as they reduce their herbicide use.

Spreading out spring planting also spreads out the risks associated with weather. Staggered plantings allow more time flexibility for later cultivations. Later planting dates may give larger time windows for mechanical operations as rainfall decreases through the growing season. Medium and short-season varieties can be used to stretch the planting season. This strategy is more useful for soybeans and sorghum than for corn, because of weather-related reductions in yield potential when corn seeding is delayed.

Later planting dates must be balanced against yield reduction of shorter season varieties and the danger of frost. Untimely rains may cause delays well beyond the optimum planting date for the crop. Additional risks are that extra tillage trips may result in excess moisture evaporation from the seedbed and greater exposure to erosion.

"If there is a threat of severe weather, I delay planting because a heavy rain packs the ground so hard that weeds emerge very quickly," explains Larry Ketter, a farmer near Marysville who has farmed organically for the past 15 years. Delaying planting lets him get in an extra preplant tillage to remove another flush of He aims to plant corn between May 20 and June 7, and soybeans during the first week of June. He plants a bushel of soybeans per acre in 30-inch rows to get a thick stand down the row and to compensate for later losses from rotary hoeing and cultivation.

"Ideally you want to plant in soil that has just enough moisture to get the crop up," suggests Darrell Parks, who manages a diversified farm near Zeandale. The drier the seedbed the fewer germinated weeds, observes Parks. But too dry soils can create uneven crop emergence, arresting good weed management. "It is a mix of judgment and art to do this well," reflects Parks. He prefers to plant corn during the first two weeks of May. Grain sorghum and soybeans are targeted for the last week of May. Because the Parks farm has tight soils with poor drainage, he wants to get crops established before the anticipated heavier June rains.

Oren Holle recommends using waterways and grass buffers for turning equipment to reduce turn rows. Being organic relieves Holle from worrying about dribbling chemicals on the grass during turns. Ed Reznicek, an organic farmer near Goff, also recommends designing fields to optimize their length to reduce turn rows.

Increase the Seeding Rate

Higher seeding rates can lend a competitive edge to a crop by more quickly shading out weeds. Iowa State researchers report that weed populations decrease with thicker stands of soybeans. The seeding rate should be increased 5-10% to compensate for later tillage losses.

Super-thick sorghum, researched at KSU's Hays Branch Experiment Station, is a strategy to enhance crop competition over weeds. Sorghum drilled later in the season, in warmer soils, at higher seed populations, and in narrower rows usually outgrows weeds.

Manage for Even Crop Emergence

Uniform spacing of the planted crop helps shade all weeds. Crops sometimes emerge unevenly because of environmental factors that growers cannot control. Nevertheless, the following management practices can help avoid uneven stands:

- Avoid excessive tillage trips that dry or compact the seedbed.
- Remember that tilling when soils are too wet can produce cloddy soils, a major cause of uneven stands.
- Dig up some seeds during planting to monitor seed placement. If seed to soil contact is poor or seeding depth isn't uniform, adjust row openers and/or press wheel tension.
- Secondary tillage operations may need to be changed to improve soil conditions for more uniform planting.
- After planting, closely monitor corn emergence and use a rotary hoe if a sod crust is keeping corn from emerging uniformly.

(*Carter, Paul and Emerson Nafziger. Uneven Emergence in Corn. NCR Extension Publication No. 344*.)

Always Plant into Fields Free of Growing Weeds

Focus your crop management efforts to give the crop a head start over weeds. The battle against weeds is won or lost during the first month after planting. The first plant that gets the water, nutrients, and light will have a distinct competitive advantage over later plants. Consider the runt of a litter competing against litter mates. The runt never catches up. The same is true for plants. Both weed and crop plants are very good competitors if they get a head start and poor competitors if they get behind the competition.

Weeds that emerge after one-third of the life cycle of annual crops usually do not reduce the crop yield. Foxtail in corn or soybeans made very little growth if the crop was given a three week head start (Knake and Slife, 1965). For corn, three to five weeks is the critical period to work on weed control. With sorghum and soybeans the critical period is three weeks (Zimdahl, 1980). The heavier the weed pressure, the shorter the period that weed competition can be tolerated. Crops such as wheat, corn, soybeans, and sorghum have very rapid vegetative development allowing them an equal growth pace with most annual weeds. Alfalfa, on the other hand, develops very slowly and, if not adequately protected in spring plantings, may be smothered by faster growing weeds.

"Under certain management practices, we have seen as much as 75% of the weed suppression contributed by the crop," explains Dave Regehr, Extension weed specialist at Kansas State University. However, Regehr cautions, failure to control the other 25% of the weeds can ruin a crop. A weed management system based on crop rotations integrated with between crop tillage and in-crop cultivation can be used to protect yields.

Non-Chemical Weed Control After Row Crop Planting

The Rotary Hoe

The rotary hoe is an important tool for the farmer in transition to non-chemical weed control. Under the right conditions, it can give the crop a one to two week head start over weeds.

The basis for selective weed control with the rotary hoe is the depth at which seeds germinate. Row crop seed is typically placed 1.5 to 2 inches deep in the soil, whereas nearly all small-seeded weeds and grasses germinate within the top half inch of soil.

Rotary Hoe Before You See Weeds

When rainfall has stimulated a new flush of weed seed germination in the surface soil, but before the majority of seedlings have emerged, superficial tillage kills the weeds by disrupting water uptake. The hoe works best in somewhat crusted soils that have dried enough to crumble easily. A bright, hot day also improves the effect of hoeing by increasing the wilting of the weeds.

The rotary hoe is also useful to break the soil crust after a rain. This encourages crop emergence and helps dry out the soil surface to desiccate weed seedlings. Once the weed roots penetrate beneath the rotary hoe depth, the weeds are not uprooted and can not be effectively controlled by the rotary hoe. The rotary hoe is least effective on weeds that germinate from deeper than two inches beneath the surface of the soil such as cocklebur, velvetleaf, and shattercane (Gunsolus, 1990). (Refer to page 11 for tips on when to rotary hoe different crop species.)

Jim Bender’s Experiences with the Rotary Hoe and Harrow

A farmer cannot afford to be casual about when to rotary hoe, cautions Bender. He has twenty years experience farming without herbicides, and considers the rotary hoe an essential tool to manage weeds without chemicals. Timing the use of the rotary hoe is planned differently with each crop.

Corn is the crop best adapted to rotary hoeing. From planting through spike stage and early post-emergence, it tolerates hoeing with little stand loss. If weeds are germinating and soil conditions are right, Bender may make the first rotary hoe pass as early as two to three days after planting. Additional passes may be made at 4 to 10-day intervals if needed, until corn is about 8 inches tall.

Grain sorghum presents the greater weed management challenge for Bender. The first rotary hoe pass on grain sorghum is made a few days after planting, before the spike stage. There is then a “dead period” of about a week when the sorghum seedling is very vulnerable to soil disturbance. During this time, the crown node becomes established just below the soil surface.

Monitor Crops Using Economic Thresholds for Tolerable Weed Escapes

The economic cost of different weeds in the crop field varies significantly. On a per weed basis, broadleaf weeds cause greater yield reductions than grasslike weeds. On a dry matter basis, velvetleaf reduced soybean yields by twice the amount of foxtail. Cocklebur is twice as damaging as johnsongrass. Broadleaf species are more competitive with crops due to their spreading growth form and more horizontal leaves which can intercept more sunlight. However, of the world's ten most serious weeds, eight are grasslike (Aldrich, 1984).

“Weed density is much less important than weed size in causing crop losses,” states Dave Regehr, Extension weed specialist at KSU. A single weed plant that germinated and grew with the crop, is likely to be more harmful than a hundred weed plants that germinated later under the crop canopy.

A general rule is that weeds and crops that have similar growth habits, with similar demands on limited field resources, will create a pound-for-pound trade off of crop dry matter for weed dry matter (i.e., a ton of weeds in a field is there at the expense of a ton of crop. The tendency is for the combined dry matter production on a given area to be constant irrespective of the weed-crop composition. Therefore, weeds must either be prevented or removed in order to maintain the crop yield (Aldrich, 1984).

The second hoe pass should be made about one week after the spike stage. Bender considers the rotary hoe critical to effective weed control in sorghum.

Seedling soybeans may be rotary hoed up to the time when the hook-shaped hypocotyl (the soybean crook stage) nears the soil surface. The soybean crook is a turgid structure more vulnerable to physical breakage than the spikes of corn or sorghum seedlings. Breaking the soybean crook with the rotary hoe will kill the plant. When the soybean plant has a trifoliate leaf, it is again less vulnerable to rotary hoe damage. It is a good idea to hoe soybeans late in the day when they have lost their early morning turgidity. Especially in dry years, Bender waits for a visible need to rotary hoe on later-planted soybeans.

The farmer should know if good weed control has been obtained after the last rotary hoe operation. If good control has not been achieved by this important stage, later cultivation probably won't be enough to help the farmer to catch up, believes Bender. Rotary hoe speeds vary from 7-13 MPH with the 31-foot rotary hoe used by Bender.

Bender recommends the widest hoe possible within the limits of resources, terrain, and horsepower. Extra hoe width is desired to reduce wheel tracks, improve timeliness of operation, reduce end turns, and hold the tractor more level away from terrace slopes. Hydraulic wings and gauge wheels facilitate flexing on terraces and transportation. Bolt-on wheel bearings permit quick repairs in the field. The width of the hoe should match row widths so as to not create gaps or double hoeing on edges.

Bender never turns the tractor or lifts the wings until the hoe is off the ground. Lifting the wings slightly reduces the opportunity to gouge terraces or hills before turning. Backing in turns pushes the hoe weight towards the tractor making turns easier. Weights in the front of the tractor assist turning. Rotary hoe the edges of fields and waterways first, suggests Bender, to avoid working them after the soil has been packed by turns.

Harrowing can be done in place of a second rotary hoe pass in soybeans. It can also substitute for a pre-emergence rotary hoe operation. Bender uses a harrow with 15-inch long spring tines with 4 to 5 sections hung on chains. The harrow is fully mounted to permit backing up. His harrow covers ten 30" rows with flexibility to follow both terrace channels and level areas. The harrow tines are 5/16 inch thick.

The harrow cannot work in heavy plant residues but it will work through soybean stubble. The harrow tends to be too aggressive on grain sorghum. Its action works both between and in the row. Bender recommends using speed, the adjustable pitch which is normally set at a 45 degree angle, and tires for weights to manipulate the harrow's tillage aggressiveness.

Begin Inter-Row Cultivation Early

Timing of cultivation is more flexible than for rotary hoeing, but row crop cultivation should begin early enough so that the cultivator kills weeds. Research with soybeans reveals that the month after planting is the critical window for weed control to prevent yield loss (Horn and Burnside, 1985).

Several types of row-crop cultivators are common in Kansas. Rolling cultivators (Lilliston-type) may be preferred in sands and where surface soils are especially mellow. S-tine and shovel-type cultivators are also common. All these types are most effective when weed seedlings are small, and where crop residue levels are low.

High-residue cultivators have become common. These usually feature disk hillers that cut soil away from the crop row, followed by a coulter that cuts through residues and a single rather wide sweep that cuts off all weeds, annual and perennial, regardless of size, and nudges tilled soils back towards the crop row.

All cultivators should be adjusted to push soil on both sides of the growing crop row. Cultivator shields help to protect small crop plants from being covered with soil. Correct cultivator adjustment and careful driving prevents "cultivator blight." Electronic guidance systems may permit more precise cultivator adjustment, and reduce operator fatigue. Research in Illinois and Indiana has shown that cultivation can be profitable due to factors other than weed control. Cultivation can increase water infiltration on soils that are crusted. In addition, cultivation can reduce soil erosion and improve soil aeration (Johnson, 1985).

"Wet farming is always detrimental to weed control," cautions Oren Holle who farms with his brother, Leland, near Bremen. It is important to get a good start with timely preplant tillage, asserts Holle, but exercise patience when the soil conditions are unfavorable. Holle points out that row crop cultivation takes on harvest urgency when it is time to cultivate weeds. The Holles may even park their combine during wheat harvest to achieve timely cultivation of their organic row crops.

"Different organic farmers have different tips about how to use their equipment. We like our rolling cultivators but others like their curling machines and shovel cultivators," says Holle. "But it doesn't really have so much to do with the type of equipment that you use, as it is personal preference. The primary factor is to have tools that can work small crops, and timeliness," concludes Holle.

When early weed pressure is high, Darrell Parks will cultivate earlier and do the first rescue cultivation cleaning out the middle of the row with the fenders down to protect the young crop. A week later, in a taller crop, he will lift the fenders and push soil into the crop to bury weeds. (Check out the later reading resource section for the listing of "Steel in the Field" written by Greg Bowman.)

Hand Rogueing to Control the Weed Seed Bank

Despite timely and attentive weed management, escape weeds are bound to occur. Both Holle and Parks feel that walking fields to prevent seed production by large weed plants can be a good investment toward future weed control. This is especially true for deep-germinating weed species such as cocklebur, velvetleaf, and shattercane.
Since these weeds are not very vulnerable to control with the rotary hoe, reducing their seed production is especially important. Hand rogueing is also important where new weed species have been introduced in a field. Hand rogueing can provide useful work for youth, keeping dollars circulating in the local community.

Keep Field-by-Field Records of Significant Weed Problems

Weeds seldom blanket a field uniformly. Keep track of which weed species are particularly problematic and where they tend to be located. These records will be useful as you develop crop rotation plans. The most problematic areas can be planted later for extra preplant tillage or rotated sooner to improve weed management. See the example of a field weed inventory on page 13.

Summary

Successful weed control requires good crop rotations and timely tillage practices. An effective manager has to pay attention to details and monitor the crop through the growing season. It is wise to have a contingency plan, in case your weed management falls short. Depending upon your farm goals, this may be replanting, rotating to a different crop, livestock utilization, or herbicides. Keep in mind that permitting weeds to go to seed builds a seed bank. A step-by-step summary of this management guide is on page 12.

REFERENCES

Aldrich, R.J. 1984. Weed-Crop Ecology: Principles in Weed Management. Breton Publishers. North Scituate, MA.

Alkamper, J. 1976. Influence of Weed Infestation on Effect of Fertilizer Dressings. Pflanzenschutz-Nachrichten 29, pp. 191-235.

Baker, H.G. 1974. The Evolution of Weeds. Annual Review of Ecology and Systematics, Vol. 5.

Bazzaz, F.A. 1970. Secondary Dormancy in the Seeds of the Common Ragweed *Ambrosia artemisiifolia*. Bulletin of the Torrey Botanical Club 97, pp. 302-305.

Bender, J. 1994. Future Harvest. University of Nebraska Press. Lincoln, NE. (Additional references are drawn from his comments at a Sustainable Agriculture Conference in St. Marys, Kansas in 1990.)

Carter, P. and E. Nafziger. 1989. Uneven Emergence in Corn. North Central Regional Extension Publication No. 344. University of Illinois. Urbana-Champaign, IL.

Gunsolus, J. 1990. Mechanical and Cultural Weed Control in Corn and Soybeans. American Journal of Alternative Agriculture. Vol. 5(3), pp. 114-119.

Ham, G. 1989. Future Research Thrusts: Experiment Fields. A Role and Mission Report for the Special Committee on Agriculture and Livestock. Kansas State Agriculture Experiment Station, Kansas State University.

Harlan, J.R. 1992. Crops and Man. 2nd ed. American Society of Agronomy. Madison, WI.

Horn, P. and O. Burnside. 1985. Soybean Growth as Influenced by Planting Date, Cultivation, and Weed Removal. Agronomy Journal. Vol. 77, pp. 793-795.

Janssen, K.A. and D.L. Regehr. 1990. Reduced Tillage Weed Management with Minimal Chemical Input for Soybeans and Grain Sorghum. Conservation Tillage Research. Report of Progress 598. Kansas Agricultural Experiment Station, Kansas State University.

Johnson, R. 1985. A New Look at Cultivation. Crops and Soils Magazine. Vol. 37(8), pp. 13-16.

Knake, E.L. and F.W. Silfe. 1965. Giant Foxtail Seeded at Various Times in Corn and Soybeans. Weeds. Vol. 13(4), pp. 331-334.

Putnam, A.R. 1988. Allelopathy: Problems and Opportunities in Weed Management. pp. 77-88. In: M.A. Altieri and M. Liebman (ed.) Weed Management in Agroecosystems: Ecological Approaches. CRC Press, Inc. Boca Raton, Florida.

Regehr, D.L. and K.A. Janssen. 1989. Preplant Weed Control in Ridge-till Soybean (*Glycine max*) and Grain Sorghum (*Sorghum bicolor*) Rotation. Weed Technology. Vol. 3, pp. 621-626.

Regehr, D.L. Integrated Weed Management for Croplands. Kansas State University. Extension Agronomy mimeograph.

Regnier, E. and R. Janke. 1990. Evolving Strategies for Managing Weeds. In: C. Edwards (ed.) Sustainable Agricultural Systems. Proc. International Conference on Sustainable Agricultural Systems, Columbus, OH, September, 1988. Soil and Water Conservation Society. Ankeny, IA.

Zimdahl, R. L. 1980. Weed-Crop Competition: A Review. International Plant Protection Center. Oregon State University. Corvallis, OR.

Other Resources

Bowman, G. 1997. Steel in the Field: A Farmer's Guide to Weed Management Tools. Sustainable Agriculture Network. Beltsville Maryland. (For more information, contact Andy Clark, (301)504-6425 or san@nal.usda.gov.)

Shirley, C. 1993. What Really Happens When You Cut Chemicals? The New Farm. Rodale Press. Emmaus, PA.

Sullivan, P. 1997. Principles of Sustainable Weed Management. ATTRA. (To order, call (800) 346-9140.)

Crop Production Handbooks for Alfalfa, Corn, Grain Sorghum, Soybeans, Sunflowers, and Wheat, available from Kansas State University Research & Extension, through Kansas county extension offices.

CREDITS

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