2 Tillage and Cropping Systems

Tillage

Soil preparation is an important aspect of vegetable preparation. There are different approaches to field preparation and the dealing with residue left behind by the previous crop. Plowing has been associated with crop production for much of recorded history. A plow is an agricultural implement with a sharp surface used for cutting and/or turning soil. Plows allow the soil to be broken so seeds can be planted. The plow may have first appeared around 1000 BC in the Near East and existed as early as 500 BC in China (Lal *et al.*, 2007). Moldboard plows were known in Britain after the late 6th century (Hill and Kucharski, 1990). The moldboard design consists of a curved plate with a sharp edge that turns over the soil so the top layers are buried and moist friable layers are brought the surface (Fig. 2.1).

Animals were initially used to pull these implements. Wooden plows remained the standard until Jethro Wood invented a cast-iron plow with interchangeable parts in the early 1800s. John Lane invented the steel plow shortly thereafter. In 1865, John Deere patented a steel plow in the USA similar in design to ones used today. Disc harrows were introduced in the 1860s to prepare soil with minimal residue or a plowed field for planting by breaking clods and incorporating residue into the top layer. Rotary tine tillers (RTT) that are powered by a tractor's power take-off became popular during the 1960s and 1970s because they pulverize soil close to the surface creating small soil particles well suited for the planting of small-seeded vegetables (Lal *et al.*, 2007).

Since its invention almost 170 years ago, the modern steel plow has been widely used for preplant soil preparation to establish vegetable crops. Plowing to prepare fields for vegetable production is popular because it produces a friable seedbed well suited for planting small-seeded vegetables that need good soil contact to germinate. Before planting, plowed soils are often further tilled with other implements like the disc harrow or RTT (Lal *et al.*, 2007). Tillage destroys existing weeds that may compete with emerging vegetable seedlings. The emergence of some vegetables is slowed by heavy residue on the soil surface and plowing buries the remains of the previous crop. Deep plowing also aids disease control by burying contaminated residue. Bare soil tends to warm faster in the early season compared to soil covered with residue, which leads to earlier maturity, an important goal for many growers in short-season areas (Table 2.1).

However, there are several negative factors associated with plowing. The bare soil produced is prone to erosion, particularly after fall plowing or on soils that are sloped. The heavy equipment used to plow and till compacts soil, uses energy and requires labor. Also, weed seeds are brought to the surface (Table 2.1).

Deep tillage with a moldboard plow and associated implements used to prepare a field before establishing the next crop is called conventional tillage. Conventional tillage is when <15% of previous crop residue remains on the soil surface following establishment. Conventional tillage can be thought of as "full-width" tillage because 100% of the topsoil is moved and mixed so that the majority of crop residue is incorporated into the soil.

An easy and effective way to obtain early-season weed control is by the stale bed technique (Riemens *et al.*, 2007). This technique requires that the seedbed be prepared several weeks before the intended planting date so weed seeds germinate before the crop is planted. To kill the first flush of weeds, herbicides or shallow cultivation are used prior to planting. If cultivation is used, care must be taken to avoid bringing new buried weed seeds to the surface (Riemens *et al.*, 2007). The stale bed technique is sometimes difficult to employ because a wet early season may prevent soil preparation in advance of planting.

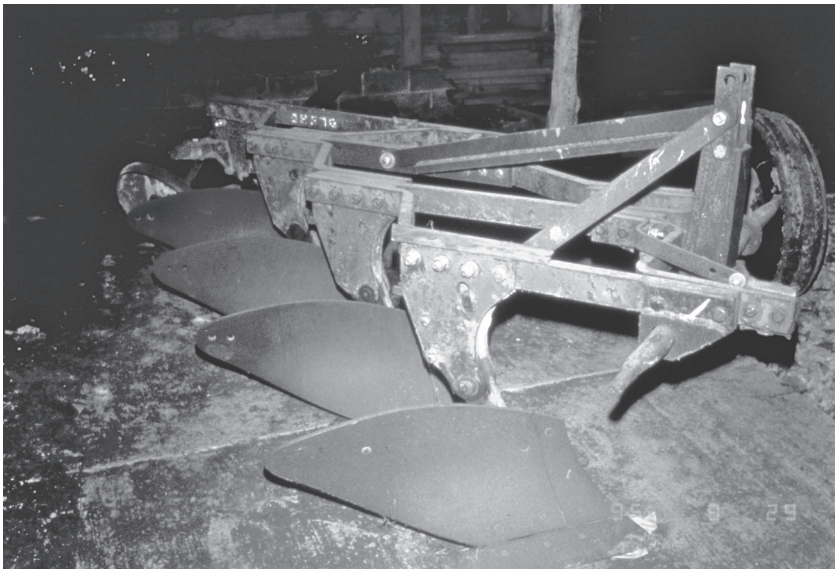

Fig. 2.1. This “four bottom” steel moldboard plow is pulled by a tractor.

Table 2.1. The advantages and challenges of growing vegetable crops using conservation tillage techniques.

Conservation tillage limitations/challenges	Conservation tillage advantages
Lowers soil temperatures	Requires less machinery
Slows germination and emergence	Requires less labor
Slower early growth	Requires less fuel
May delay spring planting	Reduces soil erosion
May increase certain diseases	Reduces soil compaction
Heavier crop residue so planter operation is more difficult	Weed growth is delayed
Weed spectrum changes	More moisture is retained in soil
Increased insect pests	

In addition to the moldboard plow, less disruptive tillage implements have been developed. Graham-Hoeme Plow Company developed chisel plows in the 1930s. The chisel plow breaks the soil surface without inverting the top layer (Fig. 2.2; Lal *et al.*, 2007).

During the last 40 years, chisel and coulter-chisel plows have helped popularize conservation tillage practices. In the 1970s–1980s a wide range of conservation tillage systems were developed.

Conservation tillage is any method of soil cultivation that minimizes soil disturbance and leaves the previous year’s crop residue in fields before and after planting the next crop (Derpsch, 1998). Crop residues reduce soil erosion, conserve moisture, inhibit weed growth and build soil organic matter. To be considered conservation tillage at least 30% of the soil surface must be covered with residue after planting the next crop. Some conservation tillage methods forego traditional tillage entirely and leave 70% residue or more. Several types of conservation tillage are used as well as combinations of conservation and conventional tillage. A few of the more popular techniques include: no-till, strip-till, ridge-till, and mulch-till (Derpsch, 1998). Each method requires specialized or modified equipment and unique management practices.

No-till systems leave the soil undisturbed from the time the previous crop is harvested until the new crop is planted. Nutrients are precision placed in the soil rather than broadcast. Transplanting or seeding is accomplished in a narrow seedbed or slot created by coulters,

Fig. 2.2. This chisel plow mounts to the three-point hitch of a tractor and can be raised and lowered hydraulically.

disk openers, or in-row chisels (Derpsch, 1998). Weed control is accomplished through herbicides, by hand, or by mowing. Cultivation is only used for weed control in an emergency. No-till systems, when managed properly, frequently out-yield fields established with conventional tillage systems because of greater moisture retention especially in dry areas (Table 2.1).

Strip-till involves planting crops in a narrow tilled space with chisels or tillers cleared of residue with row sweepers while the rest of the field is left untilled. The tilled strip offers a more favorable soil environment for the rapid germination and emergence of small-seeded vegetables because a finer seedbed is prepared and mulch is removed above the seed to encourage rapid emergence.

Ridge-till involves planting row crops on permanent ridges about 10–15 cm (4–6 in) high. The previous crop's residue is cleared from ridge-tops into adjacent row middle furrows. Maintaining the ridges is essential and requires modified or specialized equipment such as cleaners, sweeps, disk openers, or coulters. Nutrients are precision-placed into the ridges rather than broadcast over the entire field. Weed control is accomplished by hand, herbicides, or cultivation.

Mulch-till disturbs the soil with chisels, field cultivators, disks, sweeps, or blades before planting. Mulch-till leaves at least one-third of the soil surface covered with crop residue (Derpsch, 1998). Weed control is accomplished by hand, herbicides, and/or cultivation.

Conservation tillage methods are advantageous because they reduce labor, fuel costs, field preparation time, erosion, and soil compaction (Table 2.1). Conservation tillage has become the predominant method for establishing agronomic crops in much of North America and is extensively used in other parts of the world as well. The transition to conservation tillage has been slower for vegetable crops because of the extensive use of plastic mulch, which requires a smooth seedbed free of residue. Successful stand establishment of direct-seeded vegetables also requires small soil aggregates to ensure good seed-to-soil contact. A well-tilled seedbed promotes uniformity and earliness, priorities for many vegetable growers (Table 2.1). However, conservation tillage is used for vegetable crops that are not grown on plastic mulch, where earliness is not a priority, are transplanted, and are produced on highly erodible soils.

Adjustments can be made to successfully deal with some of the challenges presented by conservation tillage while retaining the many advantages. For example, adjustments for planting in cooler soils that often result from conservation tillage include shallow planting (2.5 cm, 1 in or less), good seed–soil contact, slow planting (pull the planter at 8 km/h, 5 mph or less) and use of high-quality seed. Vegetable growers who use no-till often use pelleted seed to ensure good soil contact.

Techniques for decreasing root rot disease may include: planting when the field is not excessively wet, using ridge-till or raised beds to promote drainage, install tile drainage systems in fields, treating seeds with fungicide or biological controls that reduce disease, and using disease-resistant cultivars if possible.

In conservation tillage systems, growers must adapt to planting in heavier residues compared to conventional tillage. Techniques to mitigate problems include: spreading residue widely and evenly across a field, removing wheat straw or other cover-crop materials that are slow to decompose and may interfere with emergence, using row wipers or sweepers, using planters and transplanters especially designed for planting through residue, and installing harrows on planters.

Conservation tillage may change the type of weeds that growers must control. An effective weed control program for a conservation tillage system may include eliminating perennial weeds, killing weeds preplant, using post-emergence herbicides, and planting narrow rows.

Drainage and Erosion Control

Preventing wind and water erosion are challenges for vegetable farmers. Erosion is of special concern on sloping land where water can quickly displace topsoil, especially when conventional tillage is used. A good rule of thumb is to never leave soil uncovered. This means that residue or a cover crop should always be present to preserve soil resources when a crop is not growing. There are several other management strategies that reduce or prevent erosion.

Waterways are natural or constructed outlets for water, protected from erosion by grass or other perennial cover that holds soil (Fig. 2.3).

Once established, the waterway is not tilled. Waterways serve as safe outlets for runoff water from contour rows, terraces, and other diversions. Natural drainage ways make the best locations for waterways and often require minimal shaping to produce a good channel. Natural drainage ways eventually divert water into a stream or other tributary near a field. Waterways should be designed to be wide and flat so farm machinery can easily cross and yet provide capacity to carry storm runoff safely from the surrounding areas. Weed control in the waterways is generally by mowing. Waterways should be mowed before potential weed seeds are produced. Herbicides or hand removal can be practiced for troublesome perennial weeds.

Contour cropping is the practice of tilling and orienting crop rows along lines of consistent elevation on sloped land in order to conserve rainwater and to reduce soil losses from surface erosion. In simple terms, contour cropping orients rows around a hill rather than up and down it. The crop rows act as small reservoirs to prevent rapid runoff that causes erosion and catch and retain rainwater, improving infiltration and more uniform distribution of water. Contour cropping reduces erosion and is most effective on deep, permeable soils and on gentler slopes of about 2–6% that are less than 91 m (300 ft) long. The effectiveness of contouring

Fig. 2.3. The grass waterway in the center of a harvested corn field in Ohio directs runoff through a natural drainage way that is left in sod and natural weed free vegetation to prevent erosion.

is reduced greatly on steeper or longer slopes because of possible washover of rows by runoff water. In general, contouring can reduce erosion losses up to 50% compared with up-and-down-hill tillage on slopes of from 2–6%. On steeper slopes (18–24%) contour cropping without supplementary practices reduces erosion losses by only about 10%. Grass waterways are necessary to carry the runoff water safely from the contour rows.

Strip-cropping, the practice of alternating contour strips of sod and row crops, is even more effective than contouring. The sod strips help slow runoff and filter out eroded soil. Strip-cropping reduces soil losses to about half that of contouring alone or one-fourth that of up-and-down-hill tillage. Strip widths are governed by the percent slope and vary from up to 30.5 m (100 ft) on 2–6% slopes to 18.3 m (60 ft) or less on 18% slopes and above.

Terraces are channels or ridges built across slopes to catch runoff water and shorten the length of a slope (Fig. 2.4). They are generally more effective than either contouring or strip-cropping alone and are designed especially for steeper slopes. Most terraces are designed with gradual slopes to lead water off safely into grass waterways or other suitable drainage outlets. The number and spacing of terraces depend on the soil type, slope, and cropping practices, and should be designed by soil conservation specialists. Diversion terraces are especially designed to divert larger flows of water away from buildings, gullies, farm ponds, or fields below long slopes.

For production on sloped land, drainage occurs naturally and managing the runoff is of primary concern. However, flat land with heavy soils presents a different challenge for vegetable growers. On level fields that retain moisture and drain slowly, excessive rain or irrigation can cause soil saturation and flooding for extended periods. Most vegetables prefer well-drained soils because root zone anoxia stunts growth and increases root disease and epinasty. Too much water may prevent the use of farm machinery and operating heavy machinery in excessively wet conditions will damage soil structure and cause soil compaction. Wet soils warm slowly, often limiting early season growth. Subsurface field drainage tube systems are installed where drainage is poor to reduce soil moisture to optimum levels for crop growth.

To improve drainage, vegetables are often planted on raised beds shaped after plowing and/or tillage. Raised bed culture is also necessary when plastic mulch is used (Fig. 2.5).

Mulch laying after plowing to improve drainage is popular in regions where heavy rainfalls may saturate soils for part of the growing season (Fig. 2.6).

Fig. 2.4. Terraces enable crop production on steeply sloped land in Taiwan.

Fig. 2.5. Straw mulch and raised beds to improve drainage on level ground.

Fig. 2.6. Mulch laying after plowing to improve drainage.

Surface water can be drained via pumping, ditches, or waterways, but subsurface drainage is often the best option for removing excess water. The goal of a subsurface system is to drain gravitational water from the root zone (Nwa and Twocock, 1969). Beginning in the 1800s, round ceramic tile conduits were placed end-to-end and buried under fields to remove excess water. The tile lines were oriented to feed water into a waterway or stream. Ceramic tile conduits were heavy, expensive, labor intensive to install, and easily broken. Today lines of perforated plastic tubing are laid under fields instead of ceramic or concrete tiles. The introduction of plastic tile served to reduce the cost of installation because a continuous section of lightweight, flexible line can be mechanically laid in a trench and covered relatively quickly. The spacing of depth of a subsurface drainage system will vary based on soil type, crops grown, and precipitation, but a typical flexible plastic line spacing would be 12 m (40 ft), a typical depth would be 0.75 m (29.5 in), while a minimum cover depth would be 0.6 m (23.6 in) (Nwa and Twocock, 1969). Drainage lines that are too shallow can be broken or damaged by cultivation. Roughly 25% of the cropland in the USA and Canada has a subsurface drainage system installed (Wright and Sands, 2001).

Crop Residue Management

A cover crop is planted primarily to manage soil fertility, soil quality, water, weeds, pests, diseases, biodiversity, and wildlife in an agroecosystem (Lu *et al.*, 2000; Hartwig and Ammon, 2002). Typically, a cover or green-manure crop is grown for a specific period of time, and incorporated into the soil while green by plowing or disking. Incorporating cover crops into the soil increases the microbial activity that decomposes the plant matter, releasing nutrients such as nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and sulfur (S) for the next crop. Soil microbial activity also leads to the formation of viscous materials that improve soil structure (Welbaum *et al.*, 2004). Soil structure refers to how individual soil granules clump or bind together to form aggregates. The size of the aggregates also determines the arrangement of soil pores between them. Soil with good structure is better aerated, absorbs water more quickly, and is easier to prepare for seeding than a soil with poor structure. The amount of organic matter in soil also increases with cover-crop decomposition, which improves soil health for subsequent crops.

Legume cover crops, such as beans, alfalfa, and clover, have root systems that form a symbiosis with *Rhizobium* spp. bacterium that fix atmospheric N, making them desirable green manure crops because they require little N fertilizer and have a lower carbon to nitrogen (C:N) ratio (Hartwig and Ammon, 2002). The C:N ratio in a green manure crop is a crucial factor to consider, since it will impact the rate of decomposition, the nutrient content of the soil and N availability for the cash crop. The C:N ratio will differ among cover-crop species and the age of the plant. In the C:N ratio, the value of N is always 1, whereas the value of carbon or carbohydrates is expressed in a value of about 10 up to 90. The C:N ratio should be less than 30:1 to prevent the bacteria from decomposing the green manure crop after it is incorporated into the soil, which would deplete existing soil N. If N in cover crop residue is limiting, decomposing microbes will use soil N instead, decreasing availability for crop plants. Legumes such as crimson clover and hairy vetch may have C:N ratios of 8:1 to 15:1, compared with ratios of 30:1 to 60:1 for wheat (*Triticum aestivum* L.) and rye residues (Ranells and Wagger, 1996). A high C:N ratio is beneficial if a cover crop is used to provide mulch for a vegetable crop planted into residue in a no or minimum tillage production system. For example, rye may be grown as a winter cover crop to stabilize soil. In spring, the rye is rolled or mowed to stop growth before it develops seed so tomato or other vegetables can be transplanted into the straw residue, which forms natural mulch (Fig. 2.7; Hartwig and Ammon, 2002).

In this situation, slow decomposition (high C:N ratio) of the straw cover crop is advantageous because it helps the straw act as mulch for a longer portion of the season before it breaks down. Legumes do not make good mulch crops because they decompose before the growing season for tomato or peppers are over.

Many crops can be used as cover crops (Hartwig and Ammon, 2002). Summer green manure crops that can be used with vegetables include: Egyptian clover, hairy vetch, oats, and sorghum/Sudan grass. Popular overwintering green manure crops include: hairy vetch, crimson clover, winter rye, and winter rape. The use of green manures should be a component of an effective crop management system that uses crop residues to increase soil fertility and prevent soil erosion during periods of high risk. In addition to legumes, certain cultivars of winter rape are used as a green manure crop to reduce nematode populations because of their high glycosinolate content in the residue (Potter *et al.*, 1998; Vargas-Ayala *et al.*, 2000). Glucosinolates and other natural compounds in cover crops may also break disease cycles

Fig. 2.7. A cover crop of rye straw was rolled before seed heads developed to provide mulch for a no-till transplanted broccoli crop.

and reduce populations of bacterial and fungal diseases (Everts, 2002).

Cover crops are sometimes used as "trap crops", to attract pests away from the cash crop to a habitat that is more attractive to the pest (Shelton and Badenes-Perez, 2006). Trap crop areas can be established inside a field or at other locations removed from a field. The trap crop is often grown during the same season as the cash crop. To control insects, the trap crop can be treated with a pesticide or by using sticky traps or suction (Kuepper and Thomas, 2002).

Cover crops may also be used to create species diversity in or around a vegetable field. Certain plants can attract natural predators of pests by providing elements of their habitat. This form of biological control is known as habitat augmentation, and can be achieved with the use of cover crops (Bugg and Waddington, 1994).

Cropping Systems

Much of the large-scale vegetable production in many parts of the world is an intensive monoculture where a single crop is grown in a field and other crops or vegetation are excluded during the production cycle. Intensive monoculture has evolved in countries were farmland is generally plentiful and there is a need for large concentrated harvests using minimal labor. Crop monocultures produce great yields by utilizing a plant's genetic potential to maximize growth in a uniform growing environment with less pressure from other species. The production of uniform cultivars, and particularly F-1 hybrids, bred for a specific environment, are grown at optimal spacing to use light, space, and nutrients to maximize yields. Standardized management practices for pest control, fertilizer inputs and harvesting allow growers to enjoy economies of scale, use less labor, and increase harvesting efficiency. Over the past 60 years monoculture practices including the use of synthesized fertilizers have greatly increased crop yields. Annual crop monocultures tend to rely on pesticide usage, large equipment to reduce labor, concentrated mineral fertilizers, and mechanical harvesting. Vegetable producers tend to be highly specialized because of unique equipment and expertise required to grow specific crops. Crop monocultures tend to favor large enterprises and in turn these enterprises favor and promote the system to ensure their future existence.

The ability of crop monocultures to produce large yields with reduced labor is widely accepted. However, crop monocultures can lead to loss of species diversity, the rapid spread of diseases, greater susceptibility to pathogenic attack, herbicide-resistant weeds, insects resistant to pesticides, greater corporate influence in agriculture, and increased energy usage for vegetable production (Pimentel *et al.*, 2005). There has also been a tendency for less locally grown fruits and vegetables because vegetable production in the developed world tends to concentrate in areas best suited to producing a crop and then shipping the produce to distant markets. While this practice optimizes productivity, it is very energy intensive and sometimes results in commodities that are no longer fresh when consumed. For example, to reduce post-harvest losses, cantaloupes are often harvested prematurely and may still be immature when purchased.

In other regions of the world multiple cropping is widely used. A few examples of multiple cropping systems are listed below. Polyculture is the production of multiple crops in the same space at the same time. Polycultures strive to imitate the diversity of natural ecosystems, and avoid large stands of single crops or monoculture. Examples of polyculture include multi-cropping, intercropping, companion planting, beneficial weeds, and alley cropping.

Sequential cropping

Sequential cropping is growing two or more crops in sequence in 1 year in the same field. An example of this would be growing corn and planting cucumbers in the row middles. After the corn is harvested, the corn stalks serve as a support for the cucumber vines. Another example would be seeding lettuce in plastic mulch after a summer vegetable like tomato is harvested and the plants removed from the field. Options for sequential cropping are increased where the growing season is long and there is sufficient time to mature multiple crops.

Intercropping

Intercropping is another polyculture technique where two or more crops are grown simultaneously on the same land (Fig. 2.8; Zhang and Li, 2003). An example of this would be interplanting pumpkins among agronomic or grain corn, which was a common practice many years ago in the USA before mechanical corn harvesters were developed. The corn uses vertical space while the pumpkin vines cover the soil surface. Both crops mature in the fall, so hand-harvesting corn did not damage the pumpkin vines. In this historically important system, pumpkins were collected and sold or left in the field for livestock food after they were cut open.

Relay intercropping occurs when two or more crops are grown simultaneously during part of the growing season of each other. Usually, the second crop is seeded or transplanted after the first crop has reached the reproductive stage or the later part of the growth period but before the first crop is ready for harvest. An example of relay intercropping would be seeding corn next to a developing radish crop. In many countries, intercropping is used to maximize use of arable land (Horwith, 1985).

Farmscaping

Farmscaping is a whole-farm ecological approach to pest management, particularly for insects, designed to attract natural predators to fields where cash crops are grown (Fig. 2.9).

Fig. 2.8. Intercropping of squash and Chinese cabbage in Taiwan.

Fig. 2.9. Farmscaping of a fall broccoli crop surrounded by buckwheat (bottom) and beneficial plants (left) to promote insect diversity and natural control of predators to reduce insecticide use.

Farmscaping is a polyculture system that simultaneously uses specific beneficial plants to attract insects in and around production fields to retain natural predators that are lost in monoculture production. The co-cultivation of cash crops and beneficial plants promote insect diversity and thus controls insect pests with natural predators. If implemented correctly, farmscaping provides a sustainable strategy for insect pest management with little or no pesticide usage. Critics cite the acreage lost to beneficial noncash crops as a negative aspect of farmscaping.

Managed Weeds

Some studies have suggested that overseeding (also called underseeding in some literature) a low growing plant that acts as a managed weed or living mulch in the row middles after a vegetable crop has been established is an effective alternative to conventional cultivation and herbicide use (Hartwig and Ammon, 2002). Overseeding creates species diversity and may help attract beneficial insects. This technique is commonly employed in orchard management and is used by some vegetable growers to reduce erosion and allow the overseeded plant to inhibit the proliferation of more invasive weeds (Hartwig and Ammon, 2002). White clover is an example of an overseeded plant that is low growing, has a deep root system and is a legume that can fix atmospheric N. A downside to overseeding is that the mulch crop competes with vegetables for water and nutrients. In a dry climate where irrigation must be used, the disadvantages of overseeding may outweigh the advantages.

Ratoon Cropping

Ratoon cropping is a method of harvesting a crop while leaving the roots and crown intact to grow back for additional harvests. Ratoon cropping decreases the cost of preparing the field for a new planting. The yield of the ratoon crop tends to decrease following each cycle. The term ratooning is often used with crops harvested over multiple years but can be applied to annual crops where several cuts are made during a season. Globe artichokes, spinach, and lettuce are examples of crops that can be harvested by ratooning.

Crop Rotation

Crop rotation is a simple and effective management method that should always be used for vegetable crop production. Rotation is the practice of growing unrelated crops in succession in the same field to preserve the productive capacity of the soil. Crop rotation helps control disease buildup in the soil, reduce insect pests, and preserve soil nutrition. Most growers rotate multiple crops with each crop performing a separate function to improve soil. For example, a rotation may include a deep-rooted crop to improve soil structure and legume green-manure crop to improve soil fertility. Crops from related families should not be planted in the same field in subsequent years, like cabbage and broccoli for example, because they may harbor the same disease and insect pests.

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