5

Crop Establishment: Transplanting and Direct-Field Seeding

F. J. Sundstrom*

Vegetables may be established in the field by the use of transplants, or "plugs," or by the use of pregerminated or raw seed. Whatever method is used, it is important to realize that a complete crop stand is an economic necessity. Production costs of fertilizing, cultivating, spraying, etc., are greater on a per plant basis when working with an incomplete stand. Greatly overseeding in the field is no longer a feasible alternative to assure a satisfactory stand. The high cost of seed and thinning makes this practice uneconomical.

Environmental factors such as light, soil moisture, and temperature all interact to influence crop establishment. Although complete control of these factors cannot be achieved, it is possible by careful planning and preparation to assure that the environment will be generally favorable for rapid seedling growth and development.

Direct-seeding and transplanting technology is more advanced now than it was a few years ago. The use of hybrid vegetable seed is common today; thus, seed costs are no longer only a fraction of the total production costs. This fact often justifies the additional cost of transplanting. Most hybrid vegetable seed is of high vigor, but the seed of some hybrids, such as the seedless watermelon do not have good vigor, and transplanting this crop is recommended.

---

*Present address: University of California, Davis

If crop production for an early market is the goal, cool temperature stress effects on germination must be considered. Conversely, some cool-season crops must be germinated under temperatures that are far above optimum. Many crop establishment options are available to growers, and decisions concerning direct seeding and transplanting are no longer as straightforward as in the past.

SEEDS AND SEED TECHNOLOGY

Successful crop establishment depends on many factors, the most important of which is seed quality. If poor-quality seed is used, then regardless of good cultural practices, crop production efforts are likely to be inefficient and unprofitable. The quality and yield of the harvested crop can be no better than that of the quality of the seed from which it was grown. In this light, seed quality should never be taken for granted, and growers should acquire the highest-quality seed available.

SEED QUALITY CHARACTERISTICS

Commercial seed should: (1) be "true-to-type," (2) have a high germination percentage, (3) have high vigor, (4) have no dormancy, (5) be free of foreign matter, and (6) have no disease or insect contamination.

"True-to-type" refers to the genetic purity of the seed. Any cultivar that is still actively segregating or producing variant individuals is not marketed. Crop genetic purity is maintained in part by use of a four-generation production scheme. Genetic purity is maintained by production of each generation under strict guidelines. Isolation is used to prevent undesired cross-pollination and mechanical mixing of different seeds during harvest. Minimum isolation requirements have been established by the Association of Official Seed Certifying Agencies (AOSCA) for each seed class to assure satisfactory genetic purity standards. Each generation is then identified by a specific colored labeling tag. The following progeny classes have been established:

1. *Breeder's seed.* Breeder's seed is produced under the direct supervision of the plant breeder and is the initial source of the cultivar.
2. *Foundation seed.* Foundation seed is the progeny of the breeder's seed and is handled to maintain the highest degree of purity. It is some-

times produced under contract by a foundation seed organization and is labeled with a white tag.

3. *Registered seed.* Registered seed is the progeny of foundation seed and is intended to be used for the production of certified seed. This class of seed is sometimes not maintained, and in such cases certified seed is produced directly from foundation seed. Registered seed is labeled with a purple tag.
4. *Certified seed.* Certified seed represents the final product of the certification program. It is produced either by the seed company itself or by certified seed growers in volumes necessary for commercial sale to crop producers. It is also produced under strict guidelines so the vegetable producer who is purchasing this seed can be assured of a satisfactory level of genetic purity and quality. Certified seed produced in a particular state must be certified (based on field inspection and laboratory testing) by that state's certification agency and then labeled with a blue tag.

Production and marketing of high-quality seeds are regulated in each state by a state seed certification program, sometimes recognized as "Crop Improvement Associations." Each state program, coordinated through the AOSCA, is designated by law (the Federal Seed Act of 1939) to certify seeds. Members of these associations include seed growers and commercial seed companies who are involved and interested in the production of certified seed. Standards of seed quality used by both federal and state seed testing laboratories are defined by the Association of Official Seed Analysts (ASOA). Such terms as *germination, pure seed, other crop seeds, inert matter*, etc., as well as the official "Rules for Testing Seeds," are defined and outlined by the ASOA.

Depending on the crop, certified or blue tag seed is generally labeled with at least the following information: (1) cultivar name, (2) lot number and/or origin, (3) purity (usually ±99%), (4) germination percentage, (5) date of the germination test, (6) amount of inert material (not generally a problem with vegetable seed), and (7) identification of any disease or insect control treatments.

Treatment of seeds with chemical protectants (primarily fungicides) has become a standard practice since the 1960s. Most vegetable seeds are treated to: (1) disinfect the surface of the seed from seed-borne fungi, (2) protect the seed from soil-borne fungi in the seedbed, and (3) systematically protect the seedling from damping-off organisms. By law, seed companies must identify the use of any chemical seed protectants and provide the proper antidote on the seed package.

Most seed companies now voluntarily size vegetable seed. Seed sizing serves two purposes. First, it allows selection of larger, generally more vigorous seeds from smaller individuals within a given lot. For example, larger (heavier) corn seed germinates faster, with more uniformity, and with subsequent faster crop maturity and total yield. And second, it provides greater seed size uniformity required by many advanced precision seeders. Sweet corn seed is often sized on the basis of a round or flat kernel to allow the grower to select the correct seed plate for some vegetable seeders.

Barring unusual circumstances, growers should purchase high-quality certified seed from a reputable seed company or seed dealer. Seed purchased from "feed and seed" stores or supply houses is sometimes improperly handled and stored. Seed is occasionally stored in rooms that are not climate-controlled, and high heat and humidity may significantly reduce seed vigor. At times, seed not sold from the previous year is improperly marketed without re-testing germination.

Seed germination should be tested the year the seed is sold. Germination testing can be done in the laboratory in petri dishes or in rolled germination towels, or it can be done in the greenhouse in flats filled with soil. A germination test will indicate seed germination percentage and rate (germination rate can be used as a measure of seed vigor). If necessary, the viability of those seeds that did not germinate may be measured to determine seed dormancy. Seed companies will not market any seedlots with dormancy or substandard vigor or germination.

HYBRID VS. OPEN-POLLINATED CULTIVARS

Plant breeders at universities, seed companies, and the U.S. Department of Agriculture (USDA) have improved crop performance by developing hybrid cultivars of many vegetable crops. A hybrid cultivar is the product of controlled pollination between two or more genetically distinct parental inbred lines (see Chapter 4). To produce hybrid seed, a breeder must manually cross these inbred lines each year. Such an effort is time-consuming and expensive, but the resulting hybrid normally possesses characteristics (such as increased cold, heat, or disease tolerance) superior to those of either of its parents. One particularly important characteristic of many hybrids is that of improved crop uniformity. The success of crop mechanization efforts is often dependent upon hybrid crop uniformity.

Open-pollinated (OP) cultivars are either self- or cross-pollinated species. Strict artificial isolation is essential to maintain genetic purity, because fertilization with the pollen of another cultivar will have disastrous consequences. Crops and/or cultivars may be isolated by distance, by maturity or planting date differences, or by use of isolation cages (Figure 5.1). Because maintenance and seed production of these cultivars only requires isolation, the seed of OP cultivars is much less expensive than hybrid seed. On-farm trials comparing the performance of OP and hybrid cultivars will provide growers with the information needed to choose the best cultivars for their needs.

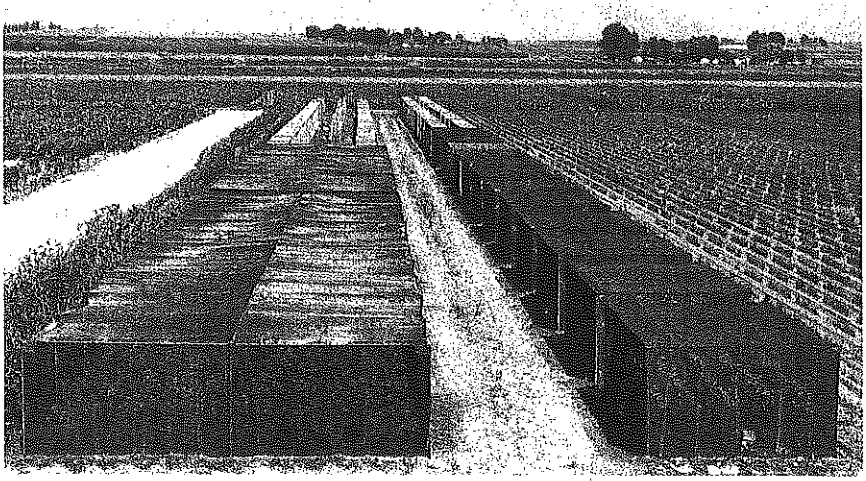

Figure 5.1. Isolation cages used in a commercial plant breeding operation.

SEED PERFORMANCE

The seed germination percentage listed on the seed label does not always represent the proportion of seed that will germinate and emerge in the greenhouse or field. Seed companies and seed-testing labs germinate seed under near-optimum conditions to measure germination. Realizing this, most seed companies understate on the label the germination percentage measured in the lab or greenhouse in order to provide the grower with a more realistic estimate of field germination.

Seed germination and subsequent seedling emergence are dependent on seed vigor. The International Seed Testing Association (ISTA) has defined *vigor* as "the sum total of those properties of the seed which determines the potential level of activity and performance of the seed or seed lot during germination and seedling emergence." To simplify, vigor is rapid, complete, and uniform seed germination. Specific laboratory tests are used to objectively determine seed vigor. Proper seed production in the field, upgrading (eliminating low-vigor seeds), and sometimes vigor enhancement techniques, all monitored by the seed company, contribute to seed and seedling performance in the seedbed.

SEED ENHANCEMENT

Seed enhancement research is now yielding many commercial successes. Basically, the objective of this work is to improve seed vigor, particularly under stressful germination conditions. One manner used for years by gardeners to shorten the time between sowing and seedling emergence is called *chitting*. This involves: (1) germination of seeds under ideal conditions until radicle (root) emergence and (2) carefully sowing/transplanting in a moistened media in the field to avoid radicle breakage or desiccation. The primary drawback to chitting is that this technique does little to improve germination uniformity or vigor.

Today, therefore, seed researchers use a technique referred to as *osmoconditioning* or *priming* to improve seed and seedling vigor, as well as to improve germination rate, uniformity, and total germination percentage. Basically this treatment involves seed imbibition in a temperature-controlled, dilute, aerated solution of an organic or inorganic osmoticum. The concentration of this solution (the identity, concentration of the osmoticum, as well as the method of imbibition, is often proprietary) controls both the rate and amount of water imbibed by the seed. The concentration of the solution is such that there is not quite sufficient free water available for the seed to complete germination (measured by radicle emergence). The seeds are allowed to imbibe water in this aerated solution for such time that upon removal, all the seeds will have exactly the same moisture content. During this slow imbibition period, seed metabolism is stimulated, and during subsequent germination and seedling development, vigor is significantly improved. Occasionally, plant growth regulators are also used alone, or in combination with an osmoticum, to stimulate germination. A properly enhanced seed will generally germinate faster, more completely and uniformly than an untreated seed, particularly under temperature or moisture stress.

The success of such research has led to the development of numerous commercial products. Most major U.S. vegetable seed companies now offer enhanced seed products. Because these seeds have been imbibed and then redried, seed handling and storage must be carefully monitored. For this reason, seed companies will sell such seed with a special disclaimer. This is not to discourage use of such products but rather to indicate the special care required to assure maintenance of high vigor. The commercially enhanced products currently on the market will perform admirably if these special precautions are carefully followed.

Another option available to growers is the use of coated or pelleted seed (Figure 5.2). When coated, small-seeded vegetables such as tomatoes, can be handled and singulated in precision seeders much more efficiently. Technology has made great strides since the time when coating involved placing a relatively thick layer of diatomaceous earth, montmorillonite clay, sand, etc., with a binder around seeds to increase size and shape uniformity. For example, full-coated lettuce seeds were once formulated at a ratio of 50 parts clay to 1 part seed. Now, ratios have decreased with new mini-coatings to 10:1. Some pelleting materials are designed to instantly split after coming into contact with moisture. This prevents any problems with oxygen availability to the germinating seed or difficulties with the radicle emerging through the pelleting material.

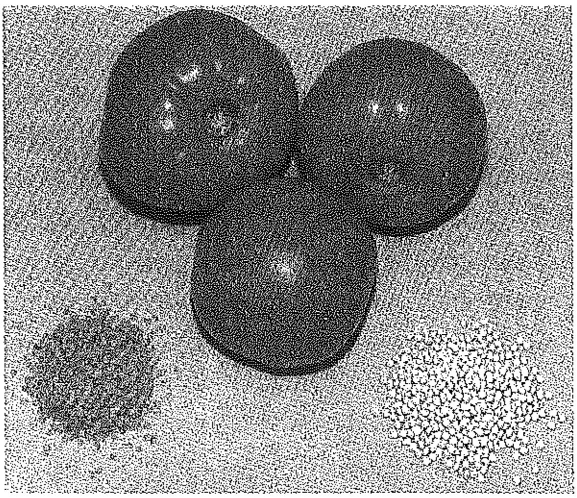

Figure 5.2. Coated seed (right) can be handled more effectively than raw seed (left) by modern precision seeders.

Pelleted seeds have the additional advantage of increased pestilence protection when fungicides and/or insecticides are incorporated into the coating material. It is possible to coat the seed, apply the fungicide or insecticide, then coat once again. This process permits the use and concentration of materials that ordinarily would be phytotoxic, because the first layer of coating material acts as a protectant to the seed. Furthermore, the outer coating layer makes seed handling much less hazardous. With today's technology, seeds that have temperature- and light-dependent dormancies, such as lettuce and endive, can be treated with growth regulators to overcome these dormancies, osmoconditioned to promote germination rate and vigor, and ultimately pelleted with fungicides and/or insecticides for successful direct-field precision seeding. Commercial coatings have been primarily developed by commercial seed companies, and their composition is proprietary. An example of the economics of using coated seed is given as follows:

> *Economics of Coated Seed.* If a grower normally sows 0.5 to 0.75 pound (approximately 300,000 seeds) of raw lettuce seed per acre, only 3.5 ounces (approximately 90,000 seeds) of coated seeds per acre, 210,000 fewer seeds per acre, would be needed. Assuming coated seed costs $0.43 per 1,000 seeds, it will cost $38.70 per acre for seed. Assuming raw seed costs $0.10 per 1,000 seeds, it would cost $30.00 per acre for seed. The increased cost of pelleted seed is only $8.70 per acre, or about the price of one carton of lettuce. Due to the use of coated seed, estimated savings on thinning alone is easily as much as $200 per acre.

Use of enhanced (coated or uncoated) seed is particularly appropriate when a grower is attempting to germinate seed under stressful environmental conditions. Enhanced seeds will germinate under conditions that untreated seeds will not. Establishment of a crop by direct-field seeding is therefore possible in conditions where, in the past, transplanting was essential. Use of these products, however, is expensive. On-farm trials will provide invaluable information as to their suitability in a particular grower's operation.

Another area of technological research that may afford exciting future opportunities is the production of synthetic seeds. Starting with disease-free plant tissue, somatic embryos are produced aseptically in vitro. The embryos can be removed from the culture media and encapsulated in synthetic gels that replace the endosperm (food reserves) and seed coat of a normal seed. Chemicals for protection against pestilence can be incorporated within this gel. The process of applying tissue culture and genetic manipulation to create commercial products has sparked the development of a number of biotechnology firms. These firms hope to capitalize patentable techniques to market superior cultivars and propagation methods.

SEED GERMINATION

A seed physiologist defines *germination* as the emergence of the radicle through the seed coat. A grower defines *germination* as the emergence of the seedling through the soil. Whatever the definition, good seed germination and seedling emergence require high-quality seed and the proper environment. Environmental factors necessary for seed germination are: (1) moisture, (2) oxygen, (3) favorable temperature, and sometimes (4) light.

Water is a basic requirement for seed germination. In their resting, or "quiescent," stage, seeds contain very little moisture. Low moisture maintains low seed metabolic activity necessary for proper storage. Upon contact with adequate soil moisture, seed metabolism accelerates and the physiological activities necessary for embryo cell elongation and division are initiated.

Vegetable seeds vary in the amount of soil moisture required for germination. Soil moisture availability can be described by the terms *field capacity* and *permanent wilting percentage*. Table 5.1 shows the response of various vegeta-

Table 5.1. Effect of Soil Moisture on Germination of Vegetable Seed

1. **Seeds germinate well in soils with moisture at permanent wilting percentage to field capacity**
    - cabbage
    - carrots
    - cucumbers
    - muskmelons
    - onions
    - peppers
    - radishes
    - squashes
    - sweet corn
    - tomatoes
    - turnips
    - watermelons
2. **Seeds germinate best in soils with intermediate moisture content to field capacity**
    - beans, lima
    - beans, snap
    - beets
    - endive
    - lettuce
    - peas
3. **Seeds germinate only when soil moisture is near field capacity**
    - celery
4. **Seeds germinate best at lower soil moisture contents**
    - New Zealand spinach
    - spinach

ble seeds to different levels of soil moisture. Although not indicated in the table, it should be noted that excessive soil moisture (greater than 40%) can be detrimental to the germination of some crops, especially beans and peas.

As seeds begin to germinate, seed respiration increases. If soil moisture levels are excessive, anaerobic conditions can occur, and seed respiration and subsequent germination can be retarded. Generally, this problem is greater in heavy-textured soils, but it can occur in any situation where there is inadequate soil drainage. Not only can flooding severely reduce germination, but it also can wash shallow-sown seeds from the seedbed. Raised seedbeds are commonly used both for drainage and for furrow irrigation purposes.

Temperature requirements for seed germination vary among vegetable crops. Table 5.2 lists minimum and maximum temperatures, in addition to the optimum range and specific optimum temperature for major vegetable crops. It is important to realize that although seeds will germinate at the listed minimum and maximum temperatures, germination rates and percentages will be less than satisfactory. Cool-season vegetables will generally germinate at temperatures close to 32°F, while warm-season crops require temperatures above 59°F for satisfactory germination.

Table 5.2. Soil Temperature Conditions for Vegetable Seed Germination

Crop	Minimum (°F)	Optimum Range (°F)	Optimum (°F)	Maximum (°F)
Asparagus	50	60–85	75	95
Beans, snap	60	60–85	80	95
Beans, lima	60	65–85	85	85
Beets	40	50–85	85	95
Cabbage	40	45–95	85	100
Carrots	40	45–85	80	95
Cauliflower	40	45–85	80	100
Celery	40	60–70	70[a]	85[b]
Chard, Swiss	40	50–85	85	95
Corn	50	60–95	95	105
Cucumbers	60	60–95	95	105
Eggplants	60	75–90	85	95
Lettuce	35	40–80	75	85
Muskmelons	60	75–95	90	100
Okra	60	70–95	95	105
Onions	35	50–95	75	95
Parsley	40	50–85	75	90

(Continued)

Table 5.2 (Continued)

Crop	Minimum	Optimum Range	Optimum	Maximum
	(°F)	(°F)	(°F)	(°F)
Parsnips	35	50–70	65	85
Peas	40	40–75	75	85
Peppers	60	65–95	85	95
Pumpkins	60	70–90	95	100
Radishes	40	45–90	85	95
Spinach	35	45–75	70	85
Squashes	60	70–95	95	100
Tomatoes	50	60–85	85	95
Turnips	40	60–105	85	105
Watermelons	60	70–95	95	105

[a] Daily fluctuation to 60°F or lower at night is essential.

Two important vegetable crops express a high-temperature–induced seed dormancy called *thermodormancy*. Many celery and lettuce cultivars will not germinate at temperatures above 79° and 86°F, respectively. This natural crop protection mechanism prevents germination and subsequent seedling development under unfavorable growing conditions. High soil temperatures in the field can be lowered, particularly in desert growing regions, by the use of overhead irrigation. Growth regulator seed treatment with ethylene and kinetin will overcome this dormancy, and breeders have now introduced some hybrid cultivars of both crops that will tolerate higher germination temperatures.

Some celery and lettuce seeds require light requirement for germination. If moisture, oxygen, and temperature requirements have all been satisfied, sunlight (or incandescent light) is required for germination to proceed. These light sources are rich in red wavelengths (ca. 650 nm) that are sensed by a protein pigment found in the seed embryo called *phytochrome*. This pigment exists in two forms: one inhibits germination, and the other promotes germination. If light is very weak, then far-red wavelengths (ca. 750 nm) predominate, phytochrome will be converted to the biologically inactive form, and the seed will be dormant. These events are important to crop producers because if celery or lettuce seeds are sown too deep (±1 inch), the seeds will likely become photodormant. For this reason, in the greenhouse, seeds are frequently not sown directly in the media, but rather on top, and then covered with wet burlap or cheesecloth to keep the seeds moist. Not all celery and lettuce cultivars are light-sensitive, but even light-insensitive cultivars become light-sensitive if they are exposed to high temperatures for several days. Growth regulator treatments (such as gibberellic acid) are used commercially to satisfy the light requirement of these seeds, circumventing many potential germination difficulties and allowing the seed to be pelleted.

SEED STORAGE

Generally, most vegetable seed will store well under favorable conditions for at least a year (Table 5.3). Even when stored under the best conditions (i.e., low temperature and humidity), seed quality cannot improve.

Table 5.3. Length of Time Seeds May Be Expected to Retain Their Vitality[a]

Kind of Vegetable	Years	Kind of Vegetable	Years
Asparagus	3	Onions	1
Beans	3	Parsley	2
Beets	4	Parsnips	1
Brussels sprouts	4	Peas	3
Cabbage	4	Peppers	3
Carrots	3	Pumpkins	4
Cauliflower	4	Radishes	4
Celery	5	Rutabagas	4
Cucumbers	5	Spinach	4
Eggplants	5	Squashes	4
Endive	5	Sweet corn	1
Kale	4	Tomatoes	3
Lettuce	5	Turnips	4
Muskmelons	5	Watermelons	5
Okra	2		

[a] When stored under favorable conditions, seed of the age indicated (from harvest not from time of purchase) should be viable. Seed is often good much longer, but specific lots may not survive as long.

Typical home refrigeration temperatures (ca. 41°F) are sufficient for good seed storage. Seed moisture will equilibrate with the humidity of the surrounding atmosphere. A relative humidity of ca. 60 percent at a temperature ca. 77°F (as would often be found within a home) is very adequate to dry most vegetable seeds to a moisture of ca. 10 percent. At this moisture level, most vegetable seeds can be safely stored under refrigeration for at least one year. Stable storage moisture and temperature conditions are important because severe fluctuations in storage temperature or moisture are harmful to seed vigor.

STAND ESTABLISHMENT

TRANSPLANTING

Perhaps the best manner to assure a complete stand of seed-propagated crops is by the use of transplants, or "plugs." When very expensive hybrid seed is used, transplants become more economically attractive. Crops such as celery and lettuce are very often transplanted due to seed germination difficulties. Other vegetable crops are not propagated by true botanical seed. Examples of some asexually propagated vegetables include artichokes, garlic, horseradish, potatoes, and sweet potatoes.

Growers often use transplanting to (1) extend a short growing season for a late-maturing crop, (2) improve land-use efficiency, (3) substantially save on the cost of expensive hybrid seed, or (4) force crop production for an early market. Western U.S. vegetable growers may transplant crops to reduce irrigation costs. A direct-seeded tomato crop in the West requires about 2.5 acre-feet of water per season, while a transplanted crop uses only 1.5 acre-feet. As water and energy costs continue to rise, this water savings becomes more important. Early-season weed control is more manageable when transplants are used, and thinning costs and damages are completely eliminated. Crop uniformity can also be improved in some crops. For example, the number of times a field of cauliflower must be harvested can be reduced from seven to three. With increasing overseas competition, many vegetable growers are now under greater pressure to provide a specific product, for a specific market, and at a specific time. Sometimes, transplanting is the only manner in which they are able to accomplish this.

Growing Transplants

Virtually all commercially produced transplants are grown in heated and ventilated greenhouses. Most transplants are grown in trays or flats; however, a relatively small bare-root transplant production industry still exists in the southeastern United States, producing primarily peppers and tomatoes. These plants are grown in raised beds, pulled, packed, and often shipped to northern growing regions. The only advantage of using bare-root transplants is that they are generally less expensive than container-grown plants.

Until recently, container vegetable transplant production was limited to growing seedlings in "Todd" expanded polystyrene planter flats or a facsimile (Figure 5.3). Today, many vegetable transplants are grown in a plug production system, very similar to bedding plant production. Plug or plug trays differ from planter flats primarily in cell size (Figure 5.4). Typical planter flats are identified by the dimensions of the cell size. A "080" or "175" means that each side of the square cell measures 0.80 or 1.75 inches, respectively. Plug

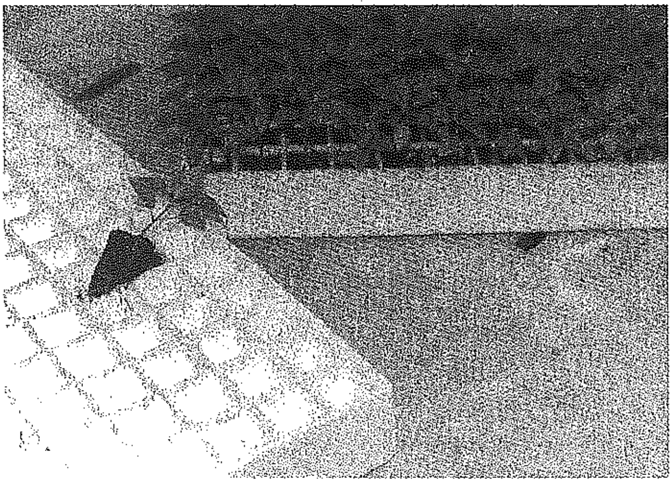

Figure 5.3. Todd planter flats illustrating size and shape of cells with pepper transplants.

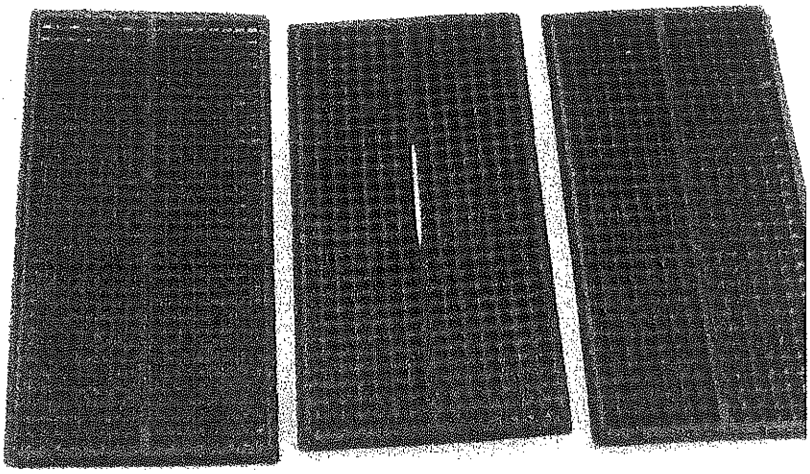

Figure 5.4. Plug trays with varying cell sizes and shapes. (Photo: courtesy of Blackmore Transplanter Co., Ypsilanti, Michigan)

trays are identified by the number of cells per flat, starting at 33 and increasing to 648.

The use of plug technology has decreased production costs per seedling and has facilitated greater transplant mechanization. As a result, the acreage of vegetables established by transplanting is increasing. Plug culture differs from planter flat production due to the very small volume of the plug media used. Since the volume of the media (generally peat-based) is very limited, it must be very uniform in texture, and well-mixed if any nutrients or lime has been added. Because of the size of the plug, the possibility of moisture stress is very great. The plug can dry out quickly, yet it can also be saturated very easily as well. For this reason, as in the bedding plant industry, some commercial plug growers use mist rooms for seed germination. These rooms are constantly "fogged" with microscopic water particles to maintain a relative humidity of 100 percent, temperature is very accurately monitored, and high-intensity artificial lighting is provided. This system is much different from a typical greenhouse mist system. The seed is mechanically placed on top of the media (Figure 5.5) rather than buried to assure that soil anaerobiosis is not a concern. After germination, seedlings are carefully adapted to a greenhouse

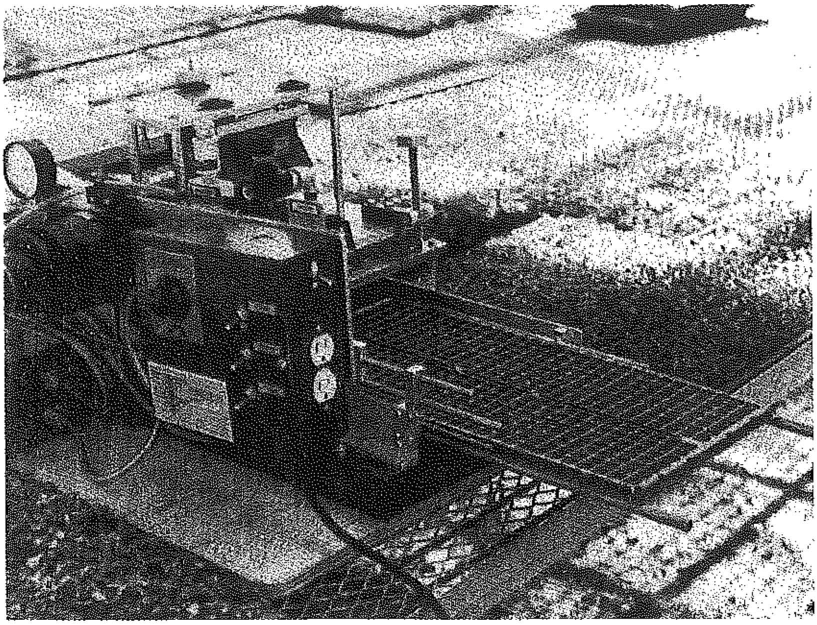

Figure 5.5. This automatic plug seeder can be adjusted to precisely place one seed of virtually any size and shape at a specific depth in each cell. (Photo: courtesy of Blackmore Transplanter Co., Ypsilanti, Michigan)

environment for further development. Plug plants may be transplanted when only two or three true leaves have developed. The smaller the plug volume, the less time a seedling can remain in the tray. One of the great advantages of using plugs is that transplanting can be completely mechanized (Figure 5.6). The business of custom operations that produce the plug and subsequently transplant it to the field is increasing.

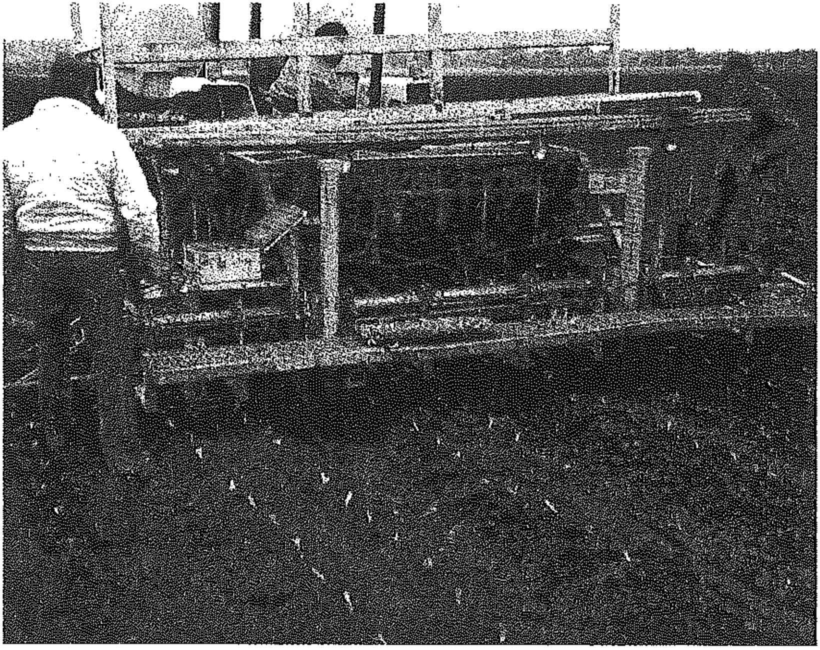

Figure 5.6. Automatic transplanter; after plug trays are placed on the conveyer, no additional hand labor is necessary for transplanting.

More traditional transplant production involves seedling production in flats with much larger cell sizes. Cells are still mechanically seeded, but flats are set at final spacing in the greenhouse for germination and production of a finished transplant. Larger cells do not necessitate as much care in regard to moisture availability, and they permit seedlings to remain in the flat until they achieve traditional transplant size (five or six true leaves). Most cells, modules, or plugs are inversely tapered and open at the bottom (Figure 5.3). This type of cell results in an "air-pruning" of the taproot, which encourages good lateral root development and orientation. Planter flats are utilized in semiautomatic transplanters such as the one shown in Figure 5.7. These transplanters require operators to pick the seedlings from the trays and drop

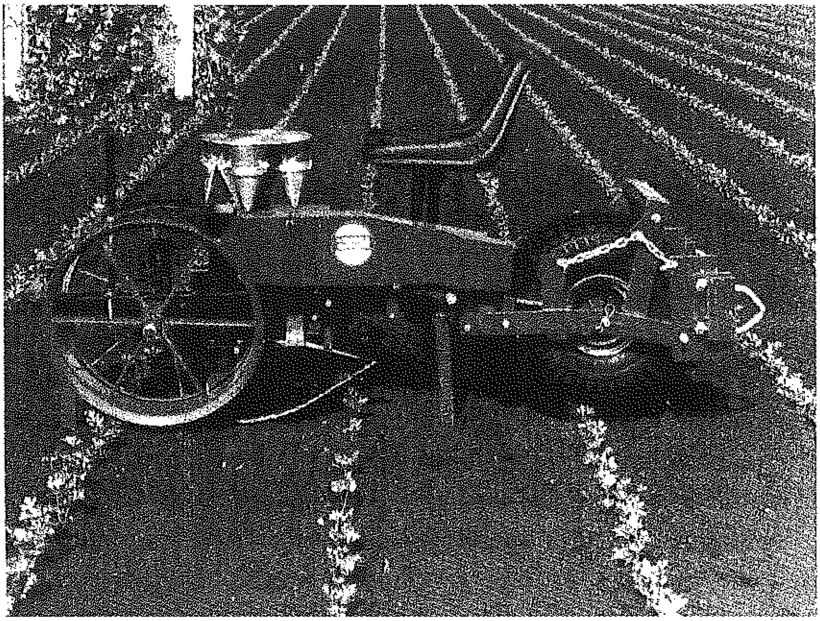

Figure 5.7. Semi-automatic mechanical transplanter unit. These single units are mounted on a tool-bar behind a tractor, and operators pull transplants from trays and drop them down rotating cups. (Photo: courtesy of Mechanical Transplanter, Holland, Michigan)

them through a chute into the bed. Planting depth and in-row spacing are accurately controlled, and seedlings are firmly packed into the soil by press wheels.

Because the seedling taproot is "air-pruned" in plug and seedling trays, the pruned taproot is unable to penetrate the soil profile as deeply. Root foraging for water and nutrients deep in the soil profile is therefore reduced. This situation is commercially important if irrigation is not available. For example, watermelons produced on deep, light-textured soils without irrigation should be direct seeded because transplanted crops are more susceptible to possible water stress.

Often, seedling performance depends on transplant cell size. Although there are subtle crop differences, generally transplants grown in larger cells produce greater early crop yields. If the length of the growing season is not limited, cell size does not affect total crop yields. When early crop yield is an objective, large cell sizes should be used. Based on the difference in the number of plants per square foot of greenhouse bench space, the cost of producing seedlings in large cells is greater.

Hardening

Before any transplant (cool- or warm-season crop) is removed from the near-optimum conditions of a greenhouse and set in the field, it should be adapted to the harsher field environment by "hardening." Hardening involves a treatment that slows or retards seedling growth before transplanting. Physiologically, hardening (1) reduces growth rate, (2) thickens the cuticle, (3) increases the waxy covering (bloom) on the leaves of certain crops, (4) increases the percentage of dry matter, (5) increases the percentage of water-holding colloids, (6) decreases the percentage of freezable water, and (7) develops anthocyanins (pink pigments) in the stems, petioles, and veins. Hardening increases the adaptability of the transplant to field conditions, which may include excessively cool or warm temperatures, water stress, wind, pestilence, etc. Generally, hardening is imposed anywhere from 7 to 14 days prior to transplanting by withholding moisture, and/or reducing temperature. Hardening should not involve any treatment such as nutrient stress that may reduce the rate of photosynthesis. If plants are grown when temperatures are high, hardening is accomplished by withholding water. If one is growing a biennial, such as cabbage, celery, or onions, lower temperatures during hardening may induce vernalization and promote premature flowering. Biennial crops should be hardened only by reducing water.

Hardening reduces seedling growth rate and allows an accumulation of carbohydrates within the tissue. This increase in carbohydrates and the corresponding increase in percentage of dry matter within the seedling is beneficial, as these carbohydrates serve to effectively drop the point at which the tissue will freeze (which is particularly important in cool-season crucifers). In addition, the carbohydrates are needed as an energy source for seedling root regeneration following transplanting. When a seedling is transplanted, damage to the root system is inevitable. Those areas of the root system that are most affected are the tender root tips, the very portion of the root that is vital for moisture and nutrient absorption. Stored carbohydrates within the foliage are therefore used for necessary root regeneration activities.

Transplanting Success

The adaptability of vegetables to transplanting varies widely between crops (Table 5.4). Transplanting success depends on how rapidly a plant can regenerate those areas of the root system that were damaged by transplanting. The more quickly a plant can absorb adequate moisture and nutrients, the greater its chances of survival. Crops such as crucifers, peppers, and tomatoes can form adventitious roots, which greatly improve the survivability of transplants. Others, such as the cucurbits, have a rapid rate of root suberization, a process that prevents root hair and lateral branch-root formation in older root tissues. The inability to form lateral branch roots and root hairs substantially reduces soil moisture and nutrient absorption. If root suberization occurs in a very young plant, as it does in cucurbits, seedlings are not easily transplanted successfully. If transplanting becomes necessary, such crops should be set in the field at a very early age. Products, such as peat pots, Jiffy 7's, paperpots, etc., that are transplanted with the seedlings and later decompose in the soil can be used to minimize root damage to such tender crops. These products, however, do not easily lend themselves to mechanization.

Table 5.4. Relative Ease of Transplanting Vegetables[a]

Easy	Moderate	Require Special Care[b]
Beets	Celery	Cucumbers
Broccoli	Eggplants	Muskmelons
Brussels sprouts	Onions	Summer squashes
Cabbage	Peppers	Sweet corn
Cauliflower		Watermelons
Chard		
Lettuce		
Tomatoes		

[a] Source: Maynard, D. H. and G. C. Hochmuth. 1997. *Knott's Handbook for Vegetable Growers*, 4th ed. John Wiley & Sons, Inc., New York.

[b] Containerized transplants are recommended.

Seedlings grown in cells or modules can be transplanted more successfully than bare-root seedlings, because roots of cell-grown seedlings suffer significantly less damage during transplanting. Pulling a plant from the seedbed is itself very damaging compared to removing a seedling from a plug tray. The entire root system of bare-root plants is susceptible to damage during transplanting, whereas a much smaller proportion of the roots of a plug are exposed to injury. Nevertheless, commercial growers continue to use bare-root transplants each year, and it appears that this market will exist for some time.

Additional factors that influence the success of transplanting are transplant age, seedling reproductive development, and field environment. As seedlings grow older, the rate of root replacement decreases. If flower bud development begins, root replacement is also suppressed. Normally, seedlings are started in the greenhouse anywhere from four to eight weeks prior to anticipated transplanting. When plugs are grown, this time may be reduced; when transplants are grown in large cells, this time may be slightly increased. The cost of transplant production is directly related to the length of time required to grow them. If seedlings must be held in the greenhouse longer than anticipated, the current stage of plant development should be maintained without reducing the photosynthetic rate. Care should be taken not to over-harden plants, which may delay maturity and in some instances even reduce crop yields.

Clipping or pruning transplants for size control should be avoided at all costs. Plant pruning removes tissue carbohydrates and results in diminished root regenerative capabilities. Pruning should be practiced only for flower or flower bud removal. When this is necessary and it is impractical to simply debud the plants, then plants should be clipped as far in advance of transplanting as possible to allow partial regeneration of removed foliage and restoration of carbohydrate reserves.

If possible, transplanting should be done as early in the morning or as late in the afternoon as feasible. High mid-day temperatures are obviously detrimental. Furthermore, relative humidity is generally higher in the early morning and late afternoon, reducing transplant desiccation. Water should be supplied immediately following transplanting. Normally a starter fertilizer solution is applied from tanks on the transplanter or tractor at the time of transplanting. The importance of the starter solution cannot be overemphasized. Starter solutions with greater concentrations of phosphorus rather than nitrogen or potassium (e.g., 10-50-10) are preferable. Phosphorus has been demonstrated to be critical in stimulating early crop root development.

DIRECT-FIELD SEEDING

Sowing seed directly in the field seedbed is the most economical manner of establishing a crop, provided seed germination and emergence are satisfactory. Of course, very often seed germination and seedling emergence are not satisfactory for a great number of reasons. This situation has led to the development of innovative methods of handling the seed with the objective of obtaining consistently complete and uniform stands.

Proper seedbed preparation is the first step in successful direct seeding. The bed must be straight, level, and free of large clods, debris, and weeds. It is possible to overwork a seedbed and almost completely destroy the soil structure. In such instances, soil pore space may be severely reduced, and any precipitation or overhead irrigation may result in serious soil crusting that will impede seedling emergence. The seedbed should only be worked to sufficiently assure that seed placement can be accurate.

Some vegetables have notoriously weak seedlings. Carrot and onion seedlings are very susceptible to soil crusting and weed competition. Soil crusting can be alleviated by the use of anticrustants, such as phosphoric acid and vermiculite. These materials are applied on top of the seedbed, covering the seed to prevent soil compaction and to enhance seedling emergence. Other seeds are particularly sensitive to soluble salts. Legume crops are intolerant of high salt concentrations in the seedbed and are therefore easily damaged by improper fertilizer placement or the use of high-salt, low-quality irrigation water. Surface, as well as subsurface, water supplies should always be tested for soluble salts, sodium, carbonates, and bicarbonates. If these are found to be excessive, it is possible to alter bed shape to reduce salt concentrations in the root zone (Figure 5.8).

Figure 5.8. Modified bed shape reduces salt buildup in the crop root zone, as well as increases daytime soil temperatures. The additional use of hotcaps ensures an early-season harvest.

Modification of bed shape can also be used to increase early-season soil temperatures to enhance seed germination and to hasten crop maturity. Simply orienting the beds in an east-west direction, sloping to the south, will increase the angle of incidence of sunlight striking the beds, and soil temperatures (at a 0.5-inch depth) will be significantly higher (ca. 10°F in late afternoon) than on flat beds.

Soil moisture has a great influence on soil temperatures in the seedbed. Heavy-textured soils hold moisture closer to the soil surface for a longer period of time than do light-textured soils. Since air warms faster than water, temperatures in the bed will be much warmer during the day in light-textured or drier fields. This situation, as well as superior drainage characteristics, makes light-textured soils ideal for early-season crop production. Good field drainage is mandatory for successful seed germination and crop production. The timing and amount of precipitation cannot be controlled, but field drainage characteristics can be improved. Adequate field drainage will reduce the risk of flooding and enable some degree of soil moisture control, critical for successful seed germination.

Seeding Dates

The date for planting various vegetable crops in the field is dependent on the geographic location, crop hardiness, length of the growing season, and time required for the crop to mature. The dates of the average last and first frosts in the United States are given in Figures 5.9 and 5.10, respectively. For seeding recommendations for specific crops and areas, it is advisable to consult local agricultural extension personnel. These individuals can also provide specific crop cultural information and recommend cultivars, planting densities, etc., that are very geographically dependent.

Seeding Methods

There are three manners to direct seed a vegetable crop in the field. One may (1) drill, (2) precision seed, or (3) plant to a stand. Perhaps the best example of drilling is to recall the function of a grain drill. It places seed so thickly in the bed that adjacent seeds are touching. Drilling is expensive and generally impractical today because of seed and thinning costs.

The last method of seeding places one seed at every point in the bed where one plant is desired. This method is risky because incomplete germination

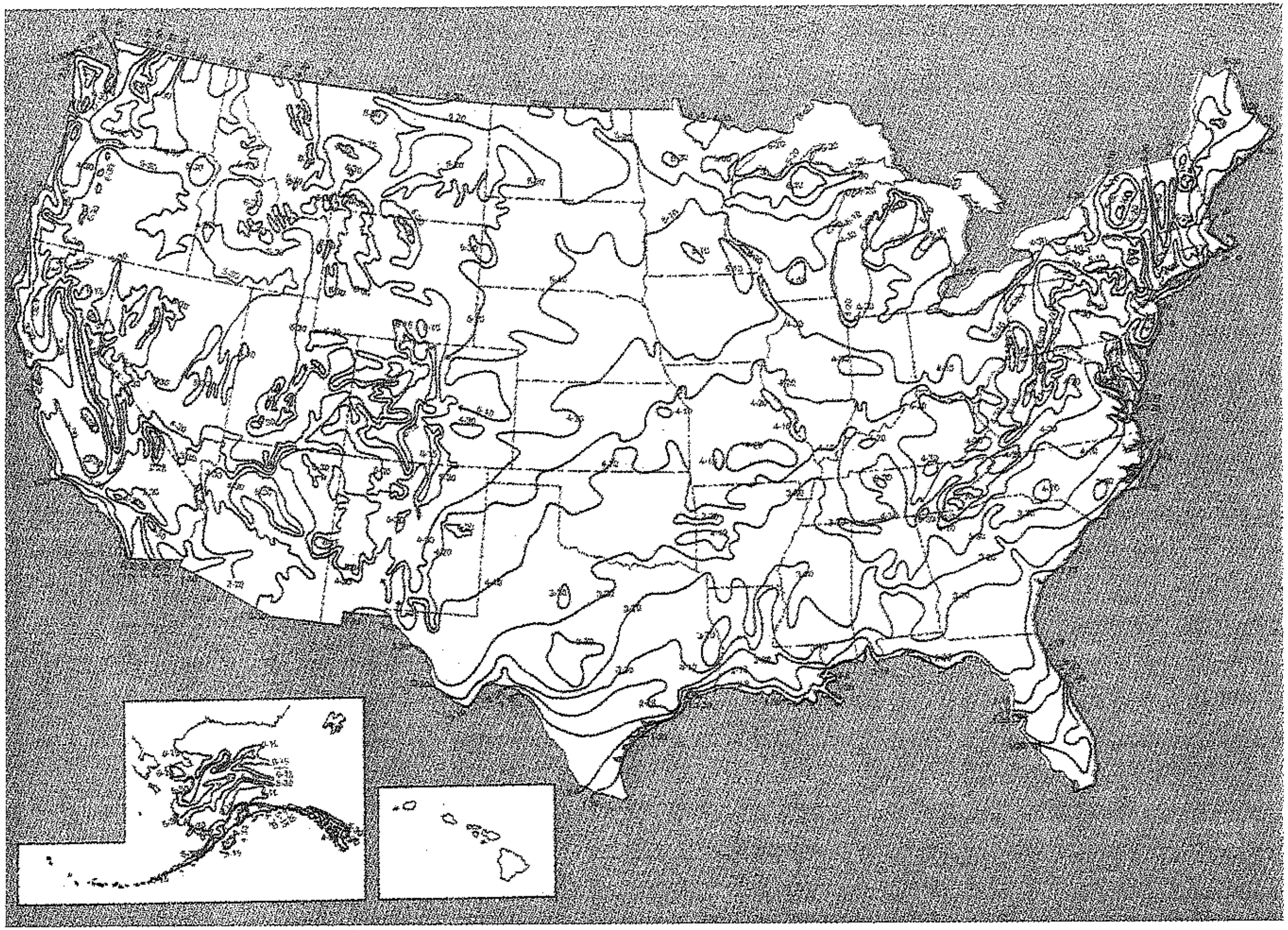

Figure 5.9. Average dates of the last killing frost in the spring in the United States.

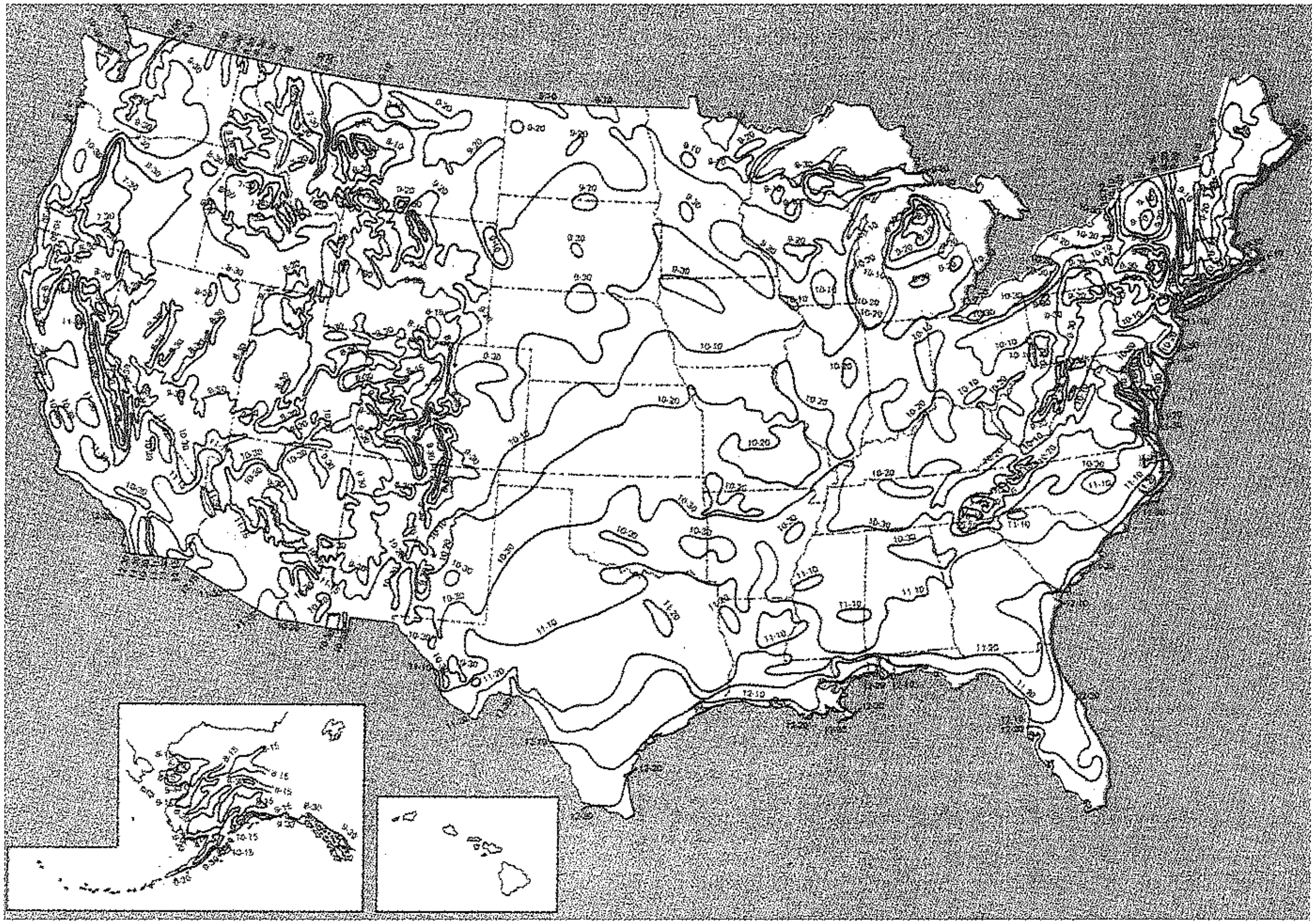

Figure 5.10. Average dates of the first killing frost in the fall in the United States.

and/or emergence, pestilence, etc., can result in an economically unacceptable stand.

The seeding method most frequently utilized in the vegetable industry today is precision seeding. Precision seeders can accurately place seeds in the bed at a pre-set spacing and depth. Precision seeders overseed to assure a satisfactory stand, but in-row seed spacing is sufficiently great (unlike drilling) that thinning damage to plants remaining in the bed is almost eliminated.

There are a variety of manners that vegetable seed may be precision planted. Some of these include (1) precision seeders that utilize seed plates, perforated belts, a vacuum, or small cups or spoons; (2) plug-mix seeders; and (3) fluid drilling seeders. The standard vegetable seeder that utilizes seed plates and has been used by the industry for the last 50 years may be referred to as a precision seeder in certain circumstances. It is possible with these planters to sow large-seeded vegetables such as legumes, okra, and sweet corn with some degree of depth control. The difficulty with these planters is with seed singulation by the seed plate, which often gets clogged or drops multiple seeds unless seed size and shape are very uniform.

In addition, older vegetable seeders cannot achieve the depth control necessary for small-seeded vegetable crops. Seeds as small as the head of a pin often do not have the necessary stored food reserves to germinate and develop seedlings with sufficient vigor to emerge at excessive depths. If the seed is sown at too shallow a depth however, high soil temperatures may damage or kill the emerging seedling. Precision vegetable seeders permit excellent depth control, which is utilized by many growers in seasonal crop production. For example, in spring broccoli production, seeds are sown almost on top of the ground where they take advantage of warmer soil temperatures to germinate. In the fall, when soil temperatures are much higher, seeds are planted deeper (0.5 to 0.75 inch) where soils are cooler and soil moisture is more available.

The primary difference between modern precision seeders and standard vegetable seeders is the manner in which they singulate the seed. Some precision seeders use interchangeable, perforated rubber belts with specific hole sizes and shapes for each crop, and when necessary, even for each crop cultivar. Others use a vacuum to hold seeds against holes in a disc. This is a very fast method, which can effectively handle unusually shaped seeds. Some of the others use a gear-driven wheel of small, interchangeable cups or spoons to individually lift and drop single seeds. It is easy to understand why uniformly sized and shaped pelleted seed are in such demand.

Plug-mix seeders are quite different from customary precision seeder because they drop seeds, mixed in a peat-based media, in hills in the bed (Figure 5.11). There are advantages and disadvantages to this method. The strong points are (1) seeds can be pregerminated (with emerged ca. 0.25-inch radicles) under favorable conditions before seeding in the bed, (2) seedlings develop and emerge in the favorable conditions within the plug (for example, without crusting), and (3) seedlings are protected against early-season herbicide injury. The weak points of this method of seeding are (1) seed number within each plug can only be estimated (by mixing a certain weight of seeds with a known volume of media), (2) seeds are uniformly mixed within the media and individual seed depth in the bed cannot be precisely controlled, (3) the peat-based porous media has a tendency to dry very quickly unless wetting agents are used, or unless it is covered, for example, with vermiculite, and (4) more than one seedling per hill may emerge, so thinning can be quite laborious, damaging, and expensive. For these reasons, plug-mix seeding is normally used only with crops such as tomatoes and cucumbers where multiple plants per hill are acceptable.

Figure 5.11. A plug-mix seeder using a heated punch to burn holes through plastic mulch to plant tomato seeds. (Photo: courtesy of S. Kostewicz, University of Florida)

Fluid drilling is similar to plug-mix seeding. A water-soluble gel rather than a peat-like media is used to disperse seeds. The concept is almost the same as with plug-mix seeding. Seeds are pregerminated under favorable conditions, and ungerminated seeds are removed before being incorporated into the gel. The gel, with seeds, is extruded through a pump either intermittently in hills or continuously in a band in the bed. The seedlings that develop and emerge in the gel have the same advantages as plug-mix seeding. Fluid drilling, however, is not limited to hill culture. It is important to note that if seeds are pregerminated before incorporation in the mix or gel, both plug-mix seeding and fluid drilling allow the grower to plant only germinated seed. This tremendous advantage, coupled with a favorable initial environment for seedling development, has allowed direct-field seeding of some vegetables under conditions where it would be otherwise ill-advised. Although both seeding methods are currently being employed in the United States, many growers have had difficulty justifying the additional expense of these precision seeders, and as a result, their use is currently limited.

With the availability of precision seeders and transplanters today, the method of crop establishment selected by the vegetable grower should be coordinated with specific cropping conditions. Large-seeded crops may be successfully precision seeded with only slight modifications of old vegetable seeders. Vegetables with very small and irregularly shaped seed may require coating and may need to be seeded with a more technologically advanced belt, spoon, or vacuum-type precision seeder. Seeding under stressful temperatures or in soils of unusual tilth (such as marl soils) may require the use of plug-mix or fluid-drilling equipment. Small seeds of inherently low vigor, and/or very specific germination requirements may necessitate germination in a seedling or plug tray in the greenhouse prior to being transplanted. Growers forcing crop production for a specific market window may need to consider transplanting, regardless of seed germination characteristics. Recent agricultural engineering and horticultural research efforts have provided vegetable growers with an array of crop establishment alternatives. It is important that the individual growers make an informed decision as to the suitability of a particular system for their specific needs.

SELECTED REFERENCES

Bewley, D. J., and M. Black (ed.). 1985. *Seeds: Physiology of Development and Germination.* Plenum Press, New York.

Copeland, L. O., and M. B. McDonald. 1985. *Principles of Seed Science and Technology*. Burgess Publishing Co., Minneapolis, Minnesota.

Hartman, H. T., and D. E. Kester. 1975. *Plant Propagation: Principles and Practices,* 3rd ed. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Justice, O. L., and L. N. Bass. 1978. *Principles and Practices of Seed Storage*. USDA Agric. Handbook No. 56.

Maynard, D. H., and G.H. Hochmuth. 1997. *Knott's Handbook for Vegetable Growers,* 4th ed. John Wiley & Sons, New York.

McDonald, M. B., and W. D. Pardee. 1985. *The Role of Seed Certification in the Seed Industry*. Crop Sci. Soc. Amer. Spec. Pub. No. 10, Madison, Wisconsin.

Sims, W. L., M. P. Zobel, D. M. May, R. J. Mullen, and P. P. Osterli. 1979. *Mechanized Growing and Harvesting of Processing Tomatoes.* Univ. of California, Div. Agric. Sci. Leaf. 2686.

Stefferud, A. 1961. *Seeds: The Yearbook of Agriculture, 1961*. USDA, Washington, DC.