Published 1988

9 Production of Hybrid Seed Corn

ROBERT D. WYCH

Pioneer Hi-Bred International, Inc.
Johnston, Iowa

The objective of this chapter is to present a current, state-of-the-art description of seed corn (*Zea mays* L.) production as it is commercially practiced in the late 1980s. The chapter draws heavily on the treatment by Craig (1977), but will highlight changes in the industry and in technology since that chapter was written.

9-1 HISTORICAL PERSPECTIVE

The first commercial hybrids were produced and sold in the early 1920s. From that modest beginning our present-day sophisticated hybrid seed corn industry has developed. Crabb (1947) described the first production of hybrid seed corn in Iowa:

> "The first contract ever drawn for the production of seed for hybrid corn gave [George] Kurtzweil the exclusive right for all time to produce the Copper Cross hybrid, a contract which, although it hasn't been exercised for a good many years, is still one of Kurtzweil's most prized possessions."
>
> "[Henry A.] Wallace said he had foundation inbred material to plant a one-acre seed plot, and the decision was made to produce the first commercial hybrid seed corn ever grown in Iowa . . . Wallace turned the seed over to Kurtzweil [in 1923]. The old East Leaming inbred was used for the seed parent, and the meager supply of the Bloody Butcher line was used as the pollinator parent. Only by very sparse and careful planting was Kurtzweil able to plant the plot that measured almost one acre on a small farm owned by Kurtzweil's father, Mathias Kurtzweil, at Altoona, just east of Des Moines . . ."
>
> "The first detasseling of commercial hybrid seed corn in Iowa was done entirely by a woman, Ruth Kurtzweil, a sister of George . . . From the time the first tassels of the parent plants began to appear on the Leaming inbred, Miss Kurtzweil went up and down, pulling them out. Few fields of hybrid seed corn since have been detasseled with such care and interest. Now that producing hybrid seed corn has become such a tremendous enterprise, Miss Kurtzweil delights in calling her friends' attention to the fact that she once detasseled all the hybrid seed corn production fields in the State of Iowa."
>
> "Copper Cross earned another distinction in 1924 when it became the first hybrid developed in the corn belt to be purchased by farmers of Iowa and elsewhere. Approximately fifteen bushels—all that was available of Cop-

Copyright 1988 © ASA-CSSA-SSSA, 677 South Segoe Road, Madison, WI 53711, USA.
Corn and Corn Improvement—Agronomy Monograph no. 18, 3rd edition.

Inari Exhibit 1025
Inari v. Pioneer

per Cross seed—was sold in the spring of 1924 at the price of $1.00 a pound, or at the rate of $56.00 a bushel."

The first hybrids to be developed were adapted primarily to the central Corn Belt; these were accepted slowly, and by 1933 approximately 1% of the Corn Belt corn acreage was planted with hybrid seed (Airy, 1955). Because of the superior performance of hybrids in the severe droughts of 1934 and 1936, farmers rapidly began accepting, and then demanding, hybrid seed.

The rapid acceptance by U.S. farmers of hybrid corn varieties in the 1930s and 1940s provided the basis on which many firms and individuals established themselves in a new and fast-growing industry. Prior to that time, only a few firms had been engaged in the hybrid seed corn business. Development of new hybrids adapted to virtually every corn-growing area of the USA and Canada helped to establish profitable corn production on hundreds of thousands of hectares outside the Corn Belt, where profitable corn production had previously been impossible on a commercial scale.

9–2 SIZE OF THE INDUSTRY

Since 1900, the area in the USA planted to corn has varied from a high of 47 million ha (116 million acres) in 1917 to a low of 24.4 million ha (60.2 million acres) in 1983 [the year of the federal government's payment-in-kind (PIK) program]. Excluding 1983, the area planted to corn between 1975 and 1985 averaged 33.4 million ha (82.5 million acres).

Planting rates vary considerably according to soil fertility levels, rainfall and irrigation availability, planting date, intended use (e.g., grain vs. silage), local custom, and finally, adaptation of specific hybrids to high plant populations. Assuming that a seed corn unit of 80 000 kernels will plant 1.4 ha (3.4 acres), it is estimated that a minimum of 24.5 million units of hybrid seed were required to plant the 1985 U.S. crop. At an estimated average retail price of $65/unit, the domestic hybrid seed corn industry has grown to a gross annual sales volume of $1.59 billion. Sales in other countries add to the total market.

9–3 TYPES OF HYBRIDS

The first hybrids produced and sold commercially were almost exclusively double crosses. However, several factors contributed to a significant transition from double crosses to single crosses within the U.S. Corn Belt, starting in the late 1950s and continuing through the 1980s. The transition to single crosses occurred because: (i) single crosses outyielded double crosses; (ii) a few companies led the way and others joined them to be competitive; (iii) farmers began to demand single crosses; and

(iv) improved agronomic practices and development by corn breeders of inbreds with higher per se yields made the production of seed of single crosses economically feasible. Single cross hybrids now comprise approximately 90% of the hybrid seed sold in North America (USA and Canada).

Modified single crosses, which are produced using related-line single crosses for either the female or male parent, were used extensively in hybrid seed corn production in the 1960s and early 1970s. Three-way crosses (single cross female parent and inbred male parent) are also a factor in the industry. Today, modified single crosses and three-way crosses account for about 10% of the North American market. While double-cross hybrids were once a significant factor in the market, their importance has decreased over the past two decades. It is estimated that they now comprise $<1\%$ of the total U.S. and Canadian market.

9–4 SEED CORN COMPANIES

Many firms have become involved in the production and sale of hybrid seed corn. Small, privately owned companies may produce and distribute only a few thousand units of seed. Operations of this size usually depend on inbred and hybrid development and research conducted by public institutions, or on that conducted by private firms that produce and sell parent seed (foundation seed) stocks. Smaller companies usually purchase foundation seed, produce their supplies of hybrid seed, and then sell it directly to farmers in their local areas.

Large companies usually carry on their own research and development programs, produce their own foundation seed stocks, produce the commercial seed, and distribute it through their own sales organizations. The majority of hybrid seed corn is sold by the various companies to farmer dealers, who, in turn, sell it to farmer customers. It is customary in the industry to deliver to dealers on a consignment basis, and to accept as "returns" seed that remains unsold by the dealer at the end of the planting season. Alternatively, the "sales agent" approach is used, with the seed remaining the property of the company until it is sold to the farmer customer (see section 9–12.2). In some geographical areas, sales are made by the seed company to jobbers or distributors who seek their own retail dealer outlets. This practice is more common in areas of relatively low sales volume.

Hybrid seed corn was at first sold in 25-kg (1-bu) packages. In the early 1960s, there began a trend to package and distribute in 23-kg (50-lb) packages. Later in that decade, the practice of packaging by kernel count became popular. At the present time, most seed corn is sold in units of 80 000 kernels.

The industry has seen both the attrition in the number of companies and great variation in the relative growth rates of individual companies. The many relatively small operations within the industry have a collective

market share of 36%, while the industry's seven largest companies have in total an estimated 64% share of the U.S. hybrid seed corn market (J. Ansorge, 1987, personal communication).

9–5 PRODUCTION OF PARENT SEED STOCKS

Large quantities of parent seed stocks (foundation seed) are required annually to plant the several hundred thousand hectares of commercial hybrid seed corn production. Most larger companies have parent seed or foundation seed departments responsible for the production and inventory of inbred and single cross parents needed for commercial seed production. In recent years, many seed companies have devoted increasing attention to developing more effective techniques and procedures to assure adequate supplies of high-quality, genetically pure stocks.

Seed corn companies must forecast future commercial seed sales and seed production plans to ensure availability of adequate parent seed supplies. Since most seed companies produce and sell many different hybrids, the number and supply of different parent seed strains that must be maintained for commercial seed production requirements is often quite large.

9–5.1 Foundation Seed Stock Increase

Foundation seed stock increase involves the maintenance and increase of inbred lines and single cross parent seed used to produce commercial hybrids. Inbreds are the basic foundation seed used in hybrid seed corn production. Inbreds must therefore be maintained and increased under rigid control to ensure satisfactory final product performance. Although procedures employed may vary among organizations, at least three important steps are usually taken: (i) establishing and maintaining a supply of breeder seed; (ii) increasing inbred seed; and (iii) producing related-line and/or unrelated-line single cross parent seed.

Breeder seed is usually derived from bulked, self-pollinated seed at the F_8 to F_{10} generation of inbreeding. The breeder has the responsibility of ensuring that the inbred is homozygous, uniform for plant type, and adequately represents the genetic constitution of the inbred. All inbred increases are made from this base population of breeder seed. Some companies have established separate programs to maintain supplies of breeder seed. Increases are produced in well-isolated blocks by natural random sib mating. In turn, this initial inbred increase is used to plant subsequent inbred seed increases and production of single-cross parents.

Both types of increase are made under stringent isolation. Procedures and standards developed by certification agencies (Hutchcroft, 1957; Cowan, 1972) indicate the importance of minimum isolation distances. Commercial companies certify all foundation seed that will be exported. Much of the parent seed for domestic use is not certified, but guidelines

developed over the years generally exceed, or at least equal, those of certification agencies.

Foundation seed fields are planned with isolation of 201 m (660 ft) as the base distance from other corn. Early studies by Jones and Brooks (1950, 1952) showed that: (i) the greatest contamination occurs in the 50 to 75 m (165–248 ft) nearest contaminating corn; (ii) pollen from border rows dilutes contamination; (iii) natural barriers may reduce contamination; (iv) an abundant supply of male corn pollen at the right time reduces contamination; (v) the direction of a field from contaminating pollen influences the amount of contamination; and (vi) "depth of field" in the direction of contamination source is important. Certification requirements in most states allow for substitution of additional male border rows for some portion of the 201-m isolation distance, but neither natural barriers nor time isolation are allowed to substitute for the required distances.

9–5.2 Procedures and Techniques

Generally, the equipment and procedures used in planting, detasseling, harvesting, drying, and conditioning of parent seed increases are similar to those used in commercial hybrid seed production. Some steps are applied more rigorously to ensure maximum genetic purity.

Variability among individual plants within the inbred population will sometimes occur. These off-types must be identified and removed (rogued) to avoid perpetuation of this variability from generation to generation. Careful plant removal (rogueing) must be practiced throughout the growing season to eliminate individual plants that exhibit phenotypes varying from the accepted phenotype of the inbred. As much rogueing as possible should occur prior to pollination to eliminate outcrossing resulting from pollen supplied by undesirable plants. Parent seed is usually harvested on the ear, allowing further selection (i.e., removal of off-type ears) to be practiced on the sorting table prior to drying and shelling (see section 9–9).

9–5.3 Quality Control

Rigid requirements must be used to maintain genetic purity at maximum levels. Genetic purity of parent seed not only helps ensure pure commercial hybrid seed but also reduces cost associated with rogueing commercial seed production fields and ear sorting at harvest. Parent seed is usually sized just as commercial seed corn. When genetic impurities occur, particularly those caused by outcrosses, they are often concentrated in specific kernel sizes, especially the large round kernels. As a result, certain kernel sizes within a specific lot may have unacceptably high levels of impurities, while other sizes in the same lot are acceptable. Careful selection of kernel sizes with the highest genetic purity can lead to improved purity of commercial seed corn.

Until relatively recently, the conventional approach to monitoring purity has been field "growouts". Growouts of a shelled corn composite of each seed lot from summer increase are often planted during the subsequent winter season to estimate genetic purity prior to use. In many cases more extensive growouts, sampling each kernel size in the lot, are conducted in the following summer growing season to obtain additional, more precise estimates of purity by kernel size. The accuracy of field growouts depends on: (i) securing a representative sample of the entire seed lot; (ii) a clean, uniform field to minimize volunteer corn and variation in plant height; (iii) favorable growing conditions; and (iv) knowledgeable personnel who are familiar with all the parental and hybrid plant phenotypes to score or "read" the growout.

Growouts are usually made in an area where the crop can be grown in the fall and winter months. Florida, Hawaii, Argentina, and Chile are most often used by U.S. seedsmen. Despite the use of winter growouts at these locations, it is difficult to obtain results early enough to make data-driven decisions on specific seed lots before the seed must be conditioned, bagged, and distributed. This is one of the factors that has led to increased reliance on electrophoresis results by some companies.

Starch gel electrophoresis (Cardy et al., 1980; Smith and Weissinger, 1984) is a recently developed technology that provides an additional means of purity analysis. The advantages of this technique include precision, rapidity relative to field growouts, absence of environmental influence on expression of genetically controlled characters, and the potential to make purity checks on developing embryonic samples collected prior to harvest (Smith and Wych, 1986). The disadvantages of this technique are the initial costs of the specialized equipment required and the cost of laboratory operation, or the relatively high cost per sample charged by commercial laboratories, if this alternative is chosen. Smith and Wych (1986) determined that the costs per seed lot for estimating percentage of female selfs by electrophoresis vs. growouts were approximately equivalent if both procedures were done in-house. However, if analysis for outcrosses is also conducted, the costs for electrophoresis may be somewhat higher than for estimation of selfs, only, due to the need to prepare and stain more gel slices. The urgency of the need for the purity information must be balanced against the comparative costs.

Seedsmen need to be aware that both growouts and electrophoresis provide useful information only to the extent that the samples are representative of a seed lot and adequate in size. The number and size of samples must be sufficient to provide an adequate measure of the variation within the seed lot being sampled.

Both growouts and electrophoresis can be used to identify accidental mechanical mixtures or mislabeling of foundation seed, which may occur at any point in production, conditioning, and inventory. For this application, electrophoresis has the same advantages and disadvantages mentioned above.

Another part of quality control of parent seed is germination. Various methods of measuring seed germination are employed and are generally performed on all usable kernel sizes of each seed lot. These methods are described in more detail later in the chapter (see section 9–11).

9–5.4 Storage and Inventory Control

Large inventories of parent seed are required. Accurate records of inventory supplies, genetic purity, and germination are maintained, since parent seed production is typically planned to provide an inventory adequate for 2 to 4 yr. Controlled environment storage facilities are used to maintain viability and quality (see section 9–12 for greater detail).

9–6 PRODUCTION OF COMMERCIAL HYBRID SEED

Agronomic practices in seed production fields are in general the same as those used to grow a commercial corn crop. However, there are some additional requirements unique to seed production. Acreages are determined on the basis of projected sales, utilizing yield levels based on breeders' research, production research, and past experience. The transition to the use of inbreds as female parents to produce single-cross hybrids has increased the need for planning, sound scientific and technical knowledge, and production technology to ensure economic success. Cultural practices used in production fields are planned to minimize risks while maximizing yield and seed quality.

9–6.1 Selection of Production Areas and Contract Growers

Successful commercial hybrid seed corn production begins with selection of a growing area and contract growers. Innovative farmers in cooperation with the seed companies have helped the seed corn industry grow into a sound business. Most seed corn production acreage is located in the Corn Belt. Expansion of the Corn Belt and increased technical knowledge have created opportunities for seed companies to expand in search of specific seed production areas. Production areas are chosen to provide such necessary factors as growing degree days, day length, lack of extreme temperatures, and specific farming practices, such as irrigation capability. By matching specific inbred needs to growing area characteristics, risk can be minimized and seed yields per female acre maximized.

Selecting growers within a production area is another important step. Generally, someone at the local production plant level will select growers who are among the most progressive and innovative corn growers in the area. The grower's location within the isolation block (see section 9–6.4) is also a factor. Seed companies attempt to select farms with high productivity indices and suitable soils that have been maintained in a state

of high fertility with good weed control. Tillage and cultural practices must be in line with approved hybrid corn production practices. Good soil structure and tilth are important in order to avoid the adverse effects of poor drainage and crusting on inbred stands. Since approximately 90 to 95% of the seed acreage will be devoted to inbred or related-line single cross parents, seed corn growers who will give special attention to management of insect and disease pests, weed competition, and fertility are needed.

Contract growers must be willing to cooperate with seed companies to alter their cultural practices and/or timing, rate, and kind of herbicides, insecticides, or fungicides. Equipment modifications are often necessary. In some areas, the seed company furnishes equipment on a lease or rental basis to the growers. In other cases, growers may cooperate in the purchase and sharing of various specialized pieces of equipment such as unit planters and detasseling and harvesting equipment.

9–6.2 Contracts

With the advent of single-cross hybrid seed production, contract growers were not content to assume the greater risks associated with inbred parents. As a result, base guarantees are made that involve payment, up to a predesignated yield level, for complete failure of the seed crop. Incentive payments are often based on published futures or cash market prices at a specified time and place. In some instances, contracts are based on government based yield calculations or locally measured commercial hybrid corn yield checks.

Usually, the type of contract used, base guarantees, and multiplier factors are based upon anticipated yield levels and degree of difficulty encountered in the production of each individual hybrid. Factors such as fertility, herbicide or insecticide costs, seedbed preparation for split-date plantings, volunteer removal, and harvesting are items for consideration within the contract. There are considerable variations in contracts among companies.

9–6.3 Management of the Production Area

The management staff at a production plant are responsible for all aspects of production. They are assisted by trained supervisory help, especially during planting, detasseling, and harvesting periods. An area of 4000 to 6000 ha (10 000–15 000 acres) of seed production responsibility is fairly typical for a production plant manager and his/her staff. Within this acreage, regional (or area) supervisors are charged with responsibility for 400 to 800 ha (1000–2000 acres). During detasseling, additional supervisory help may be employed as crew foremen, field foremen, and inspectors. The demand for additional supervisors during the summer months offers opportunities to utilize agriculture and science teachers,

principals, and other professionally trained personnel during their school vacation periods.

Communication is essential for production plant managers and area supervisors to be effective in the management of their respective areas and for coordination of activities. Particularly during detasseling, it is critical that communication be available so that people and equipment can be effectively used and moved to high priority areas as needed. Many seed companies use a combination of mobile telephones, Citizen's Band radios, and FM two-way radios.

9–6.4 Isolation of Seed Fields

Isolation is intended to assure that the hybrid cross is produced with a high degree of genetic purity. It has often been said by seedsmen that the best isolation is a perfect nick, that is, when a pollen parent starts shedding just before the female parent's silks start to emerge beyond the husk or tip of the ear shoot. In addition, plant management personnel must work with each individual contract grower to establish the location and boundaries of each seed field to conform with isolation distance requirements. Preference is also given to crop rotation of corn following soybean [*Glycine max* (L.) Merr.] (rather than following corn), because volunteer corn problems are avoided and seed corn yield is higher.

Minimum standards for isolation of seed corn production fields have been established (Anonymous, 1971) for the USA and Canada; nevertheless, some variation exists among states. When zero or one male border row is present, minimum distances ranging from 125 to 201 m (410–660 ft) are typically required between the female parent of the hybrid being produced and any other corn of the same seed color, maturity, or endosperm type. Isolation distance of 201 m is required where possible contaminant corn may have different kernel color or endosperm type. Additional distance is sometimes employed where contaminating corn may be of decidedly different pollen shedding ability (such as tropical hybrids), and where wind velocities may be high, such as in production areas near large bodies of water.

Minimum isolation distance requirements can be modified by: (i) additional border rows (Fig. 9–1); (ii) size of field and production block; and (iii) adequate natural barriers and differential flowering dates (in some states). Jones and Brooks (1952) found that natural barriers are not as effective as border rows of corn. Differential flowering times are effective in isolation if silks of female parents are not receptive when pollen from other than the male parent is present.

To optimize genetic purity, a timely nick between receptive silks on the female parent and pollen shed by the male parent is required. Differential planting dates of seed parents are often required to achieve this. Abundant amounts of male pollen are also beneficial, and some companies utilize high population density in the male parent rows to increase pollen load.



Fig. 9–1. A commercial hybrid seed production field showing additional male parent border rows for the purpose of providing pollen saturation adequate to ensure genetic purity of the hybrid seed. The strip of soybeans on the left provides the required isolation distance.

9–7 PLANTING THE SEED FIELD

9–7.1 Planting Date

The minimum soil temperature for growth of corn is generally regarded as 10 °C (50 °F). Most agronomists would also agree that the optimum time for planting corn is as soon as the soil temperature at the 5-cm depth reaches that temperature for a relatively sustained period of time. Soil moisture and potential for compaction must also be taken into account. Numerous studies indicating the advantages of early planting upon yield were reviewed by Craig (1977). More recent work is summarized by Hicks and Wright (1987) and Johnson and Mulvaney (1980).

9–7.2 Fertility

In general, inbreds have poorer rooting ability than hybrids, and may therefore be more vulnerable to nutrient deficiencies and imbalances. In the past, it has been the tendency of contract growers to overfertilize to protect against possible fertility deficiencies, while at the same time striving for a balanced fertility program. Decreases in commodity prices (upon which contract payments are based) and hence economic pressures on seed growers, as well as growing concern about groundwater contamination, suggest the need for a closer examination of fertilizer recommendations. Contract growers are encouraged to use soil tests regularly and to apply nutrients only as necessary to maintain fertility levels.

9–7.3 Herbicides, Insecticides, and Fungicides

Control of weeds, insects, and diseases within the seed field have become an integral and necessary part of seed production. Since inbreds and related-line parents are less competitive than hybrid corn with broadleaf weeds and grasses, seed growers rely heavily on herbicides for effective weed control. Production personnel work with the grower to develop a weed control program that takes into account specific weed problems, crop rotation, soil type and organic matter, equipment, and the specific parents involved with the hybrid to be produced.

Insecticides for the control of above and below ground insects are generally a must. Most companies have formulated programs that protect against insect damage to stands, the growing plant, and the female parent ear. In recent years, some seed companies have begun to rely heavily on IPM (integrated pest management) principles and scouting of seed fields to determine if and when insecticide application is justified. Selection of the insecticide to use will depend upon the specific insect to be controlled, efficacy of alternative insecticides, the level of infestation, the development stage of the seed crop, safety considerations, and the reentry period.

Fungicides have also become a regular part of the production program for protection of the more susceptible parent lines to damaging fungal diseases. Genetic resistance to disease is preferred, but chemical protection is often needed when resistance is not adequate in the parent line. Spray programs have been effective in reducing damage from foliar disease on the more susceptible lines. Monitoring the crop for disease development is beneficial in making timely applications of chemicals. Fungicides are widely used as seed treatments to give protection against seed and seedling diseases (Shurtleff, 1980).

9–7.4 Plant Density

Plant density within the seed field is planned to produce maximum yields of high purity seed of saleable kernel size. Upper limits may be imposed by the particular germ plasm being used, the average rainfall pattern or irrigation availability in the production area, and local labor supply for detasseling. Many investigators have studied plant density effects on yield of hybrid corn (Craig, 1977; Johnson and Mulvaney, 1980). Fewer published studies of inbred response to plant density are available. Some seed companies conduct plant density trials with the female parents they are using in seed production. They evaluate the yield and kernel sizeout responses of those inbreds to increasing plant density. Plant densities in current use in seed fields typically range from 54 000 to 64 000 plants per ha (22 000–26 000 plants per acre) for inbred female parents, and often exceed that level for male parents, especially with inbred males that shed a limited amount of pollen.

9–7.5 Planting Patterns

Common planting patterns in seed production fields today include 4:1 (fours rows of female parent to one row of male parent) (Fig. 9–2), 4:2, 4:1:4:2, 6:2, and solid female with interplanted male. In the first three patterns, the female parent is never more than two rows from the male parent. One-half of the female parent rows are adjacent to a male parent in the 4:1 and 4:2 patterns, and two-thirds of the female parent rows are adjacent to a male parent in the 4:1:2:1 pattern. These contrast with the formerly conventional 6:2 pattern that was commonly used for production of double-cross hybrids. The 6:2 pattern is still used to produce some single crosses, but its use is generally restricted to male parents that shed an abundant supply of pollen.

Occasionally solid planting of the female parent in 96.5 to 101.6 cm (38–40 in.) rows is utilized with either every other or every fourth between-row space being interplanted with the male parent. This accomplishes two purposes: (i) full utilization of land area for female parent production; and (ii) placement of the male parent closer to the female parent rows. In stress environments, interplanting may lead to yield and quality problems. Solid plantings are typically limited to female parents not so aggressive as to overshadow the male parent and thereby delay pollen shed, and to reasonably short male delays. Also, it is advisable to restrict this practice to male parents of sufficient stalk and root strength to avoid stalk and root lodging, which would make it difficult to detassel the female parent or remove the male parent as soon as pollination is complete.

It is a practice of many seed companies to destroy the male parent by cutting or running it down (if it is brittle enough to break) after pollination is complete. Competition with the developing female parent for nutrients or available soil moisture should, in theory, be minimized and increased kernel size and/or seed yield may result. Production research conducted by the author's company has shown mixed results on kernel size and yield responses. Characteristics of the female and male parents involved and soil moisture availability after pollination are important factors contributing to the response observed. Destroying the male parent at this stage prevents grain formation in the male rows and eliminates the risk of seed contamination at harvest.

9–7.6 Parent Delay Techniques

Shoultz (1985) summarized the results of a recent survey of the seed corn industry's use of various parent delay techniques. Split-date planting of parents, the planting of the female and male parents on different dates, is used so that the two parents "nick", or reach the flowering stage concurrently (Fig. 9–3). This has been and continues to be the most popular method of making large alterations in flowering date, so that parents of differing maturities are brought together for a timely nick.



Fig. 9–2. (*Top*) A commercial hybrid seed production field planted in a 4:1 row pattern, with four detasseled rows (female) and one pollinator row (male). (*Bottom*) Aerial view of a commercial hybrid seed production field planted in a 4:1 row pattern, shown after detasseling. Note the border male rows on the left side of the field.



Fig. 9–3. Split-date planting of parents in a 6:2 row pattern. The female rows have emerged while the male rows are just being planted.

Split-date plantings are made on the basis of some combination of days, growth stages, and/or heat units accumulated from the time the first parent was planted (Shoultz, 1985). Most success has been realized by a combination of heat units and growth stage coupled with experience and good judgment. Male parents are often planted with a double delay to extend the pollen shedding period. Plantings are timed so that peak pollen shed coincides with maximum female parent silk exposure.

Other methods in common use for obtaining small adjustments to pollen shed are: (i) variable fertilizer rates; (ii) variable planting depths between parents; and iii) clipping (Cloninger et al., 1974) or flaming (Fowler, 1967) to retard development. These techniques can provide from 1 to 4 d delay in flowering, or extend the duration of flowering by as many as 2 to 4 d (Shoultz, 1985). Clipping and flaming are rarely used to delay the female parent because both techniques typically result in reduced seed yield. Clipping has been used effectively to save a crop when weather conditions have prevented planting the delayed parent when the early parent has already been planted. This has been particularly important when it is too risky to replant the early parent because too few heat units are left in the season or when a seed shortage exists for one or both parents.

9–8 POLLEN CONTROL

Pollen control refers to the practices employed to ensure hybridization by forced cross pollination between the female and male parents.

Pollen control in the hybrid seed corn production field is extremely critical. Various methods of pollen control in seed fields have been utilized or investigated. These were aimed primarily at reducing the cost or easing the difficulty at this critical time period, while still maintaining the desired genetic purity. The two most commonly used methods today are detasseling and cytoplasmic male sterility. Craig (1977) described two other methods, genic male sterility and chemical pollen control, which are not currently in widespread use.

9–8.1 Detasseling the Seed Field

Detasseling currently represents the most widely used method of pollen control. Detasseling involves the physical removal of the tassel from the female plant, either as a manual operation or in combination with mechanical devices. To ensure that each seed field meets the necessary quality (genetic purity) standards, tassels from the female parent rows must be removed before they shed pollen and/or before silks emerge on the ear shoots of the female parent. This is an expensive operation, currently costing the seed company from $250 to $320 per female hectare ($100 to $130 per female acre) for an average female parent. Increasing wage rates and deteriorating population demographics (labor supply and its distribution) are two factors that will continue to pose challenges to the industry.

Genetic purity of intended crosses is dependent on compliance with standards established by company management and certifying agencies (Anonymous, 1971). When the female parent has 5% receptive silks (silks emerged and turgid) the following standards, as established by certifying agencies, are employed: (i) the female parent is limited to 1% shedding tassels at any one inspection and to a total of 2% shedding tassels for three inspections at different dates; and (ii) off-types in the male not over 0.2% at any inspection. Some seed companies have established more rigorous standards; e.g., not over 0.5% female shedders allowed at any one inspection and not over 0.1% male off-types per inspection. Tassels are counted as shedding when more than 5 cm (2 in.) of the central spike and/or side branches have emerged and have shedding anthers.

Major seed corn companies hire and train seed field inspectors to observe pollen control operations, report irregularities, and assist in interpreting rules for the detasseling/rogueing supervisors. These inspectors may be assigned as many as 810 to 1620 gross ha (2000 to 4000 gross acres). Before detasseling begins, they establish compliance with isolation requirements and check for volunteer corn and/or off-type plants in both female and male parent rows. When detasseling starts, the inspectors check fields to be sure that female parent tassels and off-types in male rows are properly removed. The objective is to keep those who are responsible for achieving genetic purity (plant management, area foremen, and detasseling contractors) informed, and to prevent any violation of

standards. If isolation, detasseling, or rogue removal standards are not met, inspectors report the details to plant management, so that a decision regarding corrective measures can be made.

9–8.2 Manual or Hand Detasseling

Each year thousands of workers, usually teenage youth, are employed by seed companies to perform the hand detasseling operation. This activity may last only 1 week, but may continue up to 5 weeks or more depending upon the volume of production and spread in female parent maturities planted within a seed production area. Several factors influence the magnitude and complexity of this job:

1. Tassels must be removed from all female plants in a timely manner, as previously discussed.
2. When weather conditions favor rapid corn growth, fields must be covered daily; this requires 7-d workweeks, rain or shine.
3. Some female parent plant types are easier to detassel than others.
4. Female parents whose tassels begin shedding pollen before fully emerging from the upper leaves, or which silk at about the same time as pollen shed occurs, create difficult detasseling supervision, management, and purity problems.
5. Weather conditions can greatly aid or complicate the detasseling season. A heavy rain or windstorm can lodge and tangle the female parent just as tassels emerge, making walking or driving through the field more difficult. Extreme heat can affect both the efficiency of detasselers and the emergence of silks and tassels.

Detasselers are usually organized into crews ranging from 6 up to 40 or 50 workers. The crew supervisor is responsible for recruiting, transporting, training, managing, and controlling the detasselers in his crew. With larger crews, the supervisor will have one or more assistants (sometimes called checkers) to help in crew training and managing the job to be done in the field. There will customarily be one supervisor or checker for each 6 to 10 crew members. It is important that each crew member be trained in proper detasseling technique, to minimize leaf damage and to ensure an effective detasseling job in each female parent row. The crew supervisor is also responsible for the safety and comfort of the workers while in the field.

For more effective and efficient labor utilization, detasseling carts or personnel carriers (Fig. 9–4) are frequently used, especially for detasseling taller-growing inbreds or single-cross female parents. These carts are motorized high-clearance machines equipped with platforms upon which the workers stand as they remove the tassels. The machines move slowly through the field, enabling the detasselers to look down into the plant canopy and remove the tassels more effectively and easily than if they were on foot. Usually 12 detasselers will work from each machine; for maximum effectiveness it is therefore important that all detasselers on



Fig. 9–4. A high clearance personnel carrier transporting detasselers through a seed production field. This view depicts the "second pass" through this field; during this trip, late-emerging tassels are removed.

each machine be equally skilled. It is often difficult or impossible to use these machines immediately after heavy rain or windstorms, and the detasselers must then proceed on foot.

Some seed companies employ contract detasselers for at least a part of their seed production. With this method, the contractors agree to detassel specified field areas for an established fee paid to them by the seed company. The contractors may work their own hours as long as they meet the company's established standards for timely removal of tassels. If they fail to do so, the seed company reserves the right to bring in a crew or mechanical detasselers to remove the potential problem-causing tassels before they shed pollen, and to deduct this expense from the contractor's payment. Contractors typically provide transportation for themselves and any other detasselers they employ, as well as the necessary supervision. This method often permits people employed in other jobs to earn extra income during their free time.

9–8.3 Mechanical Detasseling

Craig (1977) summarized several factors that led to increased use of mechanical detasselers in the early 1970s. Availability and cost of labor for manual detasseling continue to concern seed companies, and work to improve equipment for mechanical detasseling is ongoing.

Mechanical detasselers (Fig. 9–5) are self-propelled, high-clearance machines capable of operating even in extremely muddy fields. They fall into two basic types:

1. Cutters—a rotating cutter blade or knife cuts or shreds the top of

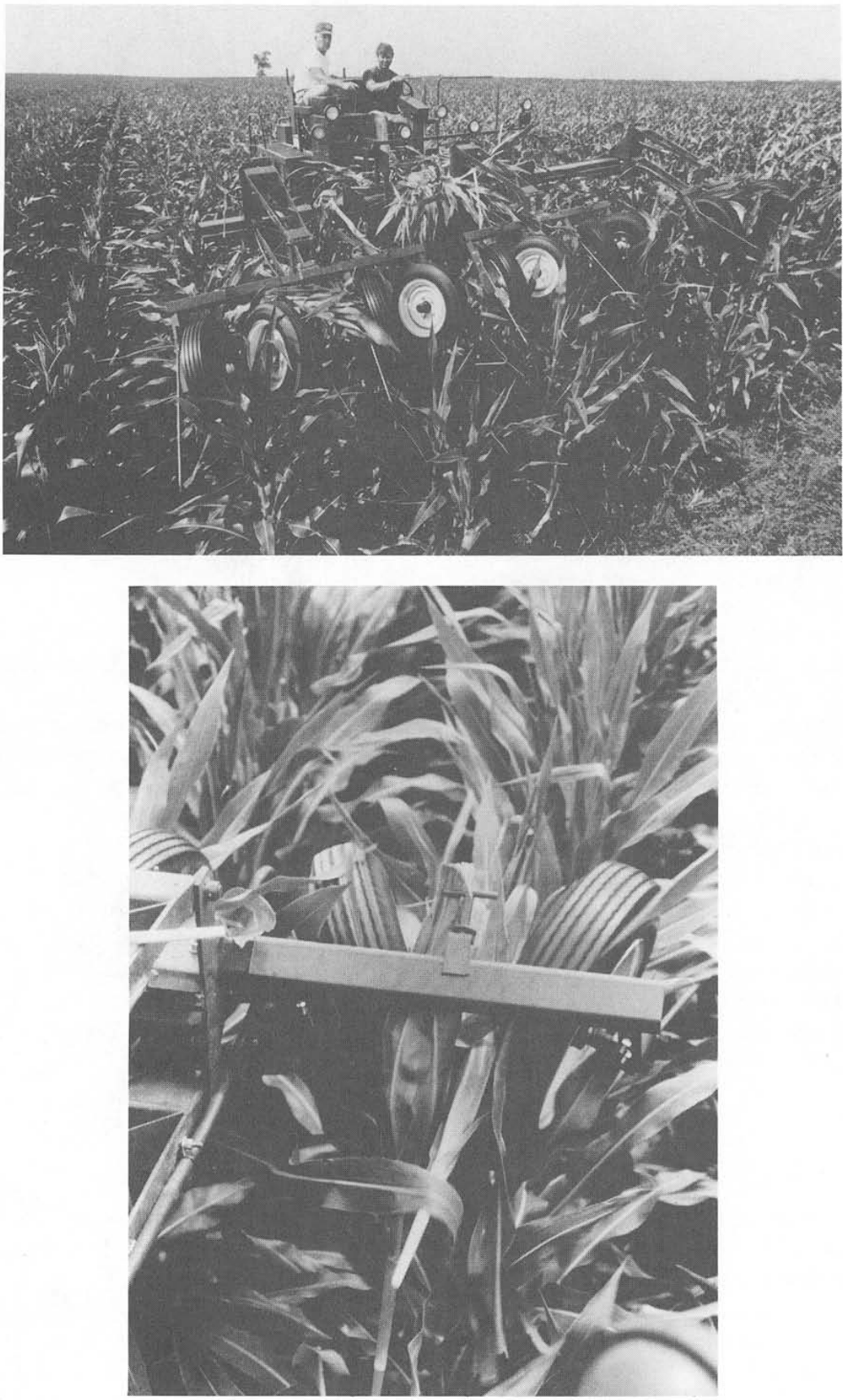


Fig. 9–5. (*Top*) A "wheel puller" machine used for mechanical detasseling of the female rows in a seed production field. (*Bottom*) Close-up view of the wheels in action.

the corn plant, including the tassel; the blades operate at various planes, from horizontal to vertical, and are adjustable in height.

2. Pullers—usually two counter-rotating wheels or rollers, adjustable in height, grasp the tassel and upper leaves and pull them upward in a manner approximating a hand detasseling operation.

The efficiency of mechanical detasselers is affected by many variables in the seed field, such as female parent morphology (leaf and tassel orientation), uniformity of female parent plant height and development, and skill of the operator. Mechanical detasseling produces best results when it is done in a uniform seed field in which the tassel is well exserted ahead of pollen shedding. As conditions become less favorable, percentage of tassels removed per pass will decrease and leaf damage will increase. The typical objective in the use of mechanical detasselers is to delay the operation as long as possible before silk emergence, to permit maximum exsertion of tassels, enabling their removal with minimum leaf damage. However, this delay increases the risk of leaving "sprigs" (partial tassels) or "hangers" in the leaf canopy. Hangers, as tassels that become lodged in the leaf canopy are sometimes called, are capable of shedding pollen for 2 to 3 d after removal (D. Langer and P. Downes, 1982, unpublished data). Hangers can lead to increased levels of female selfs, and are one of the chief objections that some companies have to mechanical detasseling machines. In all cases, some hand labor is required to move hangers to the ground and to pull entire tassels or sprigs remaining on missed, late, or short plants, or on tillers.

With most female parents, the combination of mechanical and hand detasseling will result in a cost savings when compared with hand detasseling alone. Current detasseling costs range from $198 to $247 per ha ($80–$100 per female acre) with a combination of mechanical and hand detasseling, compared to $296 to $321 per ha ($120 to $130 per female acre) for all hand detasseling (W. Beck, 1987, personal communication).

Cost savings attained through mechanical detasseling may be offset by seed yield reductions if the operation is not carefully managed to minimize leaf damage (Craig, 1977, unpublished data). To decide whether or not to use mechanical detasseling, seed companies and plant management consider variable production costs, especially current detasseling wages, and available labor supply, and weigh them against characteristics of the female parents involved and the size of the detasseling operation they face.

9–8.4 Effect of Detasseling on Seed Yield

The resumption in 1971 of detasseling as the primary method for pollen control (see section 9–8.5) renewed interest in the effect of detasseling on yield. The effect of detasseling on seed yield was considered more critical then, since inbred females had become involved due to the transitional adoption of single-cross hybrids. The development of various

types of mechanical detasseling machines also added a new dimension. A discussion of the effect of detasseling and leaf removal on seed yields of the female parents of double-cross hybrids may be found in Craig (1977).

Published work on leaf removal with inbred lines indicates that the yield response is generally similar to that of single crosses. In theory, removal of only the tassel could result in a yield increase, due to decreased shading of upper leaves and reduced competition for photosynthate and nutrients between the ear and the tassel. Hunter et al. (1973) removed the tassel, only, from 10 inbreds and observed an average increase in yield of 6.9%. As more leaves were removed with the tassel, however, greater yield reductions typically occurred. When one, two, and three leaves were removed with the tassel, yield reductions averaged 1.5, 4.9, and 13.5% relative to the yield where the tassel alone was removed. Cantrell and Geadelmann (1981) removed the tassel with two leaves. They observed yield reductions ranging from 9 to 13% across four early maturity inbreds, with an average of 11.6% yield reduction. Several other workers have reported differences among inbreds in sensitivity to yield reduction following varying amounts of defoliation (Cantrell and Geadelmann, 1981; Hunter et al., 1973; Vasilas and Seif, 1985b).

It is common to observe greater yield reductions after mechanical detasseling than after hand detasseling. Studies conducted by seed companies with mechanical detasseling machines have shown varying results. Craig (1977) cited unpublished research in which the yield of mechanically detasseled plots was from 2 to 40% less than that of hand detasseled treatments, depending upon the inbred involved and the number of mechanical cuttings. Unpublished research by C. Carter and R. York (1979, unpublished data) compared hand detasseling with wheel pullers on inbred females. These workers observed yield reductions ranging from 2 to 46% depending on the inbred line, number of wheel pulls, and timing of the wheel pulling operation.

Measurements have been made on the yield components affected by detasseling, to determine which are primarily responsible for reduced yield (Hunter et al., 1973; Pucaric and Gotlin, 1979; Vasilas and Seif, 1985a; Craig, 1977). The variables involved in these studies included the following: (i) the time of cutting or tassel removal in relation to plant development; (ii) the climatic conditions prior to, during, and after tassel removal; (iii) morphological differences among genotypes; (iv) type of detasseling machine; (v) the number of times cut or pulled; and (vi) the skill and attention of the machine operator. Although kernel number has most often been the major contributing factor, results have varied due to the differences in severity and timing of treatments employed. These complexities mean that precise statements regarding the effect of detasseling treatments on yield components cannot be made.

9–8.5 Cytoplasmic Male Sterility

For about two decades prior to the epidemic of southern corn leaf blight that swept the USA in 1970, the conversion of inbred parents to Texas cytoplasmic male sterility (*cms*-T) replaced detasseling as the predominant form of pollen control (Craig, 1977; Ullstrup, 1972). Though other male sterile cytoplasms were available, the T source (Rogers and Edwardson, 1952) proved to be the most satisfactory, because more inbreds were completely sterilized by T cytoplasm and genetic fertility restoration was more easily accomplished in this cytoplasm.

After the 1970 epidemic, the realization that the nearly complete conversion to T cytoplasm increased the vulnerability of the corn crop (NAS, 1972; Ullstrup, 1972) prompted a retreat from the extensive use of cms as a substitute for detasseling. In addition to T cytoplasm, many other male-sterile cytoplasms had been identified (Beckett, 1971; Duvick, 1965); of these, the C and S cytoplasms were the best known (Duvick, 1972). Since the use of cms was still a cost-competitive and satisfactory technique for hybrid seed production, C and S cytoplasms became important again in the late 1970s and early 1980s.

The American Seed Trade Association (ASTA) recently conducted a survey of the type of cytoplasm used in the production of seed corn to be sold in the USA. Based on number of units of expected sales for 1987, 66.1% of the seed corn was produced using 100% normal (N) cytoplasm, 22.1% involved production with *cms*-C cytoplasm (1.9% involving 100% *cms*-C and restorers, and 20.2% involving blends with N cytoplasm), and 11.5% involved *cms*-S cytoplasm (0.4% using *cms*-S and restorers, and 11.1% involving blends with N cytoplasm) (W. T. Schapaugh, 1987, letter to member companies responding to ASTA Corn Cytoplasm Survey).

There are two major ways in which cms has been used to facilitate the crossing of two inbreds. In the first case, detasseling is eliminated through the use of a female parent for which the cms conversion is completely male sterile. No detasseling is required. The other case involves combination of C or S cytoplasms in certain genetic backgrounds that result in only partial male sterility. In this situation, anther exsertion is delayed 1 to 10 d (Duvick, 1965) and usually commences after the tassel is fully extended above the leaves. At this point, mechanical detasseling can be accomplished with minimum leaf removal.

Consider the production of the single cross, A $\times$ B. If inbred A is nonrestorer genotype (rf/rf) that has been put into a male sterile cytoplasm by backcrossing, one can plant blocks of cms female A alternating with blocks of inbred B (the male) and produce completely cross-pollinated seed on inbred A without detasseling. If inbred B is also a nonrestorer genotype, the hybrid plants in a field of commercial corn would also be pollen sterile; if inbred B carries dominant restorer genes (Rf/Rf), however, the hybrid (Rf/rf) will shed pollen.

Since restored hybrids do not always shed adequate pollen (Duvick,

1959), the use of the restorer system introduces some risk for both the farmer and the seed company. Consequently, most single cross production is likely to involve a nonrestored genotype, in which from 25 to 50% of fertile hybrid seed, produced by detasseling, is blended with 50 to 75% of seed of the same hybrid produced by the cms method. This blending results in 25 to 50% of the hybrid plants in the farmer's field that will shed pollen normally.

Various methods of blending to assure complete mixing are practiced. One method is to flank the pollinator with alternating blocks of cms and normal (fertile) cytoplasm female. Another method increases the scale by planting alternating quarters of the field in sterile or normal female. Harvesting entails making one trip across the field in the cms female and a return trip through the normal female. By the time the ear corn reaches the conditioning plant, the ears of the two cytoplasms are thoroughly mixed.

9–8.6 Other Types of Sterility

Craig (1977) described in some detail the "Patterson method", which employs genic male sterility in the production of hybrid seed corn. This method is not widely used today, however, since the conversion of inbreds is complicated, time consuming, and expensive. Furthermore, additional expenses, in the form of foundation seed production inventory and quality control, are required.

Use of chemically induced male sterility in commercial hybrid seed corn production is an idea that has received considerable attention (Craig, 1977). Despite substantial research and development effort by several agricultural chemical companies, there is essentially no recent published work on this subject for corn. Likewise, a dependable and affordable commercial application of chemical hybridizing agents for seed corn production has not yet been discovered and/or developed (S. L. Kaplan, 1987, personal communication). To date, the major stumbling blocks have been either insufficient sterility percentage (Bollinger et al., 1978) or associated female barrenness (A. J. Cavalieri, 1987, personal communication).

9–9 HARVESTING THE SEED CROP

Harvest of the hybrid seed corn crop is, by necessity, closely coordinated with the operations of conditioning facilities at the production plant. The following discussion describes the operations generally used at a typical large production plant (Fig. 9–6). There are variations among companies and among locations within a single company. All operations from husking to distribution may be done at one location. Alternatively, harvesting, sorting, drying, and shelling may be accomplished at a plant

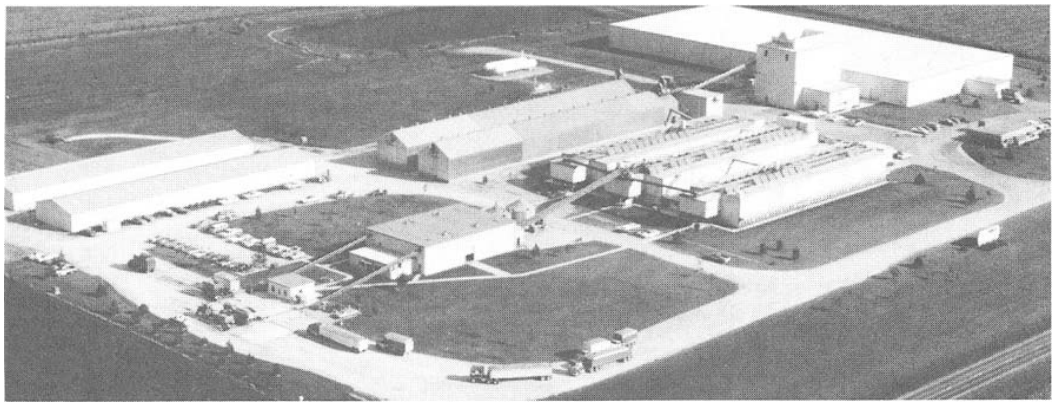


Fig. 9–6. A modern hybrid seed corn production plant located in Iowa, with facilities for all steps in conditioning, bagged seed storage in year-round controlled atmosphere conditions, and distribution of seed.

near the growing location, while the sizing, cleaning, bagging, storage, and distribution are done at other more centralized locations.

9–9.1 Maturity and Seed Quality

Harvest of the seed crop usually begins just before the developing kernels approach physiological maturity, the stage at which the kernels have reached their maximum dry matter accumulation. The moisture percentage at which kernels of inbred corn reach physiological maturity varies with genotype and environment, and ranges from 30 to 38% (A. J. Cavalieri, 1987, unpublished data; Knittle and Burris, 1976). Generally, harvest will begin when the moisture level of the seed is between 30 and 38%. The target moisture level depends upon factors such as the female parent, environment, weather forecasts, production volume and, finally, production plant capacity.

For planning purposes, projected harvest dates are typically estimated by monitoring kernel moisture percentage and heat unit (or growing degree day) accumulation, in combination with "black layer" formation (Daynard, 1969, 1972; Daynard and Duncan, 1969) and/or progression of the "milk line" (Afuakwa and Crookston, 1984). Genetic variation for field drying rates has been observed among inbreds (Carter and Poneleit, 1973; A. J. Cavalieri, 1986, unpublished data), and may be taken into account.

Timely harvest of the seed crop provides the seed company several advantages, including minimization of: (i) risk of freeze injury; (ii) field losses from mechanical pickers; (iii) risk of harvest delays due to adverse weather conditions; and (iv) quality deterioration due to insect damage, ear molds, stalk rots, and other diseases. Each of these factors contributes to the quality of the seed crop by reduction of physical damage, preservation of physiological vigor, and enhancement of appearance.

The adverse effect of freeze damage upon seed germination is a major risk to seed corn companies (Airy, 1955; Burris and Knittle, 1985). Ross-

man (1949) concluded that the amount of damage by freezing depended on temperature, duration of exposure, moisture of seed, genotype, husk protection, stage of development, and rate of drying after freezing. Studies reported by Neal (1961) indicated that injury to germination from freeze damage is directly related to kernel moisture as well as intensity and duration of exposure. The higher the moisture, the greater the effect on germination at all levels of freeze treatments.

9–9.2 Field Operations

The contract grower is responsible for harvesting the seed crop and delivering it to the production plant. Most mechanical harvesters used today are self-propelled ear corn pickers with three, four, or six-row heads (Fig. 9–7). Reduction in mechanical damage from the harvesters is accomplished by removing pegs from the husking rolls and properly adjusting the husking beds. Since harvest rate is ultimately determined by dryer capacity, a well-coordinated schedule directed by the production plant management is necessary to keep field harvest operations moving smoothly and dryers at full capacity.

9–9.3 Plant Operations

The seed is weighed as it is delivered to the plant. As the load is being dumped for movement into the husking/sorting building, the ear corn is sampled to accurately represent the grower's production of each hybrid. If maturity or moisture varies within a grower's fields, more than one sample is secured. These samples are used for measurement of grain moisture percentage and the cob and husk percentage. These data are used to calculate weight of No. 2 shelled corn delivered, which is the basis of payment to the contract grower.

While final husking is still done in the field by some companies, more than 90% of the seed corn produced in the USA is transported to the plant before it is husked a final time, sorted, and then moved to the dryers (Stanfield, 1986). In a typical husking/sorting building, ear corn is conveyed from the green corn receiving area (Fig. 9–8) to storage bins above the husking bed. The action of the husking bed removes the majority of the remaining husks before the ear corn passes over the sorting table (Fig. 9–9). In some operations, a return conveyor takes unhusked ears back over the husking bed. Usually, from four to six workers per table sort the ear corn as it passes over the table. These workers remove any diseased, off-type, or off-color ears from the seed. After sorting, the seed is conveyed to the dryers.

9–10 SEED CORN CONDITIONING

Conditioning of seed corn is the series of activities that begins with drying the ear corn and ends with the seed being bagged. The primary



Fig. 9–7. (*Top*) Mechanically harvesting ear corn from the female rows using a three-row ear corn picker. (*Bottom*) The ear corn is elevated into a trailing wagon.

steps involved are drying, shelling, cleaning, sizing, treating, and bagging. These activities are accomplished in plants of all sizes and descriptions (Fig. 9–6). Although varying in engineering, all conditioning plants are designed and built to efficiently handle quantities of seed ranging from a few thousand to several million kilograms per year.

Certain objectives must constantly be addressed during the various



Fig. 9–8. Unloading seed corn at the green corn receiving area at a production plant. The ear corn is conveyed from this area to the husking and sorting building.



Fig. 9–9. The sorting operation in progress. Workers remove undesirable ears before the ear corn is conveyed to the dryer. The conveyer above the sorting table returns unhusked ears to the husking bed.

procedures of conditioning. First, the seed must be handled in a manner that minimizes mechanical damage. Any breaks that occur in the seed coat have a direct and detrimental effect on germinability and vigor of the seedling plant (Knake et al., 1986). The extent to which germinability

and/or vigor are reduced depends on both the severity and location of the mechanical damage (Wortman and Rinke, 1951; Wright, 1948). The effects of seed coat damage can be only partially offset by the application of fungicidal seed treatment (Knake et al., 1986; Tatum and Zuber, 1943).

A second objective of conditioning is to achieve maximum plantability within the limitations imposed by the sizing equipment. The objectives of sizing seed are to achieve uniformity of appearance and to maximize uniformity of kernel size and/or shape so that seeds drop accurately with either plate-type or plateless planters. The contemporary corn farmer, who is optimizing soil fertility, selecting hybrids best adapted to specific population densities, and planting for most efficient production, cannot tolerate significant fluctuations in stand.

Finally, the production plant manager must carefully maintain conditioning schedules to ensure the orderly movement of seed lots through distribution channels to meet delivery and planting schedules.

9–10.1 Drying the Seed

Seed corn dryers (Fig. 9–10) vary considerably throughout the industry. The majority of the systems utilize a squirrel-cage or axial-vane fan system to draw fresh air through a burner and force the heated air through bins filled with ear corn. Most burners today are fired with natural, butane, or propane gas.

Drying temperatures vary from 35 to 46 °C (95–115 °F). The entire

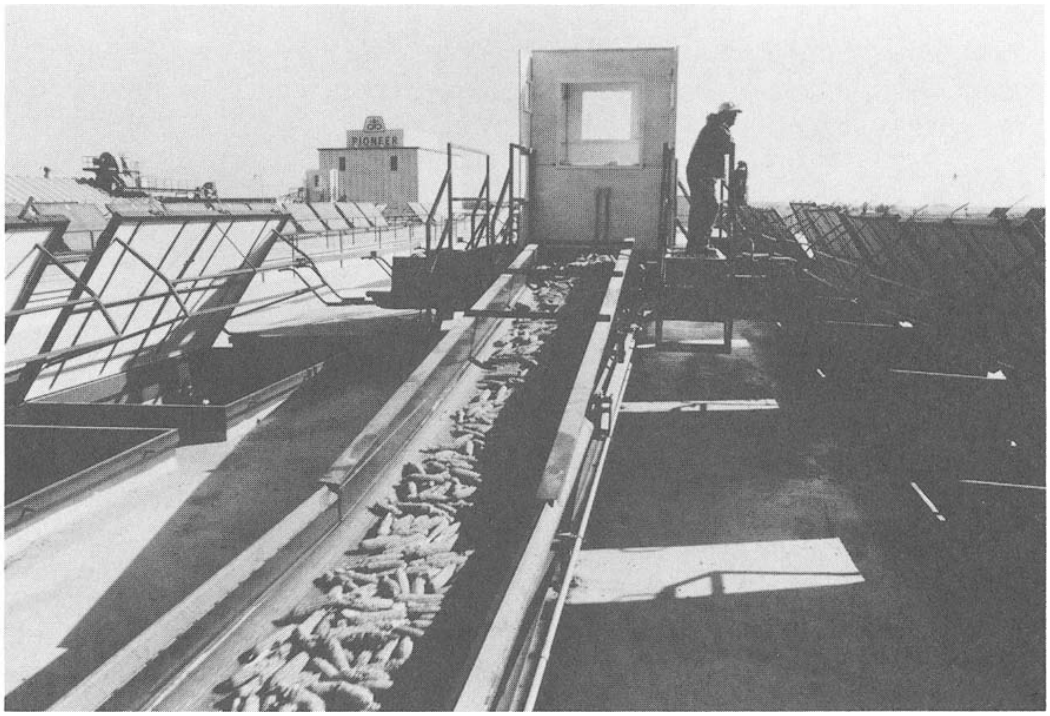


Fig. 9–10. Top view of an ear corn dryer at a seed corn conditioning facility. The doors are opened during bin filling, closed during the first half of the drying cycle, and then opened again to exhaust moisture-laden air during the last half of the drying cycle.

drying procedure is closely monitored since higher temperatures are detrimental to seed quality. Temperatures in the dryer building are measured at the point of contact with the seed. Temperatures above 45 °C (113 °F) have been reported as injurious to seed viability (Navratil and Burris, 1984; Craig, 1977), and high moisture seed is best dried at temperatures of 35 to 40 °C (95–105 °F) (Navratil and Burris, 1984; R. F. Baker, N. M. Frey, and R. D. Wych, unpublished data). It is also known that the higher the initial moisture content, the more susceptible the seed is to germination damage, and that genotypes vary in dryer sensitivity. Air temperatures of 46 °C (115 °F) may be used after moisture content of the seed has decreased to 20% or less, to complete the drying with minimal risk of germination injury. The seed corn is dried to 12 to 13% moisture, at which time it is conveyed to the sheller.

The moisture level to which seed corn is dried and held in storage also is critical. Cal and Obendorf (1972) showed that imbibition of low moisture (6%) corn kernels at temperatures of 5 °C (41 °F) resulted in malformed and delayed seedling growth. Sensitivity to imbibitional chilling was reduced when the initial kernel moisture was 13 or 16%.

9–10.2 Shelling the Seed

Shellers used for seed corn are designed so that when operated at low speeds, the seed is more or less rubbed from the cob. As the sheller speed increases, the action becomes increasingly pounding, kernel damage drastically increases, and germination declines (Airy, 1955). Therefore, it is desirable that all contact edges of the moving sheller parts be well smoothed to reduce damage. Experience has shown that with adequate horsepower, shellers can be operated at lower speeds and kernel damage is reduced by keeping the sheller full at all times.

9–10.3 Conveying the Seed

Since prevention of kernel damage is one objective of conditioning seed, it follows that each step should be evaluated to determine the amount of damage chargeable to that procedure. When studies such as this were done, some of the conveying equipment formerly used was found to be directly responsible for much of the mechanical damage (Craig, 1977). Grain augers crack and scuff seed; chain conveyors crush and crack kernels; and single tube elevator legs allow seed to be caught under belts and behind cups. Perhaps the greatest single source of damage is the dropping of seed from elevated conveyors into steel bottom bins or onto concrete floors.

Today, elevator legs are the double tube type and are equipped with either all plastic or plastic-lipped buckets. Chain conveyors are seldom used anymore, and augers have been replaced by belted conveyors. Breakage from impact on bin bottoms has been nearly eliminated by using grain spirals or ladders (Fig. 9–11) to lower seed gently with minimal

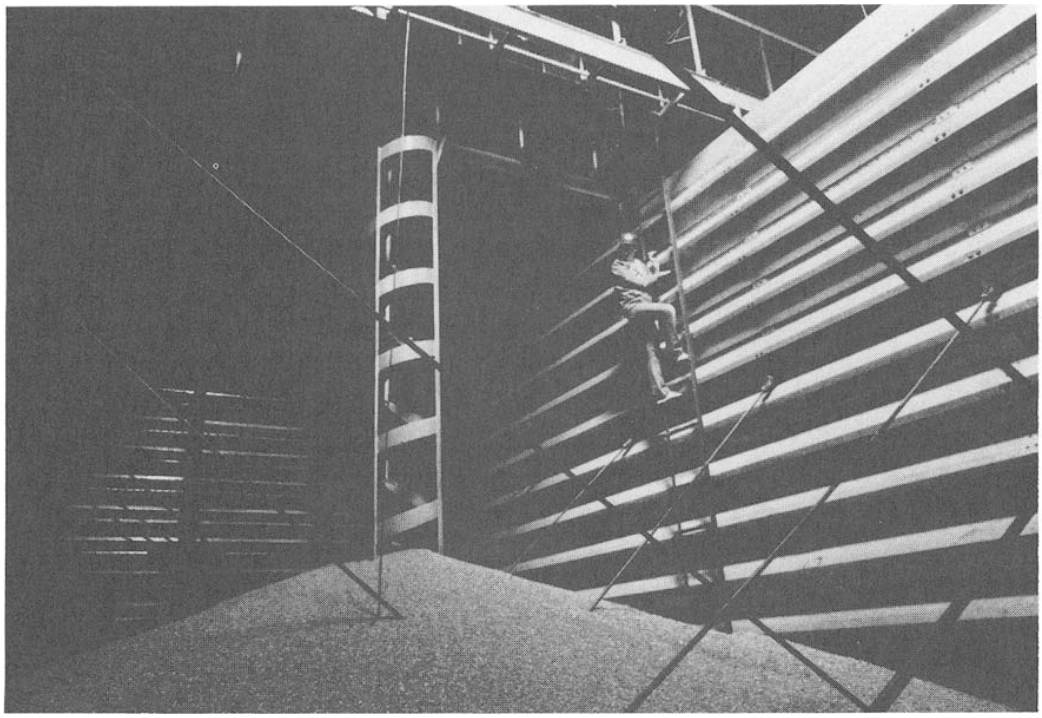


Fig. 9–11. Bulk seed in storage awaiting further conditioning and bagging. The spiral chute permits filling the bin while subjecting the seed to minimal mechanical injury.

impact. Whenever the fall distances are greater than 2 to 3 m, such equipment should be considered. Lateral conveying of seed is done either on rubber belting or with vibrating trough conveyors.

9–10.4 Cleaning the Seed

Seed corn from the sheller contains varying amounts of foreign material, consisting of bits of cob, husk, silk, pieces of kernels and, on occasion, insect larvae brought in from the field with the ear corn. Storage properties, plantability, and appearance of seed are greatly enhanced by removal of such debris. If not removed, the debris encourages storage insect problems and the development of hot spots when seed is stored for long periods. Aeration and cooling are improved by removing such foreign material, and less storage space is required.

Two types of machines are used in the first steps of cleaning seed, air screen machines and scalperators. With air screen machines, shelled corn is delivered to sloping shaker screens that remove wide, extra large kernels and cob pieces (over a 24/64; see section 9–10.5 for a description of screen size nomenclature) and narrow tip kernels (through a 15/64 or a 16/64). The seed then passes through a blast of air that lifts fines, small cob pieces, and dust which have escaped the screening action. With scalperators, shelled corn is fed onto a rotating wire mesh reel. Kernels and small cob fragments pass through the mesh, thus separating them from the larger cob pieces. An air chamber is then utilized to separate fines,

which are routed to a dust collector. Any grain removed is disposed of as feed or market corn.

When necessary, insects are controlled with an application of a slurry formulation of an appropriate insecticide to the shelled corn stream being conveyed into bulk storage bins. This is especially critical when there may be a delay between shelling and movement of bagged seed to cold storage following sizing, treating, and bagging.

In many operations, the shelled corn is cleaned again as the first step in the sizing towers. The air screen machines or scalperators (with a smaller mesh) are fed at a slower rate to achieve more extensive removal of fines and foreign material. A thorough cleaning prior to sizing is essential to: (i) reduce the amount of dust; (ii) ensure smooth rapid flow through the sizers; and (iii) permit cleaners (aspirators or gravity separators) at the end of the sizing system to operate more efficiently.

9–10.5 Sizing the Seed

9–10.5.1 Sizing

Sizing as used in the seed industry means separating kernels into uniform lots of sizes based on width, thickness, and length. The historic term *grading* carries a connotation of quality measurement that does not apply to the procedure. To determine screens to use in sizing, some seed companies secure a 760 to 1270 kg (30–50 bu) composite sample for each lot. These are run through a sample sizer to determine percent by size, kernel counts, plantability, and germination.

During sizing, seeds are passed through round hole cylinders in a descending series of screen sizes, which are measured in 1/128th in. (commonly referenced as one-half 64th of an inch). Screens are selected to separate the seed into large, medium, and small kernel sizes, and "tips" (narrow seeds for discard). In some systems, a divider cylinder is used to split the seed into "overs" and "throughs". The overs are separated with a larger screen into large and medium portions. A smaller screen divides the throughs into medium (combined with medium from the other separation) and small kernels. Another smaller round hole screen then removes the tips. Following this, slot screens from 12/64 to 14/64 are used to separate large kernels into large flat (LF) and large round (LR), medium kernels into MF and MR, and small kernels into SF and SR. Figure 9–12 illustrates this sequence. In contrast, some systems separate rounds and flats with slotted screens first. Then the rounds and flats are divided by round hole cylinders into large, medium, and small sizes. The goal of both systems of kernel size separations is to achieve seed with acceptable appearance and plantability.

Kernel sizes may be length sized if the range in length would be unacceptable to customers. Length sizers, called uniflows, remove shorter kernels, utilizing a revolving indented cylinder. Shorter kernels ride up higher on the inside of the cylinder before falling out of the indentations

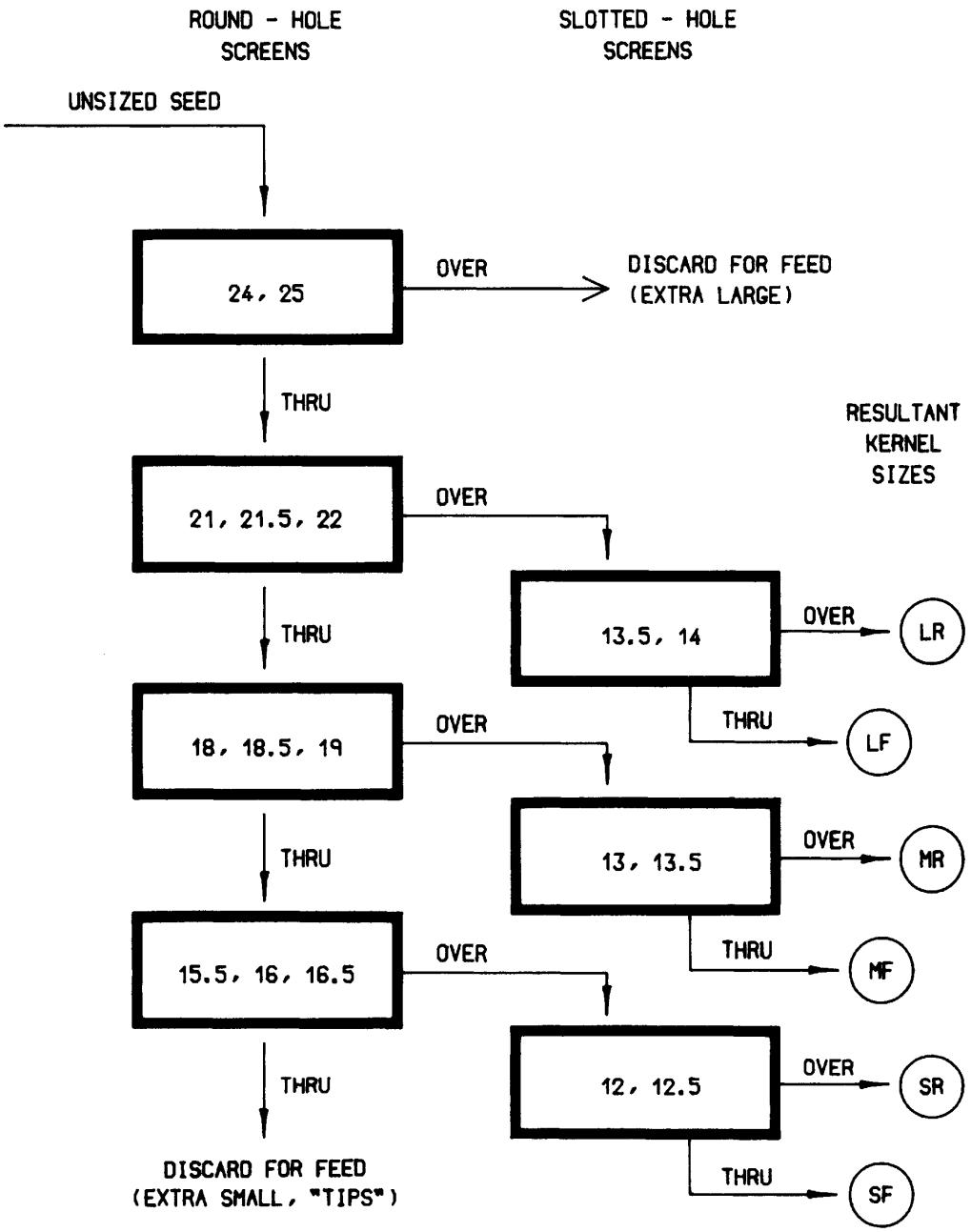


Fig. 9–12. A diagramatic outline of typical screen sizes used for sizing seed corn, using round-hole screens first and then dividing each portion (large, medium, and small) into flat and round kernels with slotted-hole screens. Screen sizes are given in 64ths of an inch.

and are captured by an adjustable tilt trough through the center of the cylinder. Uniflows may be used to remove long kernels in seed of three-way crosses and modified single crosses. Length sizing is much less common with seed from inbreds, which characteristically have rather short kernels. Length sizing generally has little effect on plantability if the shortest kernels are longer than one-half of the plate cell length.

Separation tolerances of 3/64 in. for width and thickness and 4/64 in. for length have been proposed (Bateman, 1972; McKee, 1963). The industry, however, commonly accepts a 4/64 in. range for kernel width

(round hole) and up to an 8/64 in. range for length with long kerneled seeds. Bateman (1972) suggested plantability (number of kernels dropped) tolerance with plate planters of 3% under-drop to 5% over-drop. This matches well with industry standards, but under-drop must be carefully monitored to be certain that sorting does not occur. Changing round hole screens by one-half 64th of an inch is usually sufficient to greatly improve plantabilities which are heavy or light.

Since the first "plateless" planter (John Deere® 'Max-Emerge'®) was introduced in the early 1970s, sizing methods have been undergoing change. This change has been accelerated as other equipment manufacturers have also introduced plateless planters. Each of these so-called plateless planters satisfactorily plant seed without prior separation of flat from round sizes. Consequently, most seed corn firms now offer plateless sizes (flats and rounds undivided or blended together), usually sized (and designated) further as large, medium, or small. Since variation in kernel length is no problem for these planters, the short kernels removed in length sizing are often blended into plateless sizes. Current estimates indicate that 85% or more of the corn in some areas is planted with plateless planters. Consequently, up to 60% of the sales of some companies is in plateless kernel sizes.

9–10.5.2 Cleaning Sized Seed

Removal of damaged and diseased kernels, which are usually lighter in weight than sound kernels, is accomplished through the use of aspirators or specific gravity separators. Aspirators have high capacity, but the separation is not as fine as with gravity separators. Consequently, aspirators tend to discard more desirable kernels without as thorough removal of imperfect seeds. Operation of gravity separators requires more skill, because adjustments must be made not only on the feed rate and air flow, but also on the tilt and pitch of the gravity deck and on shaker speed. Quality counts before and after cleaners are vital to satisfactory operation.

Conditioning of seed corn often has little effect on germination but appearance is greatly improved. Improved equipment and a higher comprehension of seed quality by discriminating customers has resulted in excellently conditioned seed being sold in the marketplace today.

9–10.6 Planter Plate Selection

Practically all seed corn companies offer planter plate suggestions for customer convenience. The process of making planter plate checks not only identifies the plates that should be suggested to the customer, but also serves as a check on the accuracy of sizing. If the check planter will not drop the seed accurately, adjustments are made on the sizing equipment to improve accuracy. Most plate selection is done on actual planter test stands provided in recent years by the DICKEY-john® Corp. Planter

stands are often electronically monitored, which makes this step faster and eliminates human error in counting drop accuracy. Planting suggestions are also made for plateless planters.

9–10.7 Treating the Seed

Most seed companies apply a fungicide or a combination fungicide/insecticide to the seed before bagging. The purpose of treating conditioned seed is to protect against seedling diseases and to give short-term protection against storage insects. Properly treating seed may also help offset vulnerability to disease caused by mechanical damage (Knake et al., 1986; Wortman and Rinke, 1951; Wright, 1948).

A typical dosage of the fungicide captan [*cis*-*N*-((trichloromethyl)thio)-4cyclohexene-1,2-dicarboximide] is about 0.6 g a. i. per kilogram of seed (600 ppm; 0.54 oz/bu). In areas where head smut disease is prevalent, Vitavax® or Vitavax®/thiram [bis(dimethylthio-carbamoyl)disulfide] fungicides are utilized in place of captan. A purplish or reddish dye is usually added to the fungicidal slurry to impart a distinctive color to the seed corn. This enables easy identification that treatment has been added. The treatment is spray metered on the seed in a rolling cylinder drum. A smooth uniform application is desired. During extremely cold weather, methanol may be added to prevent spotty treatment due to crystal formation.

Until recently, malathion (*O,O*-dimethyl phosphorodithoate of diethyl mercaptosuccinate) and methoxychlor [2,2-bis(p-methoxyphenyl)-1,1,1-trichloroethane] were the insecticides most commonly included in the treating mix. Use of these chemicals is now declining, due to efficacy and cost considerations, stricter governmental regulations, and the introduction of newer chemistries that are effective at lower application rates. Insecticide and fungicide use will continue to be a dynamic reflection of new chemistry, cooperative research between the chemical companies and the seed corn industry, and the regulation climate imposed by the Environmental Protection Agency and the Food and Drug Administration.

9–10.8 Bagging the Seed

Most seed corn today is packaged by automatic or semi-automatic equipment (Fig. 9–13). A specified amount of seed is weighed, the bag is hung and filled, a tag is sewn on, and the bag is coded. Only one or two operators are needed to monitor this operation and keep it running smoothly. Nearly all seed corn in the USA is packaged in multi-ply bags, most of which contain a moisture barrier of free polyethylene or a polyethylene-coated sheet to protect against external water. A crinkled outer ply with a nonslip coating improves handling and stacking ability.

A relatively new innovation is the replacement of sewing by the use of heat-sealed bags. The advantages of heat sealing are to: (i) make entry

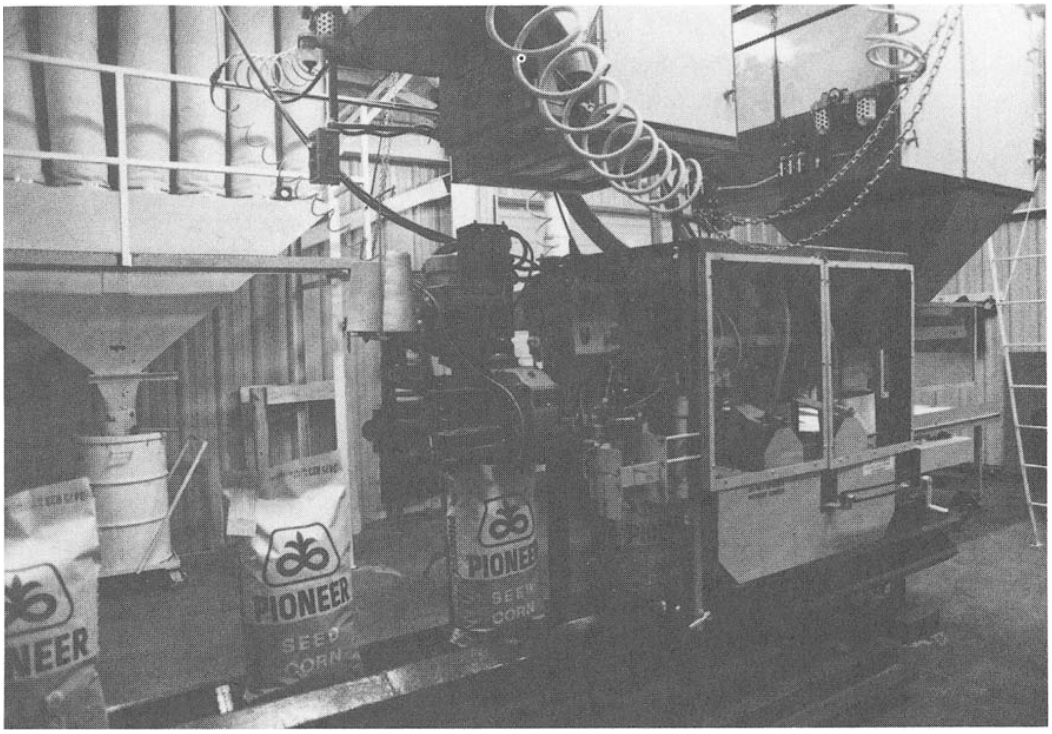


Fig. 9–13. A typical bagging line in which the seed is weighed and dropped into the bag. Information such as bag weight, kernel size, and seed lot code is printed on the bag, and a preprinted tag is attached as the bag is sewn closed while traveling on a belt conveyor. The bags are subsequently stacked on pallets.

into the bag by moisture and insects more difficult; (ii) eliminate problems caused by malfunctioning sewing heads; and (iii) save the cost of sewing thread. Pressure sensitive labels which are preprinted by computers can be used in place of sewn in tags.

Package size has moved from the bushel bag (25 kg, or 56 lb) to units weighing 23 kg (50 lb) and, in recent years, to units with 80 000 kernels per bag. A problem with bagging all units with 80 000 kernels is that different kernel sizes neither weigh the same nor require the same volume. Bag weights may vary from 13 to 32 kg (30–70 lb) and a variety of bag sizes is necessary so that all bags will be full regardless of kernel size. In addition, palletizing bagged seed becomes difficult because of the different bag sizes. A partial solution to these problems has been achieved by some companies who have resumed varying kernel count per unit by kernel size, so that bag weight is near 22 kg (48 lb).

An important final step in conditioning is collecting and saving a representative sample of each seed lot. Trickle samplers are often used, but care must be exercised to ensure that the sampling tube draws from all the flow. Otherwise, stratification in the flow may cause the accumulation of a nonrepresentative sample. The sample thus obtained is used by quality assurance for germination and purity tests, verification of kernel counts, and checks for damaged kernels and inert material. State and federal laws require certain information to be printed on each bag or on a tag or label affixed to each bag. Requirements vary from state to

state, although attempts have been made to standardize these requirements.

9–11 QUALITY ASSURANCE

During the past 10 to 15 years, many changes have taken place in the techniques, equipment, and inbred parents that affect seed corn quality. Because of higher yield goals and increased production costs, farmers demand and, in general, receive high-quality seed. It is the goal of seedsmen to supply adequate quantities of a product that retains the genetic gains incorporated into a given hybrid by the corn breeder. To help realize these goals, most companies maintain a quality assurance program to monitor all phases of seed production.

The quality assurance program should have well-defined procedures and standards that are understood by all levels of management. Data should be collected according to rules and procedures outlined in *Rules of Testing Seeds* (Anonymous, 1981), the AOSCA *Certification Handbook* (Anonymous, 1971), and the *International Rules of Seed Testing* (Anonymous, 1985). Often more strict and precise rules and procedures have been adopted by company management.

Isolation standards and tests for genetic purity were described earlier in the chapter as they pertained to production of parent seed stocks and commercial hybrid seed corn (see p. 568–571, 573). The rest of this section deals with standards for specialty corn and quality assurance procedures that are conducted during and after conditioning.

9–11.1 Specialty Corn

Seed production and quality control procedures for maintaining genetic purity of white, waxy, high-lysine, and high-amylose corn are somewhat stricter than those outlined above for yellow dent corn. These specialty corns differ from normal yellow dent by being homozygous for recessive alleles at one or more critical loci. Thus, contamination arising from any foreign pollen would mask the expression of the desired trait.

Production standards are more demanding for specialty corn. Any expression of xenia in the kernels must be removed in order to meet genetic purity standards. Most waxy and high-amylose corn is marketed with $<3\%$ normal endosperm. See Bear (1975) for a discussion of purity requirements for these specialty corns.

Isolation standards to minimize contamination in specialty seed corn have been set at 201 m (660 ft) plus four border rows when the field size is 4 ha (10 acres) or less. The distance can be decreased as field size and/or the number of border rows increases. However, many commercial companies maintain the 201 m, and some require as much as 402 m (1320 ft), as a minimum isolation distance.

When contamination does occur, such as yellow kernels in white corn,

procedures have been established to remove the obviously impure seeds. The original method was to pick out the yellow kernels at the sorting tables before drying the ears. Although electronic devices sensitive to minute color changes can be used, the equipment is expensive and its capacity is limited, so few companies use color sorters. With waxy corn, a special technique to identify dent contamination is used (Jugenheimer, 1958). An iodine solution applied to exposed endosperm starch causes the waxy kernels to stain reddish brown, while normal-starch kernels stain blue-black. The iodine stain converts a chemical property to a color test that is ultimately equivalent to the detection of yellow kernels in the white seed.

9–11.2 Physical Quality

Physical quality is measured by the amount and kind of damaged kernels present and by the viability and vigor of the seed. These traits affect field emergence, establishment and uniformity, and ultimately yield (Knake et al., 1986; Wortman and Rinke, 1951; Wright, 1948; see Craig, 1977 for additional, older references).

Seed corn is said to be in its best physical condition when it has attained physiological maturity and is still in the field on the ear of the female parent plants. Many activities affecting physical quality are performed from the time the seed is harvested until it is planted by the customer. Seed left standing in the field after physiological maturity is subjected to conditions that lower quality, such as cold temperature, disease, and insect damage. Seed corn is subjected to mechanical damage during harvest, drying, shelling, cleaning, sizing, treating, and bagging. Isolating and identifying the source, nature, and extent of physical quality problems, and recommendation of preventive or corrective procedures, are responsibilities of quality assurance.

9–11.3 Sampling

Seed quality is measured by testing a representative sample of a lot or prescribed quantity of seed. Samples taken at all steps through the conditioning sequence are vital to the monitoring of seed quality. This is especially true if freezing temperatures have occurred in the field when moisture percentage of kernels exceeds the low temperature, measured in Fahrenheit degrees.

Samples should be large enough to enable running the desired test and a retest, if necessary. However, securing a new sample is usually preferable to retesting the original sample. Between the time the samples are collected and the quality tests are conducted, samples must be stored under conditions preserving the original quality as nearly as possible. Standard procedures for taking representative samples, and the necessary equipment needed, have been described (Anonymous, 1940, 1981; Justice, 1972).

9–11.4 Purity Analysis

Purity analysis for seed corn is done more for genetic purity than for determining percent of pure seed, as is practiced for quality control in small grains, soybean, and forage grasses. Beyond the endosperm purity and color checks described earlier for waxy and white hybrids, electrophoretic tests may be run to check for presence of selfs, outcrosses, off-types, or rogues. Although these tests are time consuming and expensive, they are quite accurate if the sample is representative and the isozymic patterns of the parents of the hybrid have been defined (Smith and Weissinger, 1984; Smith and Wych, 1986).

Maximum tolerances for genetic impurities have not been established by state or federal seed laws or seed certification agencies. Therefore in-house standards are employed by those seed companies that routinely conduct purity analyses. For single-cross hybrids, the presence of more than 5 to 6% selfs, or a combination of selfs and other off-types totaling 6 to 8%, are commonly used criteria for decisions to not offer a seed lot for sale. Growouts, however, might disclose that from 2 to 3% off-types would be neither detectable nor objectionable to customers, if the maturity, kernel color, and stature were similar to the hybrid. Alternatively, even 0.1% of taller off-type plants might generate considerable negative feedback from customers.

9–11.5 Germination

The germination test is the most frequently used procedure to measure product quality. Standard methods and guidelines for germination testing of seeds (Anonymous, 1981) and the necessary equipment and procedures (Justice, 1972) have been established. Most of the larger companies have established their own seed testing laboratories, but state, university, or private laboratories are also utilized.

Once a system has been established, accurate and consistent evaluation of the seedlings in the test is of greatest importance. The data collected constitute the germination percentage that is printed on the seed bag (usually on a sew-on tag), as required by both state and federal seed laws.

Standard germination tests are conducted under nearly ideal conditions; since field conditions seldom approximate the ideal, other tests have been developed to measure seed deterioration or vigor. Seed vigor is defined by the Association of Official Seed Analysts (AOSA) as "those properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions" (Anonymous, 1983). Differences in vigor between two lots of seed that are otherwise genetically alike may not be obvious from percent germination in the standard warm test (Delouche, 1973; Pollock and Roos, 1972).

9–11.5.1 Cold Test

Most seed companies use some type of cold test as a routine test for vigor. The most commonly used procedures have been reviewed elsewhere (Anonymous, 1983; Martin and O'Neil, 1987; McDonald, 1975). Craig (1977) stated that cold test results indicated the ability of seed to emerge when soil conditions are cold and wet and may reflect the amount of mechanical damage a seed lot has undergone. Currently, however, uniform procedures and agreement on the value of the cold test as a measurement of quality do not exist in the seed industry. Burris and Navratil (1979) discussed the variability inherent in various cold test procedures and the consequent lack of comparability of results from one laboratory to another. Cold testing using one established technique within each seed company may nevertheless be useful for judging seed lots as to suitability for sale following carryover storage conditions, early freezes, etc.

9–11.5.2 Tetrazolium Test

This biochemical test with 2,3,5-triphenyltetrazolium chloride quickly identifies seed viability. Enzymatic activity in living tissue turns the colorless tetrazolium red; loss of enzymatic activity in dead tissue leaves the tetrazolium colorless. The tetrazolium test is further used to evaluate internal seed injury, insect injury, frost damage, and viability of dormant seed (Bennett and Loomis, 1949; Goodsell, 1948; Moore, 1958; Porter et al., 1947).

9–11.5.3 Accelerated Aging Test

In the accelerated aging test (sometimes called the *rapid aging test*), seeds are stressed prior to the germination test (Anonymous, 1983). The conditions suggested by the AOSA for seed corn are to expose the seed to nearly 100% relative humidity at 42 °C (108 °F) for 96 h. The percentage survival is an index for longevity of seed viability in storage and a good measure of seed vigor.

9–11.5.4 Electrical Conductivity Test

Electrical conductivity of steep water (seed leachate) has been studied as an index of seed quality, but has not yet received widespread use because of procedural variability.

9–12 STORAGE AND DISTRIBUTION

9–12.1 Storage

The basic requirements for seed storage space are that it be dry, free of rodents and grain storage insects, and capable of being held within

certain temperature limits (Airy, 1955). Seed is at its highest quality level at physiological maturity and can only deteriorate from that point onward. The goal of seed storage is to maintain physiological quality throughout the storage period by minimizing deterioration. The best storage conditions can only maintain quality.

Storage for both bulk and bagged seed is necessary (Fig. 9–14). In some companies, facilities have been designed to take advantage of the same space for both. As the bulk seed is moved out for conditioning, the bagged seed can be moved into the vacated storage areas. At most facilities, however, the total volume of seed that must be stored exceeds bulk storage capacity; therefore, some seed must be bagged and moved to warehouse storage (often cold storage) to allow the completion of conditioning. Stored bagged seed is normally palletized and moved with forklift trucks (Fig. 9–14).

Storage of seed corn, either bulk or bagged, for prolonged periods at temperatures above 10 °C (50 °F) leads to deterioration of seed quality. For this reason, bulk seed should be cooled after the drying and shelling steps. This is usually accomplished by aeration of bulk bins with ambient air. Further, surplus bagged seed should be stored during the summer at or below 10 °C and at relative humidity levels between 45 to 55% to maintain the desired moisture content and seed quality. Early work (Airy, 1955; Sayre, 1948) indicated the influence of reduced temperature and moisture level on the maintenance of quality and longevity of stored



Fig. 9–14. Bagged seed corn in storage on pallets in preparation for distribution to sales representatives. Some seed companies now use a "stretch wrap" machine that automatically surrounds the pallet of seed corn with a protective plastic wrapping prior to storage and/or shipment. Forklift trucks are used to move pallets around the warehouse.

seed. Specifications for equipment and buildings for controlled atmosphere storage and its effects on stored seed have been reported (Beck, 1969; Dahlberg, 1967; Stanfield, 1971, 1972).

Hybrid seed corn companies must produce seed supplies over and above that which market forecasts indicate will be sold in the subsequent sales year. Some carryover seed, as this unsold seed is called, is desired as insurance against unpredictable consequences of weather, government programs, etc. Seed companies normally anticipate growing approximately 30 to 40% more seed than estimated sales requirements, to fill supply channels and to hedge against possible reduced yields from production acreage. A recent example illustrates how this practice benefits North American agriculture. The 1983 seed corn production acreage in the USA was substantially lower than in previous years, in anticipation of the impact of the federal government's PIK program on 1983 seed sales and anticipated carryover. However, drought reduced 1983 seed field yields severely in many production areas. Seed supplies for the 1984 planting season would have been critically short had it not been for adequate quantities of high-quality carryover seed inventoried in controlled-atmosphere warehouses.

9–12.2 Sales and Distribution

There are basically two common methods of sales and distribution of seed corn from the production plant or warehouse to the customer. The method used most widely throughout the Corn Belt involves farmers serving as farmer-dealers (or sales representatives or sales agents). The second method, involving seed distributors and/or dealers, is more common where corn acreage is less concentrated.

As the name implies, the farmer-dealer or sales representative is usually a farmer who is also a part-time salesman. This method of distribution depends on the local sales representative to: (i) call on his neighboring farmers to solicit their business: (ii) write the order; (iii) receive and store the seed until delivery; (iv) arrange for pick up or delivery; (v) complete the sale and collect the account; (vi) arrange for return of unsold seed to the production plant or warehouse; and (vii) provide service to the customer as needed. The sales representative is usually under the supervision of full-time company employees, commonly referred to as district sales managers. In the author's company, the sales representative never takes actual ownership of the seed corn.

In contrast, a seed distributor or a seed dealer purchases the seed corn from the seed company, and in turn sells the seed to other dealers and/or to farmer customers. Seed may be sold by the seed company directly to a seed dealer, bypassing the seed distributor. Alternatively, seed may be sold to a distributor who in turn sells it to one or more seed dealers. The dealer is often employed in related agricultural endeavors, such as fertilizer or chemicals, other seeds, livestock feeds, farm supply

stores, or elevator operators. This method of operation is especially adapted to areas where sales volumes are not great enough to justify the farm-to-farm calls of the local salesman, but are compatible with the existing business of the store or elevator.

ACKNOWLEDGMENT

The author gratefully acknowledges the following co-workers in Pioneer Hi-Bred International, Inc. who contributed significantly in the preparation of this manuscript: Marc Albertsen, Jim Ansorge, Raymond Baker, Wayne Beck, Tony Cavalieri, Jack Cavanah, Irv Deihl, Don Duvick, Jack Duvick, Bill Frank, Andy Gyorgy, Helen Hoeven, Mark Johnson, Dave Langer, Curt Maas (photography), Louis Mailloux, Rick McConnell, Diane Nelson, Bill Pitzer, Nancy Risbeck, Michelle Shriver, Walt Stohlgren, and Dan Wilkinson. Constructive comments on the manuscript from Marlin Bergman, Bill Frank, Dave Langer, and John Schoper of Pioneer Hi-Bred International, Inc., Harry Leffler and Karl Knittle of DeKalb-Pfizer Genetics, and John Nelson of Asgrow Seed Co. were also greatly appreciated.

REFERENCES

Afuakwa, J.J., and R.K. Crookston. 1984. Using the kernel milk line to visually monitor grain maturity in maize. Crop Sci. 24:687–691.

Airy, J.M. 1955. Production of hybrid corn seed. *In* G.F. Sprague (ed.) Corn and corn improvement. Agronomy 18:379–422.

Anonymous. 1940. Federal Seed Act of August 9, 1939. (53 Stat. 1275) with amendments. U.S. Gov. Print. Office, Washington, DC.

----. 1971. Certification handbook. Pub. 23. Revised 1984. Assoc. Off. Seed Cert. Agencies, Raleigh, NC.

----. 1981. Rules for testing seeds. J. Seed Technol. 6(2). (Revised 1986).

----. 1983. Seed vigor testing handbook. Assoc. Off. Seed Anal. Handb. Contr. 32:1–88.

----. 1985. International rules for seed testing. Seed Sci. Technol. 13(2).

Bateman, H.P. 1972. Planter metering, soil and plant factors affecting corn ear populations. Trans. ASAE 15:1013–1020.

Bear, R.P. 1975. A marketing program for waxy maize. p. 101–104. *In* L.D. Hill (ed.) Corn quality in world markets. Interstate Printers and Publishers, Danville, IL.

Beck, J.M. 1969. Systems for controlling relative humidity and temperature. Proc. Miss. Short Course for Seedsmen 12:115–129.

Beckett, J.B. 1971. Classification of male-sterile cytoplasms in maize (*Zea mays* L.) Crop. Sci. 11:724–727.

Bennett, N., and W.E. Loomis. 1949. Tetrazolium chloride as a test reagent for freezing injury of seed corn. Plant Physiol. 24:162–174.

Bollinger, F.G., J.J. D'Amico, and D.J. Hansen. 1978. Use of phthalanilic acids to regulate the growth of corn plants. U.S. Patent 4 108 632. Date issued: 22 August.

Burris, J.S., and K.H. Knittle. 1985. Freeze damage and seed quality in hybrid maize. p. 51–74. *In* J.S. Burris (ed.) Proc. 7th Annu. Seed Tech. Conf., Ames, IA. 26–27 February. Seed Science Center, Iowa State University, Ames.

----, and R.J. Navratil. 1979. Relationship between laboratory cold-test methods and field emergence in maize inbreds. Agron. J. 71:985–988.

Cal, J.P., and R.L. Obendorf. 1972. Imbibitional chilling injury in *Zea mays* L. altered by initial kernel moisture and maternal parent. Crop Sci. 12:369–373.

Cantrell, R.G., and J.L. Geadelmann. 1981. Contribution of husk leaves to maize grain yield. Crop Sci. 21:544–546.

Cardy, B.J., C.W. Stuber, and M.M. Goodman. 1980. Techniques for starch gel electrophoresis of enzymes from maize (*Zea mays* L.). Institute of Statistics Mimeo no. 1317. North Carolina State Univ., Raleigh.

Carter, M.W., and C.G. Poneleit. 1973. Black layer maturity and filling period variation among inbred lines of corn (*Zea mays* L.). Crop Sci. 13:436–439.

Cloninger, F.D., M.S. Zuber, and R.D. Horrocks. 1974. Synchronization of flowering of corn (*Zea mays* L.) by clipping young plants. Agron. J. 66:270–272.

Cowan, R.J. 1972. Seed certification. p. 371–397. *In* T.T. Kozlowski (ed.) Seed biology, Vol. 3. Academic Press, New York.

Crabb, A.R. 1947. The hybrid corn makers. Rutgers University Press, New Brunswick.

Craig, W.F. 1977. Production of hybrid corn seed. *In* G.F. Sprague (ed.) Corn and corn improvement, 2nd ed. Agronomy 18:671–719.

Dahlberg, R.W. 1967. Seed warehousing. *In* Proc. Iowa State Univ. Seed Processors' Short Course. September. Iowa State Univ., Ames.

Daynard, T.B. 1969. The 'black layer' — its relationship to grain filling and yield. p. 49–54. *In* Proc. 24th Annu. Corn Sorghum Res. Conf. ASTA, Washington, DC.

———. 1972. Relationship among black layer formation, grain moisture percentage, and heat unit accumulation in corn. Agron. J. 64:716–719.

———, and W.G. Duncan. 1969. The black layer and grain maturity in corn. Crop Sci. 9:473–476.

Delouche, J.C. 1973. The problem of vigor. I. A look at the germination test. Seedsmen's Digest 24:8–24.

Duvick, D.N. 1959. Genetic and environmental interactions with cytoplasmic pollen sterility in corn. p. 42–52. *In* Proc. 14th Annu. Hybrid Corn Ind. Res. Conf. ASTA, Washington, DC.

———. 1965. Cytoplasmic pollen sterility in corn. Adv. Genet. 13:1–56.

———. 1972. Potential usefulness of new cytoplasmic male steriles and sterility systems. p. 197–201. *In* Proc. 27th Annu. Corn Sorghum Conf. ASTA, Washington, D.C.

Fowler, W. 1967. Cultural practices for today's seed fields. p. 53–58. *In* Proc. 22nd Annu. Hybrid Corn Ind. Res. Conf. ASTA, Washington, DC.

Goodsell, S.F. 1948. Triphenyltetrazolium chloride for viability determination of frozen seed corn. J. Am. Soc. Agron. 40:432–442.

Hicks, D.R., and D.L. Wright. 1987. Maximizing the advantages of early corn planting. Fact Sheet NCH-35. Natl. Corn Handb. Coop. Ext. Serv, Iowa State Univ. and USDA.

Hunter, R.B., C.G. Mortimore, and L.W. Kannenberg. 1973. Inbred maize performance following tassel and leaf removal. Agron. J. 65:471–472.

Hutchcroft, C.D. 1957. Contamination in seed fields of corn resulting from incomplete detasseling. Iowa State J. Sci. 31:449–450.

Johnson, R.R., and D.L. Mulvaney. 1980. Development of a model for use in maize replant decisions. Agron. J. 72:459–464.

Jones, M.D., and J.S. Brooks. 1950. Effectiveness of distance and border rows in preventing outcrossing in corn. p. 3–18. Oklahoma Agric. Exp. Stn. Tech. Bull. T-38.

———, and ———. 1952. Effect of tree barriers on outcrossing in corn. p. 3–11. *In* Oklahoma Agric. Exp. Stn. Tech. Bull. T-45.

Jugenheimer, R.W. 1958. Hybrid maize breeding and seed production. p. 157. *In* FAO Agric. Dev. Paper 62. FAO, Rome, Italy.

Justice, O.L. 1972. Essentials of seed testing. p. 301–370. *In* T.T. Kozlowski (ed.) Seed biology, Vol. 3. Academic Press, New York.

Knake, R.P., W.A. Beckwith, and S.C. Shen. 1986. Effect of pericarp damage and seed treatment formulations on cold test and field performance of corn. p. 106–120. *In* Proc. 41st Annu. Corn and Sorghum Res. Conf. ASTA, Washington, DC.

Knittle, K.H., and J.S. Burris. 1976. Effect of kernel maturation on subsequent seedling vigor in maize. Crop Sci. 16:851–855.

Martin, B., and M. O'Neil. 1987. Laboratory tests for the assessment of vigor in maize. p. 209–219. *In* J.S. Burris (ed.) Proc. 9th Annu. Seed Tech. Conf., Ames, IA. 24–25 February. Seed Sci. Ctr., Iowa State Univ., Ames.

McDonald, M.B., Jr. 1975. A review and evaluation of seed vigor tests. Proc. Assoc. Off. Seed Anal. 65:109–139.

McKee, G.W. 1963. Accuracy of seed corn grading and planter plate recommendations. Pennsylvania Agric. Exp. Stn. Prog. Rep. 240.

Moore, R.P. 1958. Tetrazolium tests for determination of injury and viability of seed corn. p. 13–20. *In* Proc. 13th Annu. Hybrid Corn Ind. Res. Conf. ASTA, Washington, DC.

National Academy of Sciences. 1972. Genetic vulnerability of major crops. U.S. NAS, Washington.

Navratil, R.J., and J.S. Burris. 1984. The effects of drying temperature on corn seed quality. Can. J. Plant Sci. 64:487–496.

Neal, N.P. 1961. The influence of freezing temperature of varying intensities and duration of the germination of seed corn at different stages of maturity. p. 67–73. *In* 16th Annu. Hybrid Corn Ind. Res. Conf. ASTA, Washington, DC.

Pollock, B.M., and E.E. Roos. 1972. Seed and seedling vigor. p. 313–387. *In* T.T. Kozlowski (ed.) Seed biology, Vol. 1. Academic Press, New York.

Porter, R.H., M. Durrell, and H.J. Romm. 1947. The use of 2,3,5-triphenyltetrazolium chloride as a measure of seed germinability. Plant Physiol. 22:149–159.

Pucaric, A., and J. Gotlin. 1979. The yield and seed size as affected by the number of leaves removed with tassel in maize inbred lines and single crosses. p. 259–266. *In* Proc. 10th Meet. Maize Sorghum Sect. Eucarpia, Varna, Bulgaria. 17–19 September. European Assoc. for Res. on Plant Breeding, Wageningen, Netherlands.

Rogers, J.S., and J.R. Edwardson. 1952. The utilization of cytoplasmic male-sterile inbreds in the production of corn hybrids. Agron. J. 44:8–13.

Rossman, E.C. 1949. Freezing injury of inbred and hybrid maize seed. Agron. J. 41:574–583.

Sayre, J.D. 1948. Storage tests with seed corn. p. 57–64. *In* Proc. 3rd Annu. Hybrid Corn Ind. Res. Conf. ASTA, Washington, DC.

Shoultz, D. 1985. An evaluation of parent delay techniques. p. 151–160. *In* Proc. 40th Annu. Corn and Sorghum Res. Conf. ASTA, Washington, DC.

Shurtleff, M.C. (ed.) 1980. Compendium of corn diseases. 2nd ed. Am. Phytopathological Soc., St. Paul.

Smith, J.S.C., and H.H. Weissinger. 1984. Rapid monitoring of purity in seed lots of hybrid maize: Modifications of current technologies. Maize Genet. Coop. News Lett. 58:103–105.

----, and R.D. Wych. 1986. The identification of female selfs in hybrid maize: A comparison using electorphoresis and morphology. Seed Sci. Technol. 14:1–8.

Stanfield, Z.A. 1971. Use of seed vigor research data in design and justification of equipment and facilities. Search. 1972.

----. 1972. Conditioned seed storage — justification, design and operation. Proc. Mississippi Short Course for Seedsmen 15:71–75.

----. 1986. One-step husking system for seed corn. p. 121–133. *In* Proc. 41st Annu. Corn and Sorghum Res. Conf. ASTA, Washington, DC.

Tatum, L.A., and M.S. Zuber. 1943. Germination of maize under adverse conditions. J. Am. Soc. Agron. 35:48–59.

Ullstrup, A.J. 1972. The impacts of the southern corn leaf blight epidemic of 1970–71. Annu. Rev. Phytopathol. 10:37–50.

Vasilas, B.L., and R.D. Seif. 1985a. Defoliation effects on two corn inbreds and their single-cross hybrid. Agron. J. 77:816–820.

----, and ----. 1985b. Pre-anthesis defoliation effects on six corn inbreds. Agron. J. 77:831–835.

Wortman, L.S., and E.H. Rinke. 1951. Seed corn injury at various stages of processing and its effect upon cold test performance. Agron. J. 43:299–305.

Wright, H. 1948. Processing seed corn to avoid injury. p. 32–37. *In* Proc. 3rd Annu. Hybrid Corn Ind. Res. Conf. ASTA, Washington, DC.