CIMMYT
International Maize and Wheat Improvement Center

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**Correct citation:** MacRobert, J.F., P.S. Setimela, J. Gethi, and M. Worku. 2014. Maize Hybrid Seed Production Manual. Mexico, D.F.: CIMMYT.

**ISBN:** 978-607-8263-26-4
**AGROVOC descriptors:** Maize; Hybrids; Varieties; Seed production; Seed industry; Plant breeding; Plant genetics
**Additional Keywords:** CIMMYT
**AGRIS category codes:** F03 Seed Production
F30 Plant Genetics and Breeding

**Dewey decimal classification:** 631.523

**Cover photo:** Mosisa Regasa/CIMMYT

Printed in Mexico.

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## Introduction

Maize hybrid seed provides farmers with varieties containing improved genetics, such as high yield potential and unique trait combinations to counter diseases and adverse growing conditions. However, the quality of hybrid seed depends greatly on field production methods, both in adherence to quality assurance standards and implementation of appropriate agronomic management. While open pollinated maize seed production is relatively straightforward, hybrid seed production requires additional field practices that are critical to success.

Hybrid maize seed production involves deliberately crossing a female parent population with a male parent in isolated fields. Thus, from the very start of hybrid seed production, the identity and arrangement of the two parent populations determine the outcome. Each hybrid variety is composed of a specific combination of a female (seed bearing) and male (pollen providing) parents. The field management of the two parents is also important and requires attention to timing of planting, elimination of off-types, removal of tassels from the females before pollen shedding, separate harvesting of the female seed and careful shelling and processing of the seed to maintain seed quality. The sequentially dependent nature of the process means that any errors in earlier stages have a significant impact on following stages and major errors or problems can result in complete failure or rejection of the crop. This manual provides a guide to maize hybrid seed production, with particular reference to field procedures, so that seed growers and seed companies can cost-effectively obtain productive and quality seed suitable for farmers.

## What is a maize hybrid?

Simply put, a maize hybrid results from the fertilization of one maize plant by another genetically un-related plant. The plant that bears the seed is called the female or seed parent, while the plant that provides the pollen to fertilize the female is called the male or pollen parent. In other words, the female plant is crossed with the male plant to produce hybrid seed. This seed bears a unique genetic make-up from the female and male parents and will produce a plant with particular characteristics. Plant breeders produce the female and male parents of each hybrid to generate progeny with particular characteristics, such as plant maturity, disease resistance, grain color, food processing quality and so on. It is this unique hybrid seed that farmers will sow in their fields. When a farmer purchases a particular hybrid, he or she expects the seed to perform in the field as designated by the variety description.

With maize, there are a number of possible kinds of hybrids, such as single-cross, three-way, double-cross and top-cross hybrids. These hybrids differ in their parental composition but, in all cases, the hybrid seed sold to farmers is a cross between two parents – a female and a male. Since maize has separate male and female plant parts, it is relatively easy to make a cross between two plants. In a hybrid seed production field, male and female parents are planted in sequential row patterns, usually with three-to-six times the number of female plants or rows to a single male plant or row. The male flower (tassel) of the female plant is removed (detasseled) before pollen shed, so that the only source of pollen for the female flower (the cob or ear) on the female plants is the tassels on the male plants (Figure 1). Detasseling of the female is necessary to prevent any pollen from the female pollinating the female silks. If this occurs, known as "female-selfing," the result is a significant loss of seed quality that will clearly be seen in a crop grown from the seed. Female-selfing is to be avoided at all costs.

The ratio of the number of female rows to male rows in the field is usually on the order of 3:1 for single-crosses and three-ways but may extend to 8:1 for double-cross hybrids (Figure 2). The actual ratio that is planted depends on a number of factors, but principally on the pollen production of the male,

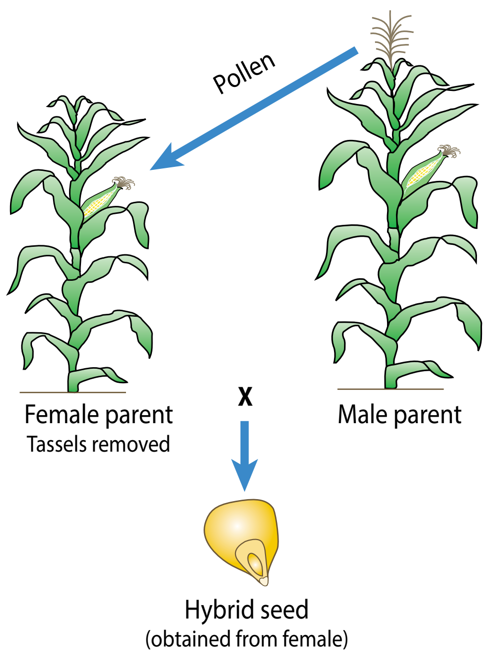



**Figure 1. Hybrid maize seed is produced by using designated female and male parents, removing the tassels from the female plants before silk emergence and allowing male plants to provide the pollen for fertilizing the silks.**

the height of the male tassel relative to the female silk and the size of the female plant. Furthermore, the timing of pollen shed of the male and silking of the female must coincide. If the male and female plants are known to flower at different times, adjustment in the sowing dates of each component will be required to ensure flowering synchrony of the two parents. The hybrid seed that is useful to farmers is harvested from the female plants. Plants and seeds from the male rows are usually discarded before harvest to avoid mixing of seed from the parents.

With this preliminary description of maize hybrid seed production, it is clear that numerous key factors determine the success and quality of hybrid seed production, including the following:

- Female and male parent identity, purity and identity preservation.
- Ratio of female to male rows in the seed field.
- Timing of planting of the female and male plants.
- Timely removal of the tassels from the female plants before they shed pollen and before silk emergence.
- Timing of female silk emergence relative to male pollen shed.
- Avoidance of contamination of female silks with unwanted pollen, particularly from females, off-type males and foreign pollen.
- Avoidance of seed mixtures between and within the male and female plants.

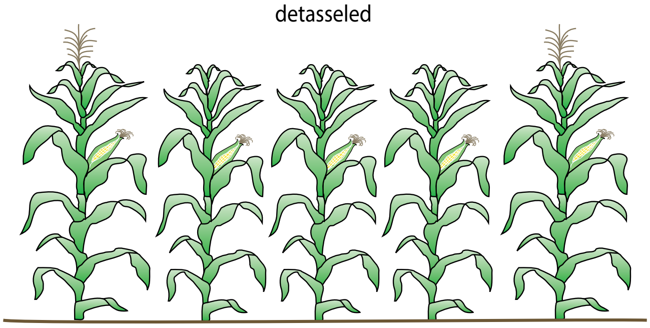



**Figure 2. Diagrammatic representation of male and female rows in a maize hybrid seed production field.**

Each of these key issues will be discussed in greater detail, along with important agronomic management factors.

## Hybrid composition

The basic building blocks of maize hybrids are inbred lines. Inbred lines are the result of repeated self-pollination of particular maize populations to produce a plant that essentially has a fixed and uniform genetic composition. Consequently, all the plants of a particular inbred line are identical, but each inbred line will differ in its genetic composition from other inbred lines. Because maize is normally cross-pollinated, inbred lines are usually smaller, less vigorous and lower-yielding than open pollinated maize plants due to a phenomenon called "inbreeding depression." But, when two unrelated inbred lines are crossed to form a hybrid, the resultant seed produces plants with restored vigor and a significantly higher yield than either of the two parents. This is known as "hybrid vigor," and it is this vigor that is exploited in hybrids and makes hybrid varieties useful to farmers.

The most common types of hybrids in maize are single-cross, three-way and double-cross hybrids (Table 1). A single-cross hybrid is made by crossing two inbred lines; a three-way hybrid is made by crossing a single-cross hybrid with an inbred line; while a double-cross hybrid is made by crossing two single-cross hybrids. Two other types of hybrids are top-crosses and varietal crosses. A top-cross hybrid is made from an open-pollinated variety crossed with an inbred line, while a varietal cross is a hybrid of two unrelated open-pollinated varieties.

On the assumption that the best genetics and agronomic management are applied, general statements may be made about the advantages of different hybrid types. Single-cross hybrids are generally higher-yielding than other hybrid types. They are very uniform in appearance, because every plant has the same genetic make-up, but the seed yield of a single-cross hybrid is lower than other hybrids, because the female is an inbred line.

**Table 1. Common types of maize hybrids and their general characteristics.**

| Hybrid type | Female parent | Male parent | Seed yield | Seed price | Hybrid characteristic | Hybrid grain yield |
|---|---|---|---|---|---|---|
| Single-cross | Inbred line | Inbred line | Lowest | High | Uniform | Highest |
| Three-way | Single-cross hybrid | Inbred line | High | Moderate | Slightly variable | High |
| Double-cross | Single-cross hybrid | Single-cross hybrid | Highest | Low | Highly variable | Moderate to high |
| Top-cross | OPV | Inbred line | Moderate | Low | Highly variable | Moderate |
| Varietal cross | OPV | OPV | Moderate to high | Low | Highly variable | Moderate to low |

Consequently, seed of single-cross hybrids is the most expensive, but this is usually acceptable because of the high yield potential of the seed. Three-way and double-cross hybrids use a single-cross hybrid as a female, and so the seed yield is high. In fact, with double-crosses, the seed yield can be the highest of all hybrid types because a high female:male ratio may be used, given the vigor and abundant pollen production of the single-cross male. Thus, double-cross hybrid seed is the least expensive, but the resulting hybrid crop is more variable and the grain yield is usually less than that of a three-way or single-cross hybrid. Three-way hybrids are the most common in eastern and southern Africa, while in China, India, South Africa, Thailand, the USA, Vietnam, and other developed seed markets, single-cross hybrids are most common. This is because farmers in these settings aim at higher yields and can afford to pay the higher price, given that the seed cost is a lower percentage of total costs than in low-yield situations.

Varietal cross hybrids and top-cross hybrids are also used in some African countries or where seed markets require low-cost products. The advantage of using a varietal cross hybrid is that the male parent produces abundant pollen that enhances seed setting. In addition, there may be better synchrony between male tasseling and female silking, because of the greater variability in the two parents. By the same token, varietal cross or top-cross hybrids are the least uniform and least productive in farmers' fields, among the different types of maize hybrids.

## Seed classes

Hybrid seed production takes place over a number of sequentially-dependent stages. The first task is to prepare the breeder's seed of the initial inbred lines. This is done by breeders under controlled hand pollination to ensure genetic purity and identity. The breeder's seed is then bulked up over successive generations into sufficient quantities to make the final hybrid. The generations of seed bulking are termed "seed classes" (Table 2) and are carried out under national seed regulations. With each generation there may be a decline in genetic purity, but if strict procedures are followed, this decline will be minimized. National seed regulations specify the procedures for multiplying each seed class and differ slightly from country to country, but the same principles apply, namely:

- An identified source seed for each seed class.
- Isolation of the seed production field from potential contaminant sources, by distance (spatial) or time (temporal).
- Removal of off-type plants before flowering.
- Controlled pollination of hybrid crosses.
- Inspection of seed production field at critical stages to certify conformity to regulations.
- Identity preservation and seed labeling.

**Photographs showing the distinct male and female plant rows at different crop stages, from early vegetative to flowering.**

**Table 2. The seed classes that normally apply to maize hybrid seed production, especially in countries following the OECD[1] Certification Standards. In some countries, basic seed is termed "foundation seed."**

| Seed class | Code | Produced from | Label colors |
|---|---|---|---|
| Pre-basic seed | A | Breeder's seed | Violet band on white |
| Basic seed | B | Pre-basic or breeder's seed | White |
| Certified seed (1st Generation) | C1 | Basic or higher seed classes | Blue |

[1] The Organisation for Economic Co-operation and Development (OECD). cf. www.oecd.org/tad/code/seed-rules-complete.pdf

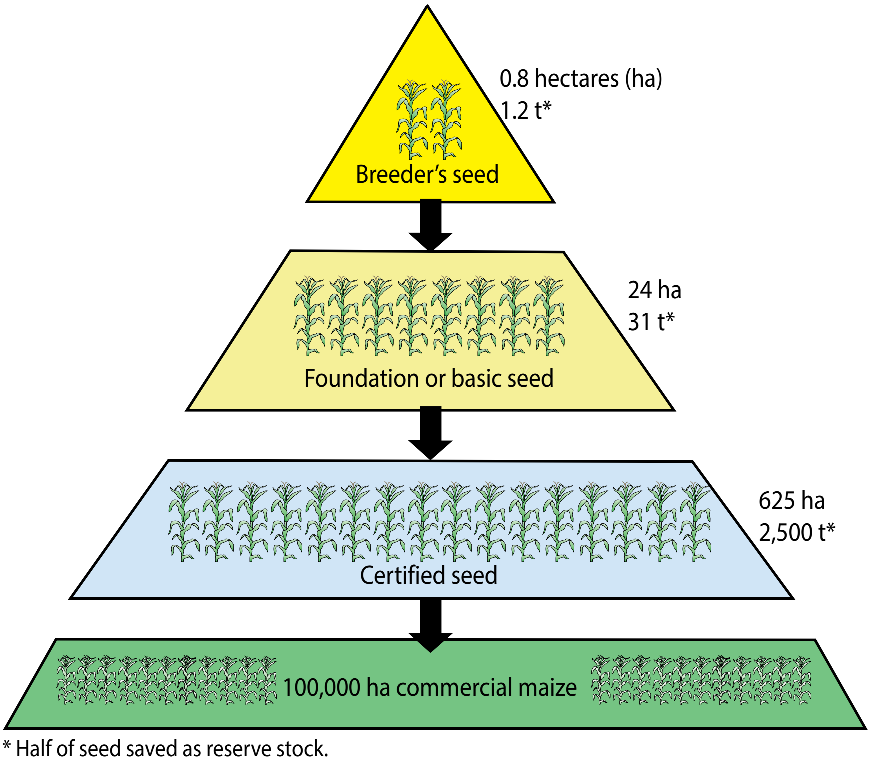



**Figure 3. Schematic representation of the scale-up of maize hybrid seed from breeder's seed through basic seed and certified seed production for commercial production in farmers' fields.**

## Planning seed production requirements

The quantity of seed to be produced ought to be tied to the marketing plan of the seed company. From the planned future sales, the seed production plans of each seed class are established, based on the seed yields and seeding rates of the seed classes to be produced. It is usual for seed companies to plan to produce 50 to 100% more pre-basic and basic seed, and 10 to 25% more certified seed, than estimated sales requirements. This is to cover for production risks, such as droughts and quality failures, and possible losses due to seed processing or deterioration. Excess production may also serve as a buffer in the event that actual sales exceed plans.

For three-way and double-cross hybrid seed production, the respective single-cross components have to be produced before the final hybrid cross can be made. The number of component isolation productions for the various seed classes for each hybrid type varies from 5 to 7 (Table 3).

Seed production planning may be a complex task if a number of hybrid varieties are produced with many different parents. Poorly-made plans or mistakes in production along the seed class sequence will have deleterious consequences on future productions and sales, and hence profitability. Insufficient foundation seed is a common reason why good hybrids fail to reach the market. The key calculations required for this planning process are given in Box 1. For planning hybrid production, assumptions have to be made about seed rates and yields of the female and male components, which

**Table 3. The number of isolation seed production fields for the production of different hybrid types.**

| Hybrid type | Pre-basic | Basic | Certified | Total |
|---|---|---|---|---|
| Single-cross | 2 | 2 | 1 | 5 |
| Three-way | 3 | 2 | 1 | 6 |
| Double-cross | 4 | 2 | 1 | 7 |
| Top-cross | 2 | 2 | 1 | 5 |
| Varietal cross | 2 | 2 | 1 | 5 |

will be a function of the ratio and plant densities of females and males in the field. As a general rule of thumb, seed requirements are 20 kg/ha for the female and 7 kg/ha for the male when considering the field as a whole, but these may vary significantly depending on required plant density, seed weight and germination percentage. Thus, when establishing the actual seed rate at sowing, consideration should be given to desired plant density, seed weight, germination percentage and expected field losses at emergence (Figure 4).

**Box 1: Seed calculations**

Seed required (kg) = area (ha) x seed rate (kg/ha)

$$\text{Seed rate (kg/ha)} = \frac{\text{plant density (plants/ha) x seed weight (kg)}}{\text{germination rate x (1 – field loss rate)}}$$

$$\text{Area required (ha)} = \frac{\text{seed production plan (t)}}{\text{seed yield (t/ha)}}$$

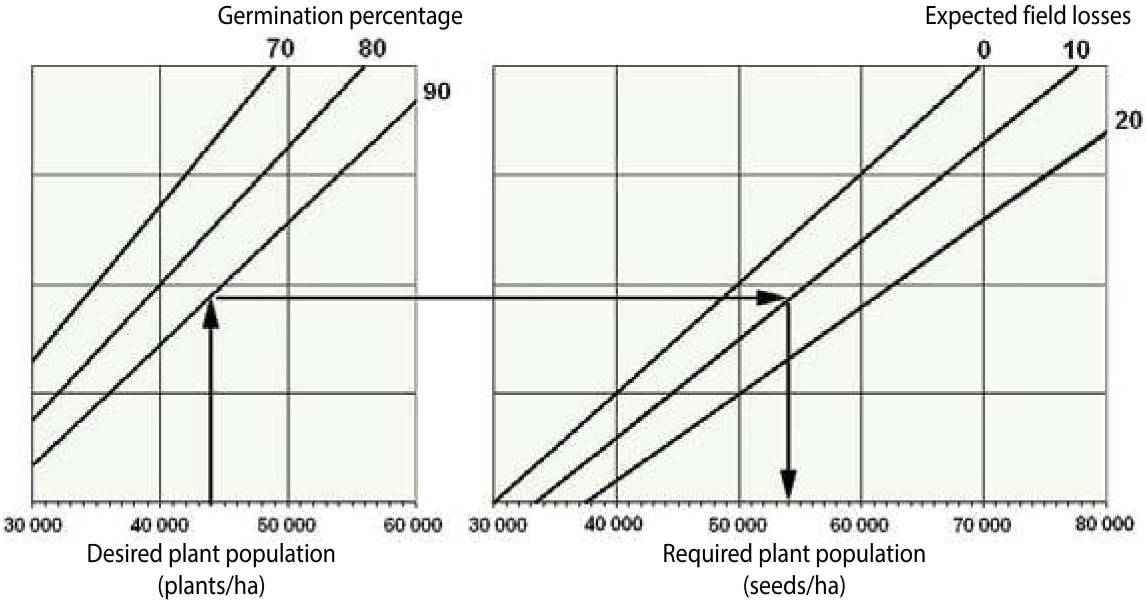



**Figure 4. A simple means to calculate the required seed population for maize, based on the desired plant population, germination percentage and expected field losses. The example shows that for a desired plant population of 44,000 plants/ha, a germination of 90% and field losses of 10%, the required seed rate (seed population) is 54,000 seeds/ha.**

## Pre-basic, basic and certified seed production

The rules and procedures for certified seed production are laid down in the national seed regulations of the country in which the seed is to be produced. The aim of certification is to produce seed with an acceptable level of genetic purity and a specified seed quality in terms of minimum germination percentage (usually 90% for maize), maximum seed moisture (12.5%) and minimum seed purity (99% pure seed with less than 3% total defects). Genetic purity is assured by using the correct seed parents of the right seed class, growing the seed in isolation from contaminant crops removing off-types and, in the case of hybrids, controlling the pollination of the female (Box 2).

Certification procedures are based on standards for growing conditions (e.g., field history, isolation, female-male identity preservation, removal of off-types and detasseling of female plants in the case of hybrid production), field inspections, prevalence of weed seeds, proportion of defective seeds, germination percentage and seed moisture content. If a seed field or seed lot does not meet the prescribed standards for the intended seed class, it will be rejected for certification. Consequently, seed producers must be familiar with and adhere to the national seed regulations for the seed class that is being grown.

**Box 2: Hybrid seed crop genetic contamination**

The main sources of genetic contamination of a hybrid seed crop are:

- Seed admixture in the parents prior to sowing.
- Impure seed sources and inadequate removal of off-types.
- Foreign pollen contamination due to inadequate spatial or temporal isolation.
- Re-growth plants of the same crop from previous seasons.
- Poor detasseling of the female, resulting in female selfing.
- Poor synchronization of male and female plants, exposing the female plants to a greater risk of contamination from foreign pollen.

The standards for pre-basic and basic seed production are higher than those for certified seed production (Table 4), particularly as regards isolation requirements and the maximum percentage of off-types. The standards are evaluated in every seed field by means of field inspections and laboratory tests. The field inspections are required to verify the origin of source seed, identify the variety, determine the cropping history, check isolation distance (or time) and production practices and ensure that all certification procedures are adhered to. Usually, three-to-five field inspections are required through the season. Following shelling or threshing, samples of seed are taken for laboratory tests to evaluate the purity of the seed, presence of other seeds, the germination percentage and the moisture content. The sampling procedures assure that a sufficiently representative sample is drawn from the seed lot. For seed sampling, the entire seed lot should be accessible to the seed sampler to enable the collection of a representative sample. This is the final stage in the certification process, and if the seed lot passes all the standards, it is granted certified status.

## Field management of hybrid seed production

Since seed has higher value than grain, the standard of management to be applied ought also be higher. However, in principle, agronomic practices for seed crops are similar to those for normal crops, in that due attention must be given to field practices that improve yield (e.g., optimizing timing of planting, appropriate and calibrated fertilizer application, conservation agriculture and water management) and to minimizing factors that reduce yield (e.g., water stress, weeds, pests and diseases). In addition, safe procedures must be followed when using machinery or applying fertilizers and chemicals.

In types of hybrid seed production where one or both parents are inbred lines, extra care needs to be taken with those lines, which tend to be weak and more susceptible to environmental stresses (e.g., diseases, certain herbicides and nutrient stress) than hybrids. Seed of inbred line parents is usually smaller than normal maize seed. While seed size does not necessarily affect germination percentage, it may affect ability to emerge quickly and resultant seedling vigor. Consequently, inbred lines should not be sown too deep or into a cloddy seed bed. If sowing is done by machine, differential calibration of the planting units for the male and female may be necessary, based on required plant density, seed size and germination percentage of each of the two parental components.

The better the agronomic management applied to a seed field — especially in timing of operations and the efficiency and appropriateness of fertilizer, herbicide and pesticide application, weed control and water management — the greater will be the yield potential. However, because these production factors are determined by field context and environment, they will not be discussed in detail. Local expert advice relevant to each seed field should be sought. Here, only issues related to hybrid quality assurance will be discussed, but note the following general principles for good crop management:

- Well before planting time, collect soil samples from the seed field and obtain a soil nutrient test report and fertilizer recommendation. With three-way and double-cross hybrids, the females have higher yield potential than the females of single-cross hybrids, so nutrient removal by the females will be greater in seed production fields of three-way and double-cross hybrids. In the case of single-cross hybrid production, the female is an inbred line, which uses less fertilizer but still requires a fertile soil to produce well. This also applies to the males of single-cross and three-way hybrids.
- If the soil is acidic, apply lime with appropriate calcium and magnesium ratios according to the soil clay content, soil pH and soil test results. Lime should be applied three to six months before sowing, to have time to take effect (lime applied at sowing will not be effective for the emerging crop).

**Table 4. The minimum Southern Africa Development Community (SADC) seed certification standards.** BS = basic seed; CS = certified seed; OPV = open pollinated variety. Standards might be different in individual SADC countries and elsewhere.

| Common name | Field standards | | | | | | Laboratory standards | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum isolation distance (m) | | Maximum % of off-types (based on 1,000 plants) | | Minimum number of inspections | | Minimum germination (%) | | Minimum % pure seed (by weight) | | Maximum moisture (%) |
| | BS (B) | CS (C) | BS (B) | CS (C) | BS (B) | CS (C) | BS (B) | CS (C) | BS (B) | CS (C) | (All classes) |
| Maize OPV | 400 | 200 | 0.5 | 1.0 | 4 | 3 | 90 | 90 | 99 | 99 | 13 |
| Maize hybrid | 400 | 350 | 0.1 | 0.3 | 5 | 5 | 70 | 90 | 99 | 99 | 13 |

- Apply phosphorous and potassium fertilizers just prior to or at the time of sowing. The effectiveness of these fertilizers is greatest when they are applied in a band alongside and below the seed. Ensure that there is no direct contact between fertilizer and the seed so as to avoid fertilizer burning of the germinating seed. About one-third of the total nitrogen fertilizer should be applied at or before sowing.
- Inbred lines may be more sensitive to micronutrient deficiencies than hybrids. Observe the growth of inbred lines, looking for nutrient deficiency symptoms, and correct these with foliar or soil-applied fertilizers if required. Where known micronutrient deficiencies occur in the soil, correct these with pre-plant fertilizers.
- Certain maize herbicides, especially those in the Sulfonylurea and Chloroacetamides groups, may be phytotoxic to inbred lines. Check with the seed company representatives regarding which herbicides may be applied to the seed parents being grown. When applying post-emergent herbicides, it is advisable to band apply these between the rows, avoiding foliar contact.
- Time sowing so that flowering occurs when reliable rains are expected, but also at a time that will avoid the crop maturing during wet weather, so as to avoid rain damage to maturing seed in the field.
- The sowing of hybrid seed is critical—it determines crop establishment and potential. Therefore, sow the two parents at the recommended times, aim for the correct plant density and conduct operations to achieve a uniform emergence. Ensure the micro-seedbed is optimal for germination and emergence, considering seed-soil contact, sowing depth, soil moisture conditions and avoiding compaction. Beware of soil pests and seedling diseases that may reduce stand establishment and apply recommended seed treatments or pesticides to the soil, if needed.
- Monitor and manage the crop throughout the season, controlling weeds (inbred lines are particularly sensitive to weed competition), pests and diseases, and providing irrigation if possible. In most seed regulations, weedy fields, especially at harvest, will disqualify a seed crop from certification.
- The remaining two-thirds of the nitrogen application may be applied in two side-dressings, one at the 4-5 leaf stage and the other at the 8-10 leaf stage. Use the application method best suited to the type of fertilizer, crop stage, machinery available and weather conditions. Avoid wastage of nitrogen by leaching, run-off or volatilization.
- At flowering time, check for stalk borer and bollworm on the silks of the females, as these pests may feed on the silks and reduce seed set or feed on the developing kernels and reduce seed quality and yield.
- The four-week period spanning the flowering stage of seed maize is most sensitive to water deficits. If a dry spell occurs at this time, irrigation will significantly improve yields.
- In countries where maize is grown on acid soils, it is beneficial to do a foliar application of 100-150 g/ha of sodium molybdate at the mid-silk to milk-dough stage of the females. This increases the molybdenum concentration in the seed and helps overcome molybdenum deficiencies in the field.
- Foliar applications in the late vegetative and early grain-fill stages with recommended fungicides for expected diseases will improve yields and seed quality. Apply these chemicals according to label instructions.
- Harvest the seed as early as possible, considering drying facilities and processing requirements. Reducing the time mature seed remains in the field improves seed quality by minimizing pest and disease infestation.

## Flow diagram for seed production

Hybrid seed production is a step-wise process, with each step influencing the following steps (Figure 5). Managing hybrid seed production involves two parallel processes: the technical aspects of the seed crop, such as female-male ratios, detasseling, etc., and the agronomic field management of the female and male plants. Furthermore, there is a close relationship between the grower of the seed, the seed company for whom the seed is being grown and the regulatory agency that will certify the seed crop. It is evident therefore that maize seed production is more complex and dynamic than grain production. Success depends on beginning with a thorough understanding of the whole process, planning crop areas, inputs, activities and labor requirements, maintaining good communications with labor, the seed company and regulators, and carrying out management activities in a timely and efficient manner. The ultimate goal of hybrid seed production is the high yield of seed that meets quality standards. Only when this is achieved can any thought or hope of profit be considered. Thus, successful hybrid seed production begins with planning the whole process from the beginning to the end. Be certain to match the proposed area of seed production with financial, labor, time, machinery and management resources.

### Selecting the seed field

The best fields on a farm should be used for hybrid seed production, but other considerations include:

- Accessibility – the seed field needs to be inspected regularly and therefore must be easy to reach throughout the season.

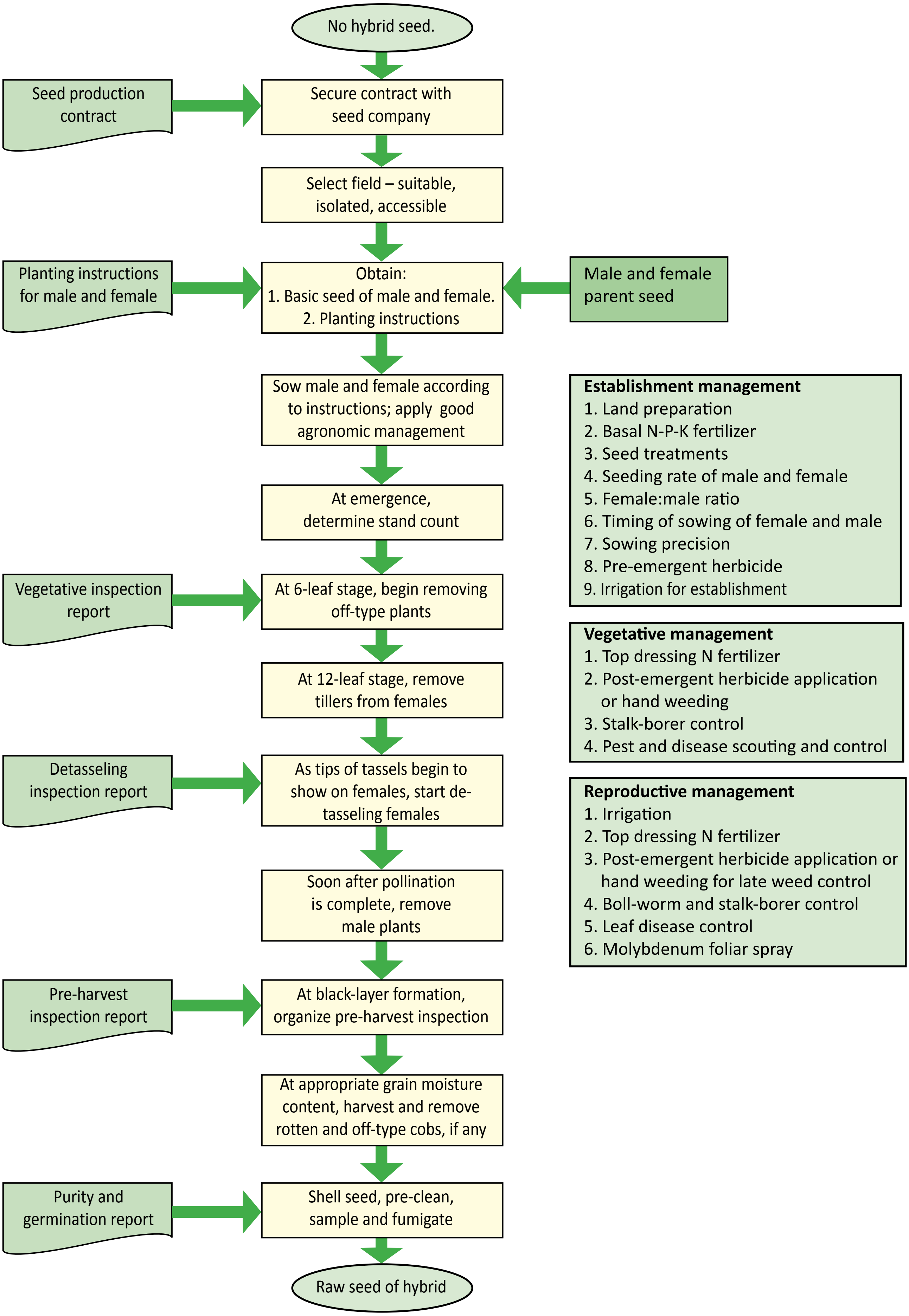



**Figure 5. Flow diagram of hybrid maize seed production for a seed grower.**

- Cropping history – the previous crop should not be maize, to minimize the possibility of re-growth plants in the seed field.
- Isolation – the field must be sufficiently isolated from contaminant maize crops by the required distance or time.
- Size of field – due to the time pressure for detasseling in hybrid seed fields, a maximum field size of 10 to 40 ha should be planted at one time, depending on labor availability. Blocks of about 10 ha are most manageable for detasseling and quality assurance. Smaller fields may increase the risk of foreign pollen contamination. Larger fields may not allow efficient detasseling.
- Field map – this is helpful to establish the size of the field, isolation distances and for future records.
- Registration of the seed crop – usually seed regulation authorities require seed fields to be registered within a short time of establishment. Ensure that this is done.

### Crop establishment

The establishment of a crop is one of the most important stages, since decisions taken at sowing will affect the entire life cycle of the crop. Usually, the seed company will provide planting recommendations for a hybrid (an example is given in Table 5). At this stage, the following points are noteworthy:

- Ensure the correct parents are assigned to the seed field and that the female and male seed is clearly identifiable.
- Establish the ratio of female-to-male rows in the field, based on recommendations from the seed company, and implement a planting system to sow the female and male rows correctly at the appropriate seeding rates.
- Calculate the seed rate for each parent based on the desired plant density, seed weight, germination percentage and expected field losses for the female and male. Recommendations for these should be provided by the seed company (See Table 5 and Box 1).

**Box 3: Handling the parent seed**
Parent seed of a hybrid is precious, therefore handle it with care:

- Keep the male and female seed bags separate.
- Be careful not to lose the labels attached to the bags, and retain these after sowing the seed for certification purposes and for any claims that may arise.
- Store seed in a cool, dry place.
- Protect the seed from rodents and storage pests.
- Keep the seed secure from theft.
- Handle seed gently.


**3:1 female:male ratio.**


**6:2 female:male ratio.**


**2:1 squeeze row configuration, where the male row is planted in-between two normally-spaced female rows.**

**Male rows clearly marked at planting.**


**Poor stands will lead to low seed yields.**

**Table 5. An example of planting instructions for the production of a single-cross hybrid on 15 ha, assuming there will be 10% in-field loss of emerging plants, post germination.**

| Parent | Female | Male |
|---|---|---|
| Name | CML444 | CML312 |
| Seed lot number | 20121501 | 20130102 |
| Row ratio | 3 | 1 |
| Row width | 75 cm | 75 cm |
| Established plants/ha | 50,000 | 40,000 |
| Germination percentage | 85% | 95% |
| Seed weight | 40 g | 35 g |
| Seed rate (seeds/ha) | 65,300 seeds/ha | 46,800 seeds/ha |
| In-row seed spacing | 20 cm | 29 cm |
| Seed rate (kg/ha *per se* parent) | 26.1 kg/ha | 16.4 kg/ha |
| Seed rate (kg/ha of seed field) | 19.6 kg/ha | 4.1 kg/ha |
| Total seed required for 15 ha | 294 kg | 62 kg |
| Notes | Detassel early as tassel may shed pollen before full exertion. Female is slightly susceptible to ear rots, so cob selection at harvest will be required. | Male susceptible to MSV, therefore seed treat with appropriate pesticide before sowing. |
| Planting split | | Plant male 3-days after female. |

- Know and implement the recommended planting split between the female and male. This will be specified in the planting instructions for the hybrid, and may require more than one sowing of the male in some cases.
- Apply a field-marking system to identify which rows are planted to the male and female. If mechanical planters are used, clearly mark the male seed box. If hand planting is used, know the row ratios and which are the male and female rows. At sowing, place markers on the field edge at each male row so that these may be identified by laborers and throughout the growing period to ensure that only the female rows are detasselled.
- Apply any special treatments, such as chemical seed dressings or fertilizer, to the parents and be sure to use only recommended herbicides. In some instances either or both parents may be susceptible to certain diseases or pests and will therefore require chemical control measures to assure a good harvest.
- Ensure that planting equipment is thoroughly clean from contaminant seed before sowing.


**Examples of foundation (basic) seed of female (single-cross) and male (inbred) parents.** Note the different colored seed bags to assist in field identification of the two parental components.

- After crop emergence, take plant stand counts to determine whether the desired plant density has been achieved. If plant densities are well below recommendations, re-planting may be required. Note that it is not advisable (or allowed in most certified seed regulations) to "gap-fill" plant stands that have inadequate numbers of plants at emergence. This is because differential growth and flowering will make it difficult to assure adequate seed quality.

**Roguing: removal of off-types**

During the vegetative growth of the seed crop, regularly inspect the field for pests, weeds and diseases and control these as necessary. From the 6- to 12-leaf stage and before tassels emerge, remove off-types from both male and female rows. Off-types are usually clearly identifiable as taller or smaller, earlier- or later-flowering, or plants with characteristics distinctly different from the norm. Descriptions of the distinguishing characteristics of the parents should be available from the seed company, and will include aspects such as the angle of the leaf blade to the stem coloration of the leaf sheath and stem, and the shape of the tassel (Table 6). Persons who conduct roguing must become familiar with these characteristics so that only off-type plants are removed. Off-type plants should be completely destroyed. Beware that in some cases, after cutting the off-type plant at the base, side shoots may grow and produce an undesirable cob and tassel. Thus, it is best to uproot off-type plants.

**Table 6. Distinguishing characteristics of maize plants during the vegetative and flowering stages.**

| | |
|---|---|
| **Leaf** | Angle between blade and stem.<br>Attitude of blade (i.e., straight or curved).<br>Width of blade.<br>Anthocyanin coloration of sheath. |
| **Stem** | Anthocyanin coloration of internodes.<br>Degree of zig-zag.<br>Anthocyanin coloration of brace roots. |
| **Plant** | Height.<br>Ratio of height of insertion of ear to plant height. |
| **Tassel** | Length of main axis above lowest side branch.<br>Length of main axis above upperside branch.<br>Time of anthesis (pollen shedding).<br>Anthocyanin coloration of base of glume.<br>Anthocyanin coloration of glumes excluding base.<br>Anthocyanin coloration of anthers.<br>Density of spikelets.<br>Angle between main axis and lateral branches.<br>Attitude of lateral branches.<br>Number of primary lateral branches. |
| **Ear** | Time of silk emergence.<br>Anthocyanin coloration of silks.<br>Intensity of anthocyanin coloration of silks. |

For efficient roguing, note the following recommendations:

- Limit the roguing team to 10-12 people including the supervisor, because larger groups get easily distracted. If more people are needed to rogue the fields, divide into several groups and assign them to different parts of the field, giving specific responsibilities for specific sections.
- Select responsible people for the roguing team and provide training on the identification and removal of off-type plants.
- The team should start in a corner of the field and work through it slowly, walking parallel to and in the same direction down the rows.
- Each member of the roguing team should have a narrow zone to observe. For maize consider a maximum of two adjacent rows.
- Use large stakes to mark areas of the field that have been rogued.
- The position of the sun and wind movement can affect the team's ability to identify undesirable plants.
- After several hours of roguing, a person tires and becomes less efficient. Thus it is advisable to rogue relatively few hours per day. Roguing teams may work most efficiently during the early morning or late afternoon.
- The supervisor should concentrate on overseeing and inspecting roguing team activities, than actually roguing.

**When to rogue**

Roguing should be conducted before genetic or physical contamination occurs and during times favorable for visual identification.

- Rogue volunteer plants; these are easily identified by size and position out of the rows (post emergence).
- During vegetative development, rogue off-type plants that deviate from the given genotype with respect to root and stalk development, plant type, pigmentation, leaf and stem pubescence, etc. Effective roguing during this period will help reduce the work load during the critical flowering period.
- At the flowering stage, important agronomic and morphological characteristics can easily be identified. This is the critical stage to prevent genetic contamination of crop. Roguing on male plants must be complete before pollen shedding begins. Roguing on female plants should be complete soon after silk-emergence.

**Detasseling**

In hybrid maize seed production, detasseling of the female plants must meet the required standard and be conducted in a timely fashion. Any delays in detasseling or inadequate detasseling that results in tassel-stubs or missed plants will seriously diminish the genetic purity of the hybrid seed and might result in rejection for certification. Note the following:

- The tassels on the female plants must be removed before they begin to shed pollen.
- Detasseling must commence when the top 3-4 cm of the tassel is visible above the leaf whorl.
- Detasseling must continue every day until complete, come rain or shine.
- Some female parent plant types are more easily detasseled than others. For example, some female parents have tassels that are physically hard to pull out, others break easily and some begin shedding pollen before fully emerging from the upper leaves. Tall female plants, especially when the female is a single-cross hybrid, are difficult to detassel. In top-cross or varietal cross hybrids, where the female is an open pollinated variety, time of tassel exertion in the female population will vary. Lastly, with some parents, silks emerge much earlier or later than pollen shed. All these situations, may be compounded and make for difficult detasseling supervision and potential management problems. Close supervision of the field is crucial.
- Detasseling may take two to three weeks, depending on the field size, uniformity of the crop and labor availability.
- About six people can detassel one hectare per day, but this rate will be a function of the difficulty of detasseling.
- Individual workers may be allocated specific sections of the field to detassel, so as to give responsibility and accountability. However, monitoring each person's detasseling effectiveness will be necessary to ensure that one or more laborers do not spoil the entire field.
- Removal of more than one leaf with the tassel will reduce yields.
- Mechanical detasseling to cut or pull female tassels improves efficiency, but will require manual follow-up to remove any remaining tassels or stubs. Mechanical detasseling is not always possible on three-way hybrids because the females may be too tall for the machines to drive over the crop. Mechanical detasseling usually cuts or removes one to three of the uppermost leaves, which will reduce yields.

**Synchronization of male and female flowers**

Ideally, the male plants should begin shedding pollen when the first female silks begin appearing and they should shed pollen for as long as it takes for all the female silks to emerge. However, male and female plants do not always take the same time

**Off-type plants must be cut-off at the roots before flowering to ensure destruction and prevent re-growth.**

**Detasseling involves removal of the tassel from female plants before pollen shedding.**

to reach flowering, due to different growth rates and environmental variations. Furthermore, the duration of pollen shedding may be shorter than the time for females to reach full silk emergence. Any mistiming of male and female flowering will reduce yields and expose the female seed parent to contamination from foreign pollen.

Pollen shedding and silk emergence may take place over 7 to 14 days and may not coincide, even if the male and female parents are planted on the same date. For example (Figure 6), the silks on the female may begin to emerge before the males begin to shed pollen. Indeed, the silks in the example were showing for five days before significant pollen shedding occurred, thereby exposing the female to possible contamination from foreign pollen. The time to 50% silking of the female occurred 64 days after planting, and the time to 50% pollen shedding on the male occurred 67 days after planting. To achieve a perfect nick (male-female flowering synchrony) in this case, the male would need to be planted three to five days earlier than the female.

**Late detasseling often leaves stubs of tassels which shed pollen, causing female-selfing and poor seed purity.**

**Females detasseled by machine. Note the upper leaves have been cut, but detasseling was effective and saved labor.**

If a male parent is an inbred line with a weak growth habit, or if it has a short pollen shedding period or does not produce a profuse amount of pollen, it is advisable to sow male plants on two (or even three) consecutive dates a few days apart, so that the pollen shed period covers the whole period of silk emergence. The split-planting of the male is usually done in two adjacent rows. To reduce the land required, the two split-planted male rows may be seeded relatively close together, compared to the female rows. For example, if the normal row spacing is 90 cm, the two split male rows could be sown 45 or 60 cm apart, but 45 to 60 cm away from the adjacent female rows. Where the male does not produce an abundance of pollen, the female-to-male ratio should not be more than 3:1, whereas if the male is a profuse pollen producer (as in the case of a double-cross hybrid), the female-to-male ratio may be increased to 6:1 or even 8:1. In some cases, even with single- and three-way cross hybrids, a ratio of 6:2 may be planted, but the male must be a prolific pollen producer.

In single-cross hybrid seed production, where the male and female inbred parents are of similar vigor and stature, a "squeeze-row" configuration may be feasible. In this arrangement, the male row is planted at half the normal row spacing between alternate rows of females, which are planted at the normal row spacing. For example, if the female rows are planted in their normal row spacing, say 90 cm, then in every second female row-space the male is planted at 45 cm from the female. Thus, the female:male ratio is 2:1, but effectively the female covers the entire field and the land is optimally used. However, it is important in this system to remove the male immediately after pollination, to reduce competition with the female.

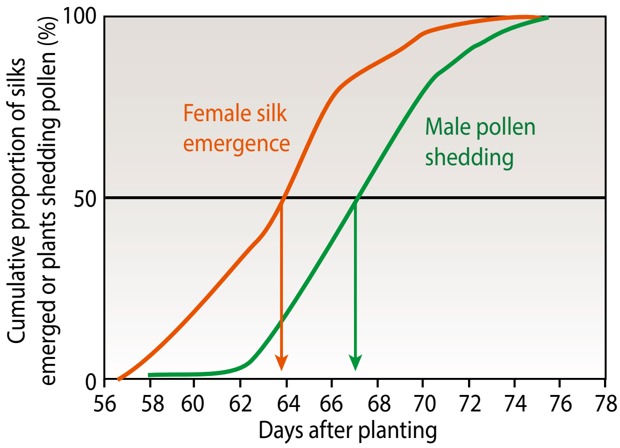



**Figure 6. An example of the progress in silk emergence of the single-cross female and in pollen shedding of the inbred male, in a three-way hybrid maize seed production field.**

Other methods of improving synchronization, especially where there is a small difference between the times of flowering of males and females, include the following:

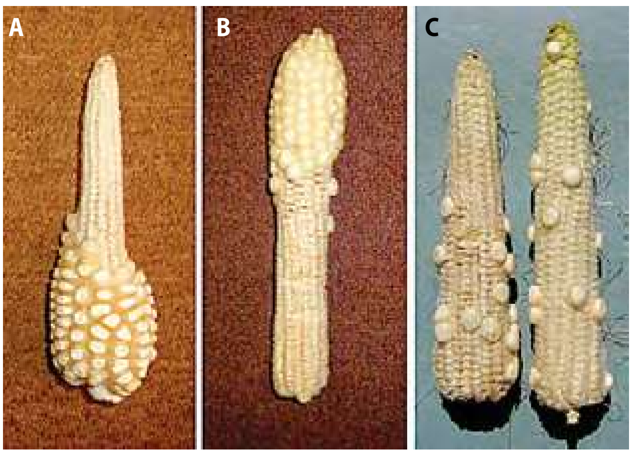
- Soaking the seed in water for 12 to 24 hours prior to sowing may advance flowering by 1 to 2 days. Soaked seed absorbs water and begins to germinate. It is therefore vulnerable to damage if mishandled. Water soaking only works with hand sowing into wet soil. Sowing soaked seed into a dry soil will likely lead to poor germination and emergence.
- Clipping the two-to-four whorl leaves of the male plants when four to six leaves are fully emerged (determined by the presence of leaf collars) is effective in delaying pollen shed by 2 to 3 days. However, if the plants are clipped too severely they may produce small tassels and less pollen than if not clipped. If clipped too late, there will be little effect on time of pollen shedding, but tassel size may be reduced.
- Burning male plant leaves with herbicide or flame at the three-to-five leaf stage may delay tasseling and pollen shed by 2 to 3 days. This has proven to be effective, if burning is not excessive.
- Adding extra phosphate and nitrogen fertilizer in the planting furrow of the male or female may hasten plant growth, particularly in soils that are not very fertile. But the hastening of plant growth may only cause flowering to occur one to two days earlier than if no fertilizer were applied or if fertilizer were broadcast.
- Irrigation applied one to two weeks before flowering will ensure that the silks emerge at the expected time, especially if the weather is hot and dry at that time.
- In cases where male plants are insufficient due to germination failures, pollen may be collected from remaining plants, bulked into "pepper pots" and applied to the silks of female plants. Alternatively, or in addition, walking through the field at pollen shed with motorized mist-blowers can blow the pollen across the female rows and improve pollination.
- Early detasseling can hasten the emergence of silks on females by one or two days.
- Cutting back the sheath on the ear can advance silk emergence by two to three days, but as the cob grows, it may extend out of the cut sheath leaves, exposing the tip to insects, birds and diseases.

**Box 4: Effect of poor synchronization on yield and grading of seed maize**

**1. Pollen too early or silking late relative to pollen**
- The base of the cob will be pollinated, with the tips empty.
- Depending on the percent seed set, yield loss is usually low, since kernels at the base of the cob are usually larger and compensate better than the normally smaller kernels at the tip.
- Expect a higher proportion of large round seed compared to other seed grades.

**2. Silking too early or late pollen shed relative to silks**
- The tips of cobs will be filled, with blind butts.
- Yield loss is usually high, since large butt kernels missing but small kernels on tip present.
- The seed will comprise mostly small round and thick grades, with a small proportion of medium flat seed.

**3. Inconsistent or insufficient pollen shed**
- The filling of the cob is irregular, with empty cobs when pollen is not available.
- Yield loss is high due to reduced kernel number.



**A: Seeds at the base of the cob indicate early male pollen or late female silks. B: Seeds at the tip of the cob indicate late male pollen or early female silks. C: Scattered few seeds indicate inadequate pollen supply.**

**Male removal**

As soon as possible after pollination, remove the males from the field. Male plants are cut at the base and either removed from the field or left to rot in the row. Removing males soon after pollination ensures that there will be no mixture of male and female seed at harvest. Male removal also improves the yield of the female by allowing more light penetration into the female rows and reducing competition for moisture. Note that weeds will take advantage of the free ground and will need to be controlled.

**Inspections of the seed crop**

Seed crop inspection is a regular and normal requirement for seed certification. Seed regulators will visit the seed field 3-to-6 times during the season to ensure that the crop meets the standards for certification. Seed inspectors need to have free access to the seed field and to all records. Cooperation and implementation of instructions concerning the seed crop will facilitate certification.

The following are key criteria assessed in such inspections:

- The seed crop is grown from an approved seed source (retaining the labels is necessary to prove this).
- The field meets the prescribed land requirements as to the previous crop.
- The prescribed isolation standards are observed.
- The seed crop has been planted with the prescribed ratios of female and male parents.
- The crop is properly rogued and detasseled to national standards.
- The crop is true to the varietal characterization.
- The crop is harvested properly to avoid mixtures.

**Maize seed harvesting**

Seed germination rate and vigor (i.e., viability), improves from fertilization of the embryo to physiological maturity, when it will reach a maximum (Figure 7). The absolute or maximum quality of the seed at physiological maturity will have been determined by the growing conditions during seed development, but whatever this quality is at physiological maturity, it will be the maximum the seed can attain. From this point onwards, no improvement is possible in seed viability. All operations from harvesting onwards therefore have to be done so as to cause the least deterioration in seed viability, while ensuring that the healthy seed is separated from inferior seed and impurities (extraneous matter and weed seeds) to achieve a specified standard of seed purity.

At physiological maturity of the crop, seed moisture content is between 30 and 35% and the crop will still have some vestiges of green in the stems and leaves. From physiological maturity onwards, the seed dries as the environment allows (Figure 8). The drier and warmer the environment and the greater the exposure of the seed to the air, the faster seed moisture will decrease. The rate of field dry-down will also be increased in cases where the cobs have few husk leaves, the cobs are poorly covered by loose husks or the cob diameter is small. Seed

**Male plants cut soon after pollination to avoid seed mixture and improve female seed yield.**

**To check if pollination has taken place on the female, carefully remove the sheath leaves and hold up the ear.** Silks that remain attached to the ear indicate that no pollination (fertilization) has taken place.

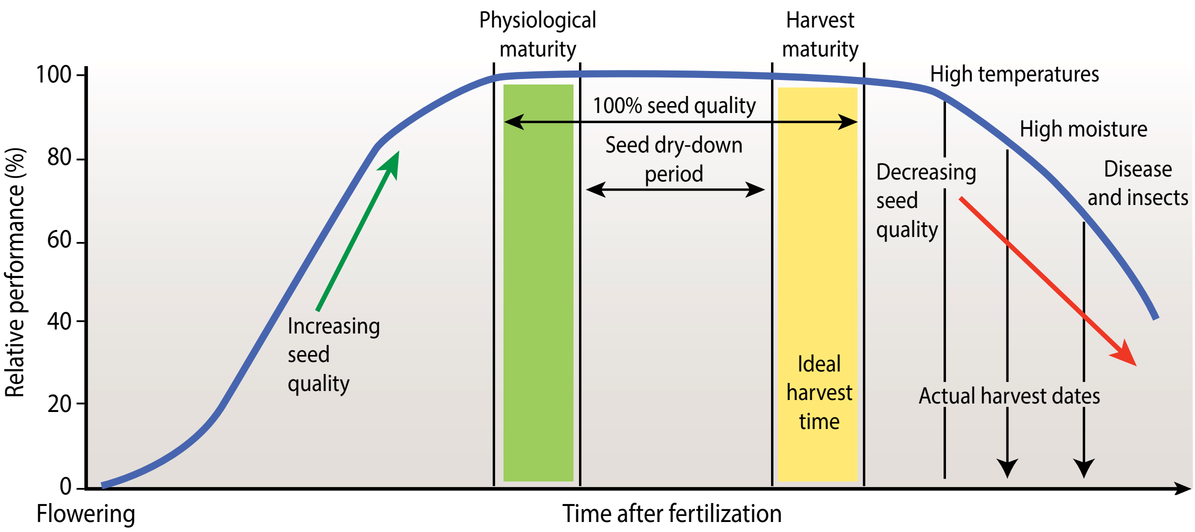



**Figure 7. Schematic presentation of the change in seed viability (germination percent and vigor) with time after fertilization of the embryo.** (From Andrews and Cabrera, 1995. Seed quality. Bulletin 1033, Mississippi State University.)

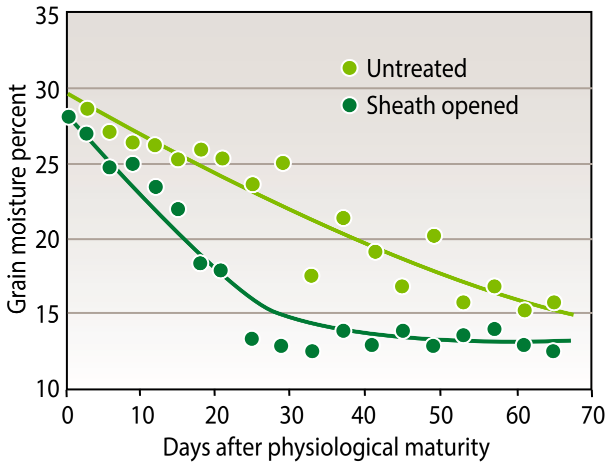



**Figure 8. The decrease in moisture content of seed remaining on the plants with time after physiological maturity, where the cob sheath leaves were either opened or untreated.** **(Date from the Agricultural Research Trust, Harare, Zimbabwe.)**

quality will remain relatively high and only decrease slightly, as long as environmental conditions are favorable and grain-eating pests are absent.

Seed quality will decline with high air temperatures, high moisture (or high relative humidity), diseases or grain borers. This basically means that the crop should be harvested as soon after physiological maturity as possible.

Maize ears may be harvested (but not shelled) at a seed moisture content of 25 to 30%, dried at moderate air temperatures (<35°C) and shelled when the seed moisture is less than 14%. If the crop is to be mechanically shelled at harvest, the seed moisture content must be low enough to enable shelling but not too low, to avoid chipping or breaking of the seed. With maize, the ideal seed moisture for shelling is between 11 and 14%. If the moisture is below 11%, mechanical shelling will cause damage. If the moisture content is above 15%, the seed will be bruised and chipped.

**Box 5: Maize ear weights in normal 50 kg hessian bags**
- A bag of de-husked ears weighs ~40 kg.
- A bag of ears with husks weighs ~30 kg.

Hand harvesting of seed maize is common and enables the elimination of diseased cobs at reaping. Since this is labor-intensive, it requires good management and supervision. Various methods have been devised to make it more efficient. The simplest is reaping cobs into sacks, which are carried out of the field by hand or on trailers. If the cobs are de-husked in the field, each laborer should be able to reap 500 kg of cobs per day, whereas if there is a mechanical de-husker and the reapers simply have to remove the cobs with husks on, then the reaping output may be increased to 1,500 kg per day per laborer. Reaping output may be increased if the cobs are thrown onto an adjacent trailer in the field, rather than being put in bags. The trailer may be fitted with a hanging curtain in the center to prevent cobs being thrown over the trailer. With the use of such a trailer system, labor output may be increased to 600 kg of cobs per day per laborer with de-husking, or 2,500 kg of cobs with the husk intact.

Mechanical harvesting of cobs with a cob picker improves efficiency. Cobs are picked after physiological maturity when the black-layer has formed at the base of the seed and when seed moisture is below 30%. The cobs are collected in a trailer and transported to the conditioning plant, where they are screened and dried if seed moisture is higher than 13%. Once the seed on the cobs is below 13% moisture, shelling may occur. Combine harvesting of seed is not recommended because it can damage the seed and removing damaged or diseased kernels from the mass of seed is difficult.

### Seed shelling
For maintenance of high seed quality, hand shelling is ideal but not always economically feasible. A laborer may be able to hand shell up to 100 kg of seed maize per day. Many types of mechanical shellers are available for crop seeds, but these vary in their impact on seed quality. Aggressive, high-speed shellers or combines will chip or break seed. Mechanical damage to seed is due to abrasion and impact. Abrasion damage mainly affects the seed coat and results from seed rubbing against rough surfaces. Impact damage may affect the entire seed and is a function of the force applied to the seed. Thus, mechanical shellers need to be operated at low speeds and adjusted to minimize seed damage. Contact edges in the threshing drum should be rounded off and smoothed to minimize pounding of the grain. The seed should preferably be rubbed off the cobs to reduce damage. If possible, mechanical shellers should also be used to separate the seed from extraneous matter, such as cobs and sheaths.

### Seed storage
Once shelled, the raw seed may be stored until delivery to the seed company factory. Raw seed may be stored in bags or bulk but no seed should be stored unless it is at a moisture content low

enough to maintain seed quality (Figure 9), which is less than 13%. However, the length of time that seed may be safely stored even at low moisture content depends on the air temperature and relative humidity. The lower the air temperature and relative humidity, the longer the seed can be stored with minimal deterioration. As a rule, if the relative humidity of the air is above 60%, seed deterioration is likely to be rapid; such conditions will increase the moisture content of the seed and foster the development of diseases and storage pests. Ideally, seed should be stored in a shed to protect it from rain and heat, while providing security.

**Protecting seed from storage pests**

Seed should be fumigated and protected against storage pests. Fumigation is usually done with phosphine gas, either released from aluminium phosphide tablets or injected from hydrogen phosphine gas canisters. Fumigation should be supplemented with insecticidal grain protectants applied directly to the seed or sprayed onto the bag exteriors and building interior, to prevent re-infection.

Seed to be fumigated should be enclosed in an air-tight plastic sheet that will prevent the escape of the phosphine gas from the seed stack. Fumigation sheets should be polythene or polyester scrim of 250 to 350 g/m$^2$ mass. If the sheets are UV protected, they should last for 3 to 4 years, provided they are cared for properly. Particular care should be taken to avoid punctures and tears. Phosphine gas is slightly heavier than air and will disperse downwards from the point of application, but will eventually spread to all parts

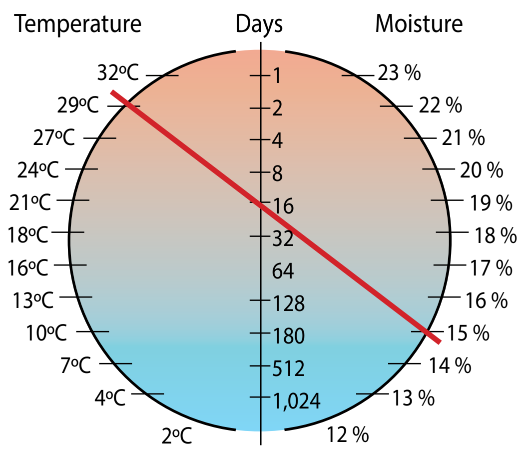



**Figure 9. Diagrammatic representation of the potential storage life of seed as a function of air temperature and seed moisture content.** The connecting line between the average air temperature and the seed moisture indicates the potential storage life of the seed.

of a contained area. Where phosphine tablets are used, these should be distributed at various places in the bag stack or bulk bins, according to the recommended dosage, to ensure rapid and even gas dispersion throughout the seed.

**Box 6: Major reasons for seed deterioration in storage**

- Low quality seed is placed in storage.
- Seed with high moisture content is stored.
- The first-in, first-out rule not followed, so that seed remains for too long in storage.
- The warehouse is not ideal; e.g., poorly ventilated, prone to heating, exposed to moisture penetration and/or insecure.
- The environment is too humid or too hot for seed storage.

The ideal conditions for phosphine fumigation are an air temperature of 21°C, a relative humidity of 60% and grain moisture of 12%. Under such conditions, the seed should be exposed to the gas for at least 10 days, but the longer the better. Time of exposure to fumigation is better than dosage. The higher the air temperature, the faster the gas will be released from the phosphine tablets. If the air temperature is less than 15°C, it is better not to fumigate.

Phosphine gas is HIGHLY TOXIC. Operators must observe safety precautions, such as placing warning signs around the fumigated area, wearing suitable protective clothing and respirators, and prohibiting smoking. Phosphine gas will corrode electrical equipment. A mixture of phosphine gas and air is combustible and will explode if ignited. Electrical equipment should be well grounded to prevent sparking or static discharges.

**Protection from rodents**

Rodents can cause tremendous damage to seed. Losses may be reduced by storing seed in rodent-proof stores, ensuring bags in seed stacks are tightly bonded to prevent rodents from penetrating into the center of the stack, and controlling rodent populations with baits and predators.

**Physical space for seed storage**

Maize seed may be stored temporarily on the cob, either in loose stacks or in cribs, provided the grain moisture is less than 13%. Cribbed or binned ears of high moisture content are prone to attacks by storage pests. Only at about 13% moisture content will the kernels and the cob be in moisture equilibrium (Table 7). At higher seed moisture contents, the cobs contain significantly higher moisture than the seed, which will promote disease development and insect growth. A key factor in cribbing maize on the cob is the width of the crib – the narrower the crib the better (2 to 3 m maximum), so as to allow sufficient natural ventilation through the cobs.

**Table 7. Equilibrium moisture contents of grain and cobs on intact cobs** (From D.E. Maier, 1996, Fact Sheet #29, Purdue University).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Grain moisture (%) | 10 | 13 | 15 | 20 | 25 | 30 | 35 |
| Cob moisture (%) | 9 | 13 | 18 | 33 | 45 | 52 | 56 |

### Storing seed in bags

Seed may be stored in bags for lengthy periods, provided the seed has a moisture content of less than 13%, the storage conditions are favorable for maintaining seed viability (i.e., cool and dry), the seed is protected from storage pests and the bags enable gas exchange and are stacked in an orderly manner. Normally, raw seed is stored in 25 or 50 kg jute or polypropylene bags prior to processing or re-packing. Where bags are to be stored in stacks, use the following guidelines:

**25 kg bags**

Stack in 3 m x 3 m stacks, with 32 bags per layer (i.e., 0.8 t) and up to 20 layers high (total of 16 t). This stack will normally take 8 bags width-wise times 4 bags length-wise.

**50 kg bags**

Stack in 7 m x 7 m stacks, with 130 bags per layer (i.e., 6.5 t) and up to 32 layers high (total of 208 t). This stack will normally take 13 bags width-wise times 10 bags length-wise.

Bags should be laid so that they are bonded together, with alternate layers laid cross-wise, to strengthen the stack. Sides should be inclined inwards with height to avoid collapse. When starting a stack, the outer ring of bags is laid first, with a gap of about 2.5 cm between bags on the bottom layer. With each successive layer, the gap between bags is reduced, so that the width of the stack reduces with height. Lanes of at least 1 m should be left around the stacks to allow for inspection, insecticide spraying or covering with fumigation sheets. Stacks that have been laid well will have a density of about 650 kg per m.[3] As a rule of thumb, 1 t of seed may be stored per 1 $m^2$ of floor space, allowing for alley ways.

**Store seed in labelled bags in well-constructed stacks on pallets with a bin card to monitor stock quantities.**

### Bulk storage of seed

The advantage of bulk storage of seed is that it requires less space, since the density of seed in bulk is about 0.75 t/$m^3$. Furthermore, with well-constructed silos and conveyors seed losses are reduced, less labor is required for handling the seed and the cost of storage bags is eliminated. Bulk stored seed is also easier to fumigate. The disadvantage is the high capital cost, although this may be offset over time with the saving in bags. Silos should always be filled and emptied from the center to avoid excessive pressure building up on one side of the silo. The angle of repose of seed of most field crops is about 25°.

### Seed drying

On most African farms, seed is left to dry in the field before harvesting and shelling. This is usually possible for summer-grown crops that mature in the dry winter period. However, it might be necessary to harvest the seed when it is above the safe storage moisture content and dry the seed artificially. Early harvesting and artificial drying of seed has the advantages of minimizing disease and insect infestation in the field, avoiding field losses from birds, rodents and theft, and enabling earlier processing and sale of seed. The disadvantages are that seed is more vulnerable to damage at high moisture content, poorly controlled drying may adversely affect seed viability and artificial drying is costly. Maize may be artificially dried pre- or post-shelling.

The most common artificial drying method is to force heated air through the cobs, to evaporate and remove the excess moisture from the seed. The cobs may be harvested at a grain moisture content of 25 to 30% and transferred rapidly to a drier, where air of moderate temperature (not greater than 35°C, cf. Table 8) is used to dry the seed to 13% moisture. The density of maize cobs is about 480 kg/$m^3$, which is equivalent to a seed density (on cobs) of about 360 kg/$m^3$. The batch-type of drier (Figure 10) is most suitable for seed, since continuous flow or re-circulatory driers involve a significant amount of seed movement, which might cause seed

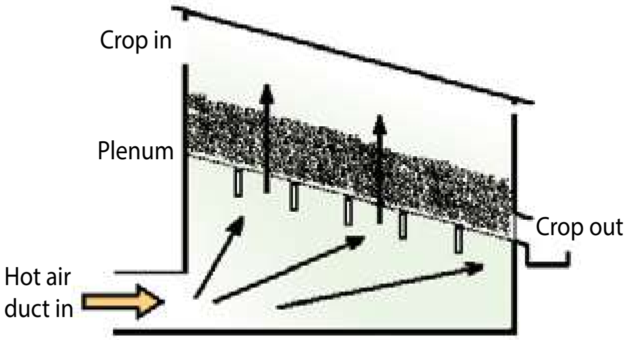



**Figure 10. Schematic diagram of a batch drier with a sloping plenum to facilitate emptying (not to scale).**

**A maize seed dryer.**

damage. In the batch drier, the cobs are stationary during drying and the crop is moved only during filling or emptying the drying bin. However, the drying pattern in batch driers is uneven, with the unevenness increasing with depth. The seed at the bottom of the batch, closest to the incoming air, will be drier than the seed at the top of the batch. Evenness of drying may be improved by ensuring that the crop is clean, having a uniform depth of seed within the drier and minimizing the depth of seed. The maximum depth in a batch drier should be 1 to 2 m for raw seed, and 2 to 4 m for maize cobs. Some driers are built to enable the reverse flow of air to improve the evenness of drying.

The rate of drying depends on the air temperature and the rate of air-flow through the seed. The maximum air temperature for seed drying is less than that for grain drying. The maximum air temperature also depends on the seed moisture content (Table 8), with lower drying air temperatures required at higher moisture contents to avoid "cooking" the seed.

**Table 8. Maximum recommended air temperature for drying maize seed, as a function of seed moisture content.**

| Seed moisture content | Maximum drying temperature |
|---|---|
| Over 22 % | 30°C |
| 18 to 22 % | 32°C |
| 12 to 18 % | 36°C |

The rate and pressure of the air flow required depends on whether cobs or seed are being dried, on the depth of crop and the required rate of drying. For example, raw seed maize requires about three times the air pressure of that for cobs, because of the greater resistance offered by the seed. The smaller the seed and the higher the bulk density, the greater the resistance to air flow through the mass of seed. Increasing the air flow will increase the rate of drying, but will require more fuel to heat the greater volume of air.

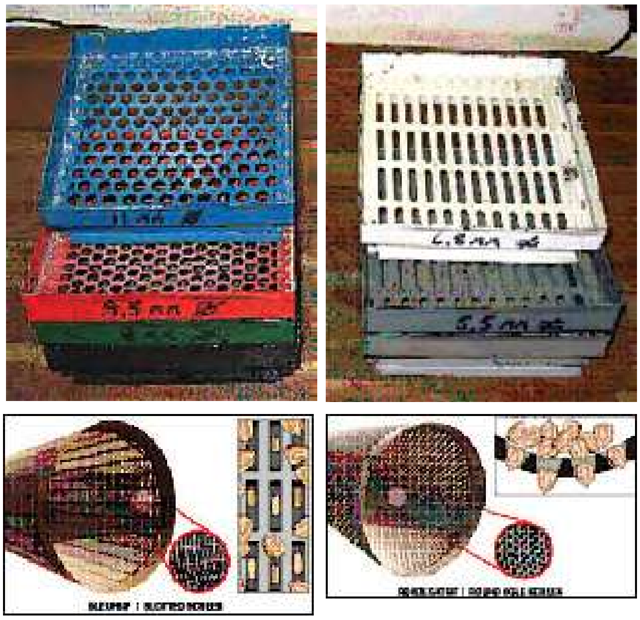
The initial moisture content of the crop also influences the drying rate, because the rate of moisture extraction is not a linear function of moisture content. Less energy is required to remove moisture from wet grain than dry grain. In general, the drying rate for seed should not exceed 0.5% moisture removal per hour.

Diverse air-heating systems are available, using a variety of energy sources (e.g., coal, diesel, cobs). The choice of system depends on the required air temperature increase, the volume of air to be heated, the availability of fuel and the cost of the system. Solar drying may be possible given that the air temperatures used are usually less than 35°C. Similarly, there are a number of fan options for creating air flow. The design of a seed drying system is complicated and requires expert advice. When designing a drier, the following issues need to be considered:

- The kind of crop(s) and the type(s) of product (raw seed or cobs) to be dried.
- The quantity of product to be dried over a specific time.
- The size and number of bins.
- The filling and emptying of bins.
- The location of the facility (accessibility, altitude, ambient air temperatures and relative humidity during drying).
- The fuel sources available.
- The type of heat exchanger required.
- The fan requirements.

### Cleaning seed

Seed leaving the sheller often contains foreign material, including bits of cob, husk, broken kernels, stones, dirt, weed seeds and insects. This debris must be removed to improve seed appearance and to promote storability and plantability. Cleaning may be done manually or using seed cleaning machines, which use a combination of screens and air movement to remove unwanted material from the seed.



**Seed separating screens.**

## Seed grading

One of the unique aspects of seeds on a maize ear is the dramatic differences in size and shape due largely to position on the ear. Large round seeds are often found at the base of the ear and small rounds at the tip. About 75% of the seed in between this round type are flattened as a result of their tightly packed position. As part of processing, the seeds are graded into various classes. These classes are determined by passing the seed through two types of screen that separate the seeds based on their length (rectangular shaped slots) and width (round shaped slots). The graded seeds are classified as large, medium or small based on length, and round, thick or flat based on thickness (Table 9 and Figure 11). It is possible to obtain extra small classes of all grades of seed.

**Table 9. Seed classes based on width and thickness.**

| | Thickness | | |
|---|---|---|---|
| Width | Round ( R ) | Thick (T) | Flat (F) |
| Large (L) | LR | LT | LF |
| Medium (M) | MR | MT | MF |
| Small (S) | SR | ST | SF |

Due to their relative sizes, the different grades have different weights per thousand kernels (TKW) and contain different numbers of kernels per specific weight (kernels per kg). The average weight of a thousand kernels and the the average number of kernels per kg of various classes are represented in Table 10. This is important because it affects field seeding rates (Figure 12).

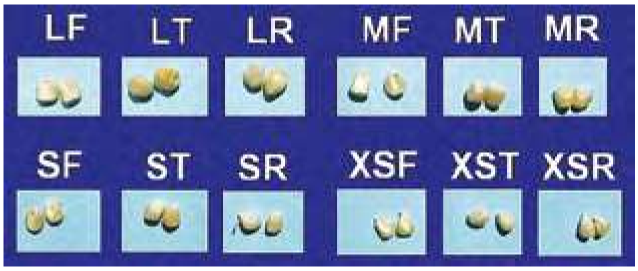



**Figure 11. Seed classes.**

**Table 10. Average thousand kernel weight (TKW) and number of kernels per kilogram of various classes of seed.**

| GRADE | Average TKW, kg | Average kernels/kg |
|---|---|---|
| LF | 0.54 | 1,871 |
| LR | 0.62 | 1,638 |
| LT | 0.60 | 1,688 |
| MF | 0.45 | 2,241 |
| MR | 0.55 | 1,830 |
| MT | 0.52 | 1,963 |
| SF | 0.37 | 2,761 |
| SR | 0.44 | 2,283 |
| ST | 0.42 | 2,438 |

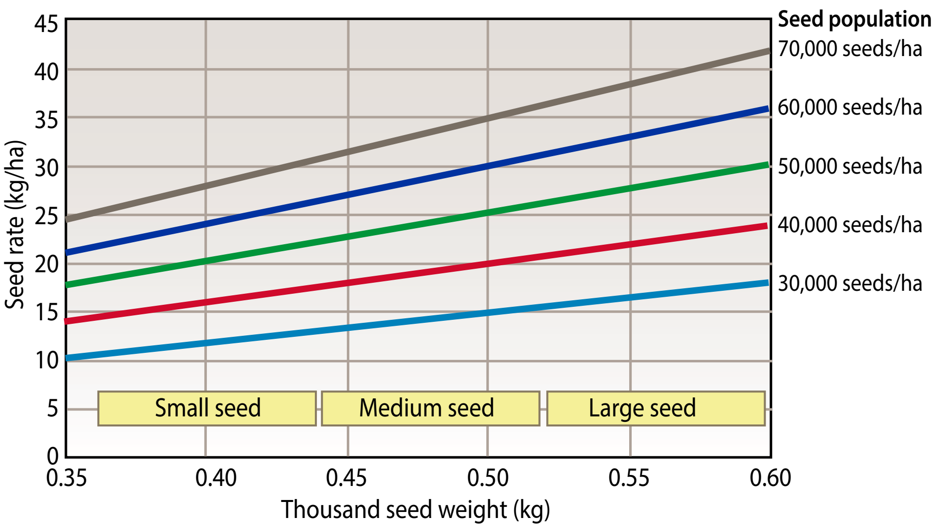



**Figure 12. Effect of thousand seed weight on the seed rate and seed requirement per hectare.**

**Seed treating**
Maize seed should be treated with a fungicide or a combination of fungicide and insecticide to protect the seed and developing seedlings from diseases and to give short-term protection against storage insects. Fungicides are particularly helpful when sowing in conditions where soils are clayey, crusted and/or cold and wet at sowing. Seed treatment chemicals may also help offset vulnerability to disease in seeds that have been chipped or cracked during harvest or conditioning operations.

The fungicides and insecticides are commonly mixed into a slurry and applied to the seed using a seed treater device. Colored dye is often added to the slurry to impart a distinctive color and thereby clearly identify treated seed. A uniform coverage of the seed with the correct dosage of chemical(s) is critical in the treatment operation. Different fungicides and insecticides are available for seed treatment. The locally registered chemicals can be used.

**Seed bagging**
Bagging is the final step in the conditioning process. A seed package accomplishes several essential functions:
- Serves as a convenient unit for handling, transport, and storage.
- Protects seed against contamination and mechanical damage.
- Provides a suitable environment for storage.
- Provides a barrier against seed loss and the escape of pesticides.
- Serves as a sales promoter.

Seed packaging material may consist of cloth, jute, plastic, paper, metal or various combinations of products. Plastic, paper, or plastic/paper combinations are the materials of choice for packaging maize seed. Clear plastic bags are preferred in some areas because farmers can see the seed. However, use of plastic bags may be risky if seed is exposed to the sun and warm temperatures, resulting in accelerated respiration and likely deterioration. Seed may be packed by hand or with semi-automatic or automatic equipment. After filling the bag with the required amount of seed, the bag is sewn or heat sealed and a tag is attached. The tag commonly includes information about the variety, seed lot number, the physical and genetic purity, germination test results and the seed treatment chemicals used. Maize seed package size varies depending on farmers' requirements, normally ranging from 1 to 25 kg.

**Seed quality testing**
After harvest, seeds should be inspected at different stages of seed processing. Tests may be conducted with samples to evaluate physical and phytosanitary quality, genetic purity and vigor.

Since moisture content has such a large influence on the life and quality of a seed, the initial quality control test is often simply an evaluation of moisture content. This is typically followed by physical purity analysis, which examines the amount and type of damaged or off-type kernels, along with the quantity of inert matter and weed seeds present in the sample.

Genetic purity analysis is important to guarantee that the seed is uniformly true to type. The conventional approach has been through post-control grow-out tests. These tests involve planting out a sample of the seed lot in the greenhouse or in an off-season field to evaluate plant development in comparison to varietal description. The disadvantages of this system include the time required and the fact that the genetic material

**Seed testing for seed purity and quality to ensure only pure seed is sold to farmers.**

**Seed is tested for germination capacity to ensure the germination percentage meets the minimum requirement for certification.**

may be evaluated in an environment where it is not well adapted, making it hard to identify off-types and true-to-type plants. Today sophisticated molecular techniques available provide precise determination of the genetic make-up of the seed.

The most common seed quality test is the germination test, which measures seed viability under ideal conditions. For a maize seed lot, 4 replications of 100 seeds each are sown either in sand or on a paper substrate and placed under adequate moisture conditions at either 25°C (with 12 hours light/day) or 20° and 30°C alternating. The number of normal and abnormal seedlings and ungerminated seeds are determined at 4 and 7 days after initiation.

Vigor tests evaluate the ability of a seed to emerge in a timely, uniform and adequate fashion under a field conditions.

To reduce the possibility of spreading harmful pathogens via seeds, four types of seed health test have been developed:

- A physical examination of the internal and external seed parts, including use of a microscope to spot pathogens.
- Plating seeds on agar followed by identification of emergent organisms.
- Germinating seeds and growing the seedlings in conditions known to encourage the development of diagnostic symptoms.
- Washing seed samples with distilled water followed by centrifugation and observations under a microscope.

**Safety**

Worker safety is an integral part of seed production.

- *Mechanical safety.* Machines should be fitted with emergency shutdown switches. Dangerous moving parts should be encased in protective cages.
- *Electrical safety.* Operators need to be protected against electric shock and precautions followed when maintaining electric components.
- *Dust and waste control.* Seed processing generates dust, which should be removed by air-extraction ducts. Cleaning plants also produces unwanted residues, which can be a fire hazard or become an environmental waste problem.
- *Hazardous chemical safety.* Appropriate safety procedures must be followed during fumigation and seed treatment.
- *Vehicle safety.* Movement of seed around the plant with tractors or fork-lifts may cause accidents.
- *Seed storage safety.* Care must be taken with seed stack construction, and silos should not be entered without due precautions.

**Seed production contracts**

Contracts are legally binding agreements between two partners. The exact nature of a seed grower contract will depend on the circumstances, but will usually contain details of the following, couched in legal terminology:

*Obligations of the farmer.*

- Agree to produce a particular seed crop and variety exclusively for the seed company.
- Produce the agreed quantity of seed.
- Follow crop management specifications.
- Allow company representatives to inspect seed fields.
- Follow the delivery schedule.

*Obligations of the seed company.*

- Supply parent seed.
- Specify services to be rendered to the farmer.
- Pay for seed at the agreed price, including any applicable bonuses or penalties.
- Follow the payment schedule.

Contracts usually also specify that the germplasm supplied by the seed company and produced by the farmer remains the property of the seed company.

Where small-scale farmers are involved in seed production, it may be necessary or preferable to establish the contract with a consortium of growers. This might be a whole village, to ensure that all farmers grow the same variety to avoid admixture or contamination of the seed, or with a cooperative or farmers' group to engender a certain degree of group responsibility and accountability. In these

**Safety not only considers work-wear but also working procedures to protect people and the environment from harm.**

cases, the contract needs to be negotiated with the village head or group leaders, with the full involvement and agreement of the community. The advantage to the seed company, apart from quality assurance, is that greater seed quantities can be produced, while negotiations, transactions and inspections are localized, simplifying management. For the community, the contract offers a level of security and may be used for collective bargaining, securing loans and community wealth creation.

**Seed pricing**
A number of options determine the price paid to seed growers and method of payment:

- The grower is paid a company-determined price per ton of seed delivered. This is the simplest form of pricing and enables the farmer easily to compare the price and profitability of seed production with other enterprise options. The seed company will calculate a price based on either (1) the average yield of seed and a presumed realistic return per ha for the farmer (e.g., if the average yield is 4.0 t/ha and a farmer expects a gross income of US $1,200 per ha, the seed price is set at US $300/t); or (2) a margin over the variable costs of production based on a seed crop budget. In the latter system, it is necessary to develop a realistic seed crop budget (see Annex 1).
- The grower is paid a proportion of the seed value upon delivery and the remainder is paid once the seed is sold. This system may be used in a cooperative setting or where the market is not assured. The farmer therefore shares the risk of seed marketing.
- The grower delivers a quota (specified quantity) of seed for which he is paid a set price per ton. Any seed in excess of the quota is delivered but is only paid for at a later date, usually once the seed is sold. This provides security for the seed company in the event that the farmer produces more than what is required, but ensures that the seed is delivered and gives the farmer potential future income when the seed is sold.
- The grower is paid a basic price per ton of raw seed, with a bonus payment for quality (e.g., freedom from defects; acceptable purity and germination) or for meeting delivery schedules. This system provides the farmer with incentives to produce quality seed according to the seed company's schedule. An alternative approach is to apply penalties in the event of poor quality or late delivery of seed.

**Record keeping**
Hybrid seed production involves many steps, most of which are affected by the environment (air temperature, rainfall, soil type) and management. The first time a hybrid is produced, it is unlikely that everything will work out well and there is usually a steep learning curve with each new hybrid produced. Consequently, it is helpful to keep comprehensive records of all stages of production and to use these records to improve production in following seasons. An example of a record sheet is given in Annex 2. In addition to these records, records for rainfall, finances, labor and seed stocks will enhance management of all farm resources. The use of a day- page diary in which daily tasks needed to be done, contacts made and notable events recorded will provide a valuable record of each season. Such record keeping will supply valuable historical information useful for present and future seed production.

## Conclusion
Hybrid seed maize can enhance farmer productivity, but this will only be possible if the seed meets high genetic, physical and phytosanitary standards. Quality seed production is assured by good management of hybrid seed fields and adherence to seed regulations. Beginning with the correct source seed, quality maize hybrid seed production involves a series of steps, each dependant on the success of preceding steps. This manual has laid out the basic procedures of each step. By following these in a timely and efficient manner and conforming to the required standards, the final certified seed will be marketable and seed growers will achieve good yields that will contribute to profitability and sustainability.

**Annex 1. Example of a seed crop budget.**

| Seed crop budget | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Crop: Maize** | Area: 10 ha | | | | Estimated yield: | 3.50 t/ha | | |
| Year: 2014 | | | | | Price per t: | US $650 | | |
| | | | | | Income/ha: | US $2,275 | | |
| | | | | | Total income: | US $22,750 | | |

| Variable costs | Rate/ha | Units | Unit cost (US $) | % area | Cost/ha (US $) | Total cost (US $) | Cost to income (%) | Remarks |
|---|---|---|---|---|---|---|---|---|
| **Seed** | | | | | **145** | **1,450** | **6.4** | |
| Female | 20 | kg | 5 | 100 | 100 | 1,000 | | |
| Male | 9 | kg | 5 | 100 | 45 | 450 | | |
| Seed dressing | | mL | - | 0 | - | - | | |
| **Labor** | **68** | **LD/ha** | | | **204** | **2,040** | **9.0** | |
| Fertilizer application | 4 | LD/ha | 3 | 100 | 12 | 120 | | |
| Herbicide spraying | 2 | LD/ha | 3 | 100 | 6 | 60 | | |
| Laybye herbiciding | 2 | LD/ha | 3 | 100 | 6 | 60 | | |
| Planting | 4 | LD/ha | 3 | 100 | 12 | 120 | | |
| Topdressing | 3 | LD/ha | 3 | 100 | 9 | 90 | | |
| Roguing | 3 | LD/ha | 3 | 100 | 9 | 90 | | |
| Detasseling | 20 | LD/ha | 3 | 100 | 60 | 600 | | |
| Weeding | 6 | LD/ha | 3 | 100 | 18 | 180 | | |
| Irrigation | 0 | LD/ha | 3 | 100 | - | - | | |
| Harvesting | 6 | LD/ha | 3 | 100 | 18 | 180 | | |
| Cob selection | 6 | LD/ha | 3 | 100 | 18 | 180 | | |
| Shelling | 6 | LD/ha | 3 | 100 | 18 | 180 | | |
| Hand-picking | 6 | LD/ha | 3 | 100 | 18 | 180 | | |
| **Fertilizer** | | | | | **350** | **3,500** | **15.4** | |
| Compound | 0.25 | kg | 700 | 100 | 175 | 1,750 | | At or before planting |
| Topdressing | 0.25 | kg | 700 | 100 | 175 | 1,750 | | 4 weeks after emergence |
| Lime | 0.35 | kg | 250 | 0 | - | - | | Maintenance at 1 kg lime /kg AN |
| **Herbicides** | | | | | **60** | **600** | **2.6** | |
| Atrazine | 3.00 | L | 20 | 100 | 60 | 600 | | |
| Metalochlor | 1.50 | L | 30 | 0 | - | - | | |
| | | L | | 100 | - | - | | |
| | | L | | 30 | - | - | | |
| **Pesticides** | | | | | **24** | **240** | **1.1** | |
| Thiodan | 4 | kg | 6 | 100 | 24 | 240 | | |
| | | L | | 100 | - | - | | |
| **Tractor and machinery** | | | | | **240** | **2,400** | **10.5** | |
| Plowing | 30 | L | 3 | 100 | 90 | 900 | | |
| Discing and rolling | 15 | L | 3 | 100 | 45 | 450 | | |
| Planting | 10 | L | 3 | 100 | 30 | 300 | | |
| Harvesting | 20 | L | 3 | 100 | 60 | 600 | | |
| Spraying | 5 | L | 3 | 100 | 15 | 150 | | |
| Irrigation | 150 | mm | 0.25 | 0 | - | - | 0.0 | |
| Drying | 2.5 | t | 100 | 0 | - | - | 0.0 | |
| Transport | 100 | km/t | 0.15 | 100 | 53 | 525 | 2.3 | |
| Total variable costs (TVC) | | | | | 1,076 | 10,755 | 47.3 | |
| Gross margin | | | | | 1,200 | 11,995 | 52.7 | |
| Return /TVC | | | | | 2.12 | | | |

**Annex 2. Example of a record sheet for maize hybrid seed production.**

| Seed production record sheet. Hybrid code: | |
|---|---|
| Field name ……………………………… | Season …………………………… |
| Farmer ……………………………<br>Contact: ……………………………..<br>Area ………… ha …………<br>Location …………………………..<br>GPS …………………………… | Crop ……………….………..<br>Seed variety ……………………….<br>Class of seed ……………………….<br>Female name …………..…  Seed lot no ……….………<br>Male name ………………  Seed lot no ………………. |

Land preparation
Date …………………………………………………………
Method …………………………………………………………

| Basal fertilizer (Including manure and lime) | Date: | Female | Male 1st | Male 2nd |
|---|---|---|---|---|
| | Type: | | | |
| | Rate/ha: | | | |

| Planting dates | Seeding rate (kg/ha) | | Plant population (plants/ha) |
|---|---|---|---|
| Female ………… | | Row width ………cm | Female ………………….. |
| Male 1st ………… | Female ………… | Female in-row ………cm | Male 1st ………..……….. |
| Male 2nd ……….. | Male ……………. | Male in-row ………cm | Male 2nd ………………..... |

| Top dressings | Date | Female | Male 1st | Male 2nd |
|---|---|---|---|---|
| | Type | | | |
| | Rate/ha | | | |

Weed control
Dates …………………………………………………………
Methods …………………………………………………………

Pest and disease control
Dates …………………………………………………………
Chemical …………………………………………………………
Methods …………………………………………………………

| Inspections | Date | Date | Date | Date |
|---|---|---|---|---|
| | Name | Name | Name | Name |
| | Ref | Ref | Ref | Ref |

| | | | |
|---|---|---|---|
| Roguing | Date | | Date |
| Detasseling | Start date | End date | No. of laborers |
| Female flowering | 5% silks | 50% silks | 95% silks |
| Male 1 flowering | 5% pollen | 50% pollen | 95% pollen |
| Male 2 flowering | 5% pollen | 50% pollen | 95% pollen |
| Male destruction date | | | |

| | | | | | |
|---|---|---|---|---|---|
| Harvest date | | Total yield from field | | Yield (kg/ha) | |
| Delivery dates | | | | | |
| Observations | | | | | |

**Annex 3. Conversion factors.**

**Area**

| | |
|---|---|
| 1 ha | = 2.47 acres |
| 1 acre | = 0.405 ha |
| 1 $m^2$ | = 10.76 square feet |
| 1 ha | = 10,000 $m^2$ |

**Volume**

| | |
|---|---|
| 1 $m^3$ | = 1,000 L |
| 1 L | = 2.11 pints |
| 1 $m^3$ | = 35.3 cubic feet |

**Mass**

| | |
|---|---|
| 1 t | = 1,000 kg |
| 1 kg | = 2,205 lbs |
| 1 t | = 36.74 bushels for 60 lbs of wheat or soybean |
| 1 t | = 39.37 bushels for 56 lbs of maize or sorghum |
| 1 bushel | = 25.4 kg for maize |

**Yield**

| | |
|---|---|
| 1 t/ha | = 893 lbs per acre |
| 1 t/ha | = 15.93 bushels per acre (56 lbs bushel = maize and sorghum) |

**Temperature**

| | |
|---|---|
| Celsius to Fahrenheit: | ˚F = 1.8 x (˚C) + 32 |
| Fahrenheit to Celsius: | ˚C = 0.556 x (˚F) – 32 |

**Pressure**

| | |
|---|---|
| 1 Mega Pascal (MPa) | = 9.9 atmosphere(s) |
| 1 Mega Pascal (MPa) | = 1 bar |

**Water measurement**

| | |
|---|---|
| 1 $m^3$ per second | = 35.32 cusec |
| 1 $m^3$ per hour | = 0.01 cusec |
| 1 cusec | = 28.3 L per second |
| 1 L per second | = 0.035 cusec |

**Concentrations**

| | |
|---|---|
| 1 g per kg | = 0.1% |
| 1 mg per kg | = 1 ppm |

**Densities**

| | |
|---|---|
| Maize grain | 750 kg/$m^3$ |
| Maize on cob (dehusked) | 480 kg/$m^3$ (80% grain) |

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ISBN: 978-607-8263-26-4