MINISTRY OF
FOOD & AGRICULTURE
REPUBLIC OF GHANA

HYBRID MAIZE SEED PRODUCTION

MANUAL

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FOREWORD

Improved seed is an input in crop production system to obtain higher yield, tolerate pest and disease incidence, adapt to climate change and improve nutrition. Improved seed determines the efficiency of all other inputs of crop production since a significant contribution to productivity is gained solely from the seed used. Knowledge of this has popularized the use of hybrid seed in modern agriculture.

Owing to the advantages of the state-of-the-art technology delivered by hybrid varieties over Open-Pollinated Varieties (OPVs), farmers in Ghana are gradually shifting from OPVs to Hybrids as exhibited by maize farmers under the "Planting for Food and Jobs" Campaign. This new development, coupled with the importation of hybrid maize seed due to its limited production in Ghana, has necessitated the compilation of this hybrid maize seed production manual which will serve as a guide for maize seed producers to successfully produce quality hybrid maize seeds for farmers.

This hybrid maize seed production manual is designed to provide guidelines on the production of different types of hybrid maize seeds. It is also hoped that this manual will contribute modestly to the goal of entrenching and increasing hybrid seed production in Ghana.

The lead author of this manual, Professor Richard Akromah, is a lecturer at the Kwame Nkrumah University of Science and Technology. Professor Akromah has many years' experience in Research and Plant Breeding and has offered training to Plant Breeding experts in-country and outside the country. Due to his vast experience, he has been consulted on many occasions by both national and international organizations for important agricultural development works. In compiling this manual, he sought expert opinion from wide range of seed sector stakeholders which include; Seed producers, Researchers, Agriculturists, Extension officers and seed marketers/traders and other actors of the seed value chain to enrich the document.

May I seize this moment to commend the author and all the experts whose opinion were sought to compile this manual. Our sincere gratitude goes to the Food and Agriculture Organization of the United Nations for their technical support in the preparation of this manual.

It is expected that our diligent seed producers and all other stakeholders along the maize seed value chain would utilize the information in this manual to enhance hybrid maize seed production in Ghana.

SETH OSEI-AKOTO
DIRECTOR OF CROP SERVICES

LIST OF ABBREVIATIONS

AEAs	Agricultural Extension Agents
BP	Better Parent
BPH	Better Parent Heterosis
DAES	Directorate of Agricultural Extension Services
DCS	Directorate of Crop Services
DUS	Distinctness, Uniformity and Stability
F1	First Offspring
FAO	Food and Agriculture Organization of the United Nations
GCA	General Combining Ability
KNUST	Kwame Nkrumah University of Science and Technology
LGB	Larger Grain Borer
MC	Moisture Content
MoFA	Ministry of Food and Agriculture
MP	Mid Parent
NASTAG	National Seed Trade Association of Ghana
NSC	National Seed Council
NVRRC	National Varietal Release and Registration Committee
OPVs	Open-Pollinated Varieties
RH	Relative Humidity
SCA	Specific Combining Ability
SRI	Soil Research Institute
UG-WACCI	University of Ghana-West Africa Centre for Crop Improvement
UN	United Nations
VCU	Value for Cultivation and Use

1.0 General Introduction

Farmers need hybrid seeds with high yield potential and unique gene combinations to withstand diseases and hostile environmental conditions. Nonetheless, the field production methods of a hybrid seed determine its quality, which must adhere to both quality assurance standards and proper agronomic management practices. Whereas production of open pollinated seeds from maize is comparatively straightforward, production of hybrid seed requires extra skills that are indispensable to the success of producing hybrids.

Production of maize hybrid seed is a deliberate act to cross the population of the female parent with a male parent in an isolated field. Thus, from the outset, the identity and arrangement of the female and male parental lines in the field would determine the outcome of hybrid seed production. Each hybrid variety consists of a specific combination of a female (seed bearing) and male (pollen providing) parents. The management of the field containing the two parents is very pertinent and needs attention to timing of planting, detasseling of the females before anthesis and pollen shedding, off-types elimination, separate harvesting of the female seed and careful shelling and processing of the seed to maintain seed quality and purity. The processes of producing hybrid maize seeds are sequential and dependent, implying that any mistake made at the early stages will have significant impact on subsequent stages. Such avoidable errors could result in a total rejection of seeds by inspectors or total failure of the crop.

From April to July 2019, the Ghana Office of the Food and Agriculture Organization of the United Nations, through a Technical Cooperation Programme, collaborated with the Ministry of Food and Agriculture and engaged KNUST to train selected Seed Companies on Hybrid Maize Seed Production. This Manual is in response to a request by the participants of the Workshop for a Production Manual that provides special management skills for producing high quality hybrid seed and contains basic information on choosing the right parents, site selection, setting planting ratios of male and female parents, synchronization of flowering, detasseling, rogueing, harvesting and post-harvest operations for growers to produce high quality hybrid seeds to farmers for increased productivity. The current manual also provides valuable insights into how seed companies could develop their own inbred lines for commercial purposes.

1.1 What is Hybrid Maize?

Hybrid maize is an F1 generation (first offspring) resulting from crossing of two or more genetically different parents. The female plant bears the hybrid (F1) seed and it is called the female or seed parent, whereas the pollen parent or the male plant is the plant that provides the pollen to fertilize the female. Maize has separate male and female plant parts and it is relatively easy to make a cross between two plants. In producing hybrid seeds on the 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. Detasseling of the female plant is done before pollen is shed, so that the tassel on the male plants would be the only source of pollen for the female flower (the cob or the ear) on the female plants. It is necessary to remove the tassels of the female to prevent self-pollination of the female plant. If this occurs, which is referred to as "female-selfing", the result is a significant loss of seed quality that will clearly be visible in a crop grown from the seed. Female-selfing is to be avoided at all costs. The number of female rows in proportion to male rows in the field is usually on the order of 3:1 for single-crosses and three-ways but may increase to 8:1 for double-cross hybrids. Number of factors account for the actual ratio that are planted, but mostly on the quantity of pollen produced by the male parent. After a successful cross pollination and fertilization, the seed harvested from the female parent is the hybrid seed that contains a unique heterozygous genotype and the ensuing plant produced from the hybrid seed will have desirable characteristics of both parents. Plant breeders (or Seed Companies) develop parental lines of each hybrid to produce an offspring with unique and particular characteristics, which includes drought tolerance, heat stress tolerance, grain color, disease resistance, plant maturity, food processing quality and higher yield. It is this special hybrid seed that are being sown by farmers in their fields.

Maize hybrids can be classified into two broad categories:

Conventional hybrids: Obtained by crossing two or more genetically different inbred lines. Examples are Single Single-cross, three-way and double-cross hybrids are the most common types of maize hybrids. 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. Examples are single cross, three-way cross and double cross hybrids as shown in Figure 1.

Single cross hybrid: A × B = F_1
Three-way cross hybrid: (A × B) × C = F_1
Double cross hybrid: (A × B) × (C × D) = F_1

Figure 1. Common types of conventional hybrids in maize

***Non-conventional hybrids*:** At least one parent is not an inbred line. Example, variety cross, top cross and double top cross hybrids. 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.

1.2 Hybrid Composition

Inbred lines are the basic building blocks of hybrid maize. Inbred lines are developed from the repeated self-pollination of particular maize populations to produce a plant that essentially has a fixed and uniform genetic composition. Subsequently, all inbred lines of a particular plant are indistinguishable, yet each inbred line will vary in its genetic composition from other inbred lines. Because maize is normally cross-pollinated, repeated self-pollination results in inbreeding depression; thus, inbred lines are usually smaller, less vigorous and lower-yielding than open-pollinated maize plants. But, when two genetically dissimilar inbred lines are crossed, a hybrid seed is formed, which produces plants with restored vigor and a significantly higher yield than either of the two parents. This hybrid superiority is known as "hybrid vigor," and it is this vigor that is exploited in hybrids and makes hybrid varieties useful to farmers.

1.3. What is Heterosis (Hybrid Vigor)?

Hybrid maize is based on the principle of heterosis (hybrid vigor) in plant breeding. It is the superiority in performance of hybrid individuals compared with their parents (Figure 2). The occurrence of heterosis is common in plant species, but its level of expression is highly variable.

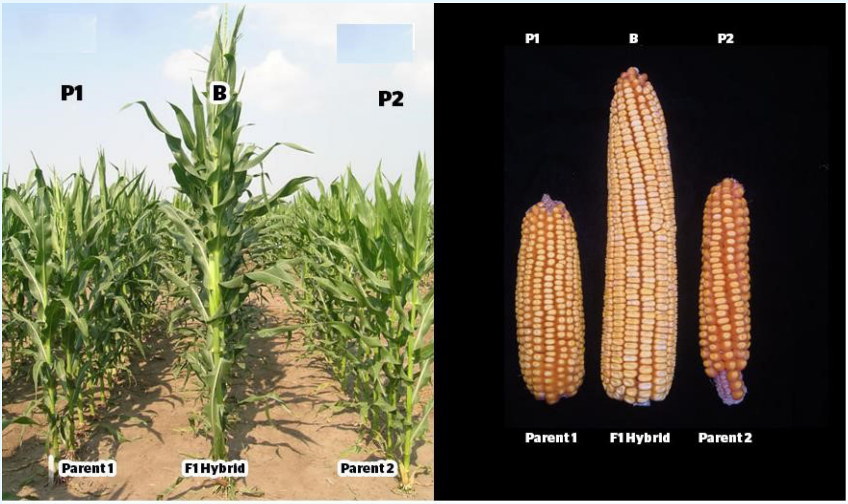


Figure 2. Hybrid vigor in maize. F1 hybrid (middle) which has a superior performance compared with the parents (on either side)

Heterosis can either be expressed as percent increase or decrease in hybrid (F1) performance over mid-parental (MP) value:

$$Mid\ parent\ heterosis = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100\%$$

or better parent (BP) value:

$$Better\ parent\ heterosis = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100\%$$

Where, $\overline{F1}$ = Mean of F1 hybrid, MP = mid-parent value

$\text{Mid Parent (MP)} = \frac{\overline{P1+P2}}{2}$, $\overline{BP}$ = Mean performance of better parent

Table 1. Estimation of hybrid superiority in grain yield over its inbred parents.

Grain yield (t/ha)						
Lines	A	B	C	A/B	A/C	B/C
Yield	1.5	1	1.4	4	6	5
Heterosis estimates						
	MP (t/ha)		MPH (%)		BPH (%)	
A/B	1.25		220		166.7	
A/C	1.45		313.8		300.0	
B/C	1.20		316.7		257.1	

Some estimations of heterosis have been provided in the Table 1.

1.4. Hybrid Cultivars

Hybrid vigor is highest at the F1 and declines in subsequent generations upon self-pollination due to a reduction in heterozygosity. Thus, as the number of heterozygous genotypes decreases in a seed lot, the amount of heterosis expressed would decrease, as a result of inbreeding depression. The amount of vigor expressed is also contingent on the type of hybrid seed produced and the level of uniformity among F1 materials constituting the hybrid seed lot. Hybrid vigor, thus, decreases in order of magnitude from single cross hybrids > three-way cross hybrids > double-cross hybrids etc. However, in terms of hybrid seed yield, synthesizing a double-cross hybrid yields the highest quantity of hybrid seeds followed by three-ways cross hybrids, and single cross hybrids. Thus, regarding cost of hybrid seeds, single cross hybrid seeds are the highest and double-cross hybrid seeds command the lowest cost.

For hybrid seeds, farmers are advised not to save seeds from previous season's harvest for replanting to prevent a decline in hybrid vigor expression. This advice is strongly recommended because, when a hybrid seed is grown and it in turn sets seeds upon maturing on farmers' fields, the harvest from the hybrid field would be a heterogeneous mixture of different genotypes of seeds. Since a hybrid plant is chiefly heterozygous in genotype, upon self or cross pollination, it would segregate into other genotypes, comprising both homozygotes and heterozygotes. The presence of the homozygous genotypes in the harvested seeds from a hybrid plant would cause inbreeding depression in the ensuing plants when planted, and one cannot phenotypically identify true hybrid seeds from the harvest. It is, therefore, advisable for farmers to buy true hybrid seeds for each season's planting from certified sources in order to derive the full benefits of hybrid seed technology.

2.0 Line Development for a Hybrid Seed Production

The success of hybrid seed technology depends on the availability of inbred lines possessing the desirable attributes of the hybrid cultivar based on the expected product profile or target. Inbreds are developed using conventional methods of repeated selfing of a derived F1 between two or more parents or using modern techniques such as **doubled haploid technology**.

Doubled haploid technology helps to rapidly produce inbred lines within a relatively short time compared with repeated selfing of derived F1.

After line development, the next important step is to evaluate the developed lines to ascertain their performance in hybrid combinations with known **testers** (Figure 3). Table 2 shows a guide for developing inbred lines for a small commercial maize breeding program for hybrid maize.

A tester is another inbred line which serves as a partner for testing derived inbred lines in hybrid combinations.

This evaluation exercise enables the identification of lines that show the highest combining abilities or heterosis for grain yield across the target markets. Of utmost importance in hybrid seed technology, is the categorization of derived inbred lines into **heterotic groups** as well as **heterotic patterns.**

A heterotic group is defined as "a group of related or unrelated genotypes from the same or different populations, which display similar combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm groups" (Melchinger and Gumber 1998). A heterotic pattern, on the other hand, refers to a specific pair of two heterotic groups, which express high heterosis and consequently high hybrid performance in their cross.

Classifying lines into heterotic groups would prevent the development and evaluation of crosses that should be discarded, allowing maximum heterosis to be exploited by crossing inbred lines belonging to different heterotic groups.

Inbred line development as shown in Table 2, and the determination of heterotic groups and patterns take time depending on the method adopted and must be done by an expert.

There are two types of combining abilities that are usually estimated from testcross evaluations; namely: **the general and specific combining abilities**.

The general combining ability (GCA) measures the mean performance of an inbred line when it is crossed with a series of other inbreds or testers. Whereas, the specific combining ability (SCA) is due to genetic effects that are specific to a hybrid combination and that are not accounted for by the GCA effects of its parents.

A specific pair of inbred lines that show high heterosis would equally exhibit high SCA. Tables 3 and 4 show the estimation of GCA and SCA for four inbred lines (A – D) using three testers (E –F).

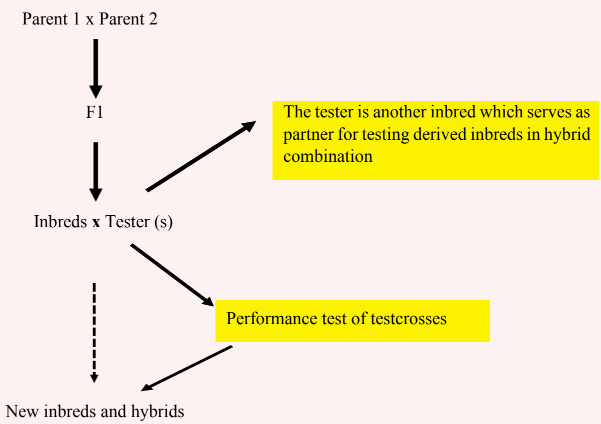


Figure 3. Line development for hybrid seed production

Table 2. A guide for inbred line development for a small commercial breeding program for hybrid maize in Ghana.

Season	Activity
Major, Year 1	(1) Grow 40 F_2 or BC_1 populations (i.e., S_0 generation) that have been formed in previous years. (2) Cross 50 selected S_0 plants in each population to a haploid inducer^{++}.
Minor, Year 1	Double the chromosomes of putative haploids to create doubled haploids^{++}.
Major, Year 2	Self doubled haploids to increase seeds.
Minor, Year 2	(1) Discard about 25 % of the derived doubled haploids based on *per se* performance. (2) Cross each of the 1500 remaining doubled haploids to an appropriate inbred tester.
Major, Year 3	Yield trials of 1500 doubled-haploid testcrosses in unreplicated trials at 2 - 4 locations in the target area.
Minor, Year 3	(1) Select top 10 % of doubled haploids based on their testcross performance. (2) Cross 150 doubled haploids to 2 testers each.
Major, Year 4	Yield trials of 300 doubled-haploid testcrosses in unreplicated trials at 4 - 6 Locations in the target area.
Minor, Year 4	(1) Select top 10 % of doubled haploids based on their testcross performance. (2) Cross each doubled haploid to 3 elite inbreds or testers.
Major, Year 5	First replicated yield trials of experimental hybrids at 5 – 15 locations.

Minor, Year 5	(1) Second replicated yield trials of advanced hybrids at 5 - 20 locations. (2) On-farm tests (i.e., 50 - 150 m^2 plots) at 20 - 50 locations/sites.
Major, Year 6	On-farm tests of precommercial hybrids at 50-100 locations/sites.
Minor, Year 6	Release 0-2 new hybrids.

++: These activities should be outsourced to a commercial entity with the expertise to produce doubled haploid plants. On-farm tests could be done on farmers' fields. Minor season evaluations require irrigation facilities to supplement rainfall.

2.1. Cultivar Release, Seed Multiplication and Certification in Ghana

The ultimate goal of a commercial breeding program for hybrid maize is to release a hybrid variety with high yield and superior performance to existing cultivars (**commercial heterosis**). After rigorous testing of promising hybrid combinations in different environments (location/season/year) as depicted in Table 2, the seed company will select one or few hybrid combinations for release to the agricultural system for use. The new hybrid cultivar may be released for specific adaptation or broad adaptation in target areas. For a hybrid cultivar, the parental lines are the most precious assets to the seed company and must be protected.

One of the decisions during cultivar release is naming the new hybrid cultivar. The specific steps of cultivar release process vary among countries. In Ghana, there is the **National Varietal Release and Registration Committee** (NVRRC) under the **National Seed Council** (NSC).

A new cultivar submitted for release must satisfy **DUS/VCU** criteria. DUS stands for distinctness, uniformity and stability, while VCU means value for cultivation and use. For hybrids, the DUS/VCU criteria are applied to the parental lines.

Based on the reports of the evaluation, the NVRRC will recommend to the NSC to register the new variety in the national catalogue of species and varieties of cultivated crops.

After developing, naming, release and registering a new hybrid variety, the seed company must make the hybrid cultivar available for commercial multiplication for sale.

Seed multiplication is under the supervision of a certifying agency for compliance with genetic purity and identity of the original source.

The seed certification system is a legally sanctioned system to maintain quality of seeds during multiplication, post-harvest operations, and distribution. Thus, it is a quality assurance process.

Seed certification involves field inspection, seed quality tests, and pre/post-harvest quality checks of **pedigree seeds**.

"A pedigree seed is seed of a named cultivar that is produced under strict supervision of a certifying agency for compliance with genetic purity and identity of the original source."

It is the legal obligation of a commercial seed company to maintain the marketable form of a newly introduced hybrid cultivar, so that it can be released at intervals as needed in its authentic form for commercial multiplication. In Ghana, the following classes of pedigree seed is recognized during multiplication (Figure 4):

- **The pre-basic/breeder seed:** this class of seed is under the direct control of the developer of the cultivar. The developer assumes responsibility for maintaining the genetic constitution and purity of parental lines. The breeder seed has the highest level of genetic purity of any class of seeds. The breeder seed is used to establish foundation seed. Generally, farmers do not have access to the breeder seed. It is usually given a white with diagonal violet stripes tag for quick identification.

- **Foundation/basic seed:** this is the first generation increase or progenies of the breeder seed. Its genetic purity is close to the breeder seed and it can be used to directly produce certified seeds or through registered seeds. It is usually given a white tag for identification.

- **Registered seed:** it is produced directly from foundation seeds and serves as the source for certified seeds. It is normally grown by farmers under contract with a seed company. Registered seed may be commercially accessible to farmers for use. It is usually given a purple tag for identification.

- **Certified seed:** it can be produced directly from foundation seeds or through registered seeds. It is grown in isolated fields under legally prescribed conditions to satisfy the minimum genetic purity and identity of the cultivar. This class of seed is what usually goes on sale to farmers for commercial use.

Generally, as one moves from the breeder through to the certified seed category, there is exponential increase in seed quantity, but genetic purity decreases.

Figure 4. Classes of pedigree seed in Ghana's certification system.

2.2. Causes of loss of genetic purity during seed multiplication

During seed multiplication, genetic purity may be lost through one or a combination of the following reasons:

- Mechanical admixture
- Natural outcrossing due to pollen contamination from nearby fields
- Mutations
- Multiplying seeds of the variety in an area of non-adaptation

Preventive measures for ensuring high genetic purity include:

- Plant in isolation either by distance or by time. Isolation by either distance or time, should be considered because it prevents contamination by foreign pollen. Isolation by time is strongly recommended, hence, it is advisable to install irrigation facilities to augment precipitation. The **minimum isolation distance recommended is 400 meters for maize in Ghana.**
- Rogue out off-types.
- Plant in areas of crop adaptation.
- Enforce quality control measures (e.g. sanitation, cleaning of equipment).

2.3. Choosing the Right Parental Lines for Hybrid Seed Production

The success of a hybrid maize seed production system depends on the selection of the right inbred lines as parents. As explained above, parents are selected in hybrid maize seed production based on their combining abilities or heterotic responses. Inbred lines that have exhibited high hybrid vigor (better-parent and commercial heterosis) for grain yield and other important agronomic traits must be used as parental lines.

Table 3. GCA for maize grain yield (t/ha) in crosses between heterotic groups (Data from Bernardo, 2014)

Inbred	A	B	C	D	Mean	GCA
E	11.33	10.41	9.71	10.18	10.41	0.2
F	11.05	11.42	9.3	9.07	10.21	0
G	10.54	9.93	9.36	10.25	10.02	-0.19
Mean	10.97	10.59	9.46	9.83	**10.21**	
GCA	0.76	0.37	-0.76	-0.38		

GCA = $MP\ of\ inbred - \mu$; Where MP = mean of hybrid combination of an inbred; μ = overall mean (**10.21** t/ha) in Table 3. Eg. **For line B, its GCA = 10.59 - 10.21 = 0.37**. Similarly, **the GCA of line F = 10.21 - 10.21 = 0.**

Table 4. SCA for maize grain yield (t/ha) in crosses between heterotic groups (Data from Bernardo, 2014)

Inbred	A	B	C	D
E	0.16	-0.37	0.06	0.15
F	0.08	0.84	-0.15	-0.76
G	-0.24	-0.46	0.1	0.61

SCA = $HP - \mu - GCA_1 - GCA_2$; Where HP = hybrid performance; GCA_1 & GCA_2 = GCA of parent 1 & 2. Eg. For hybrid F/B, *HP* = 11.42, = 10.21, GCA of line F = 0, GCA of line B = 0.37 from Table 3, so its SCA is calculated as = **11.42 - 10.21 - 0 -0.37 = 0.84**

Based on the SCA estimates in Table 4, it could be seen that inbred line B, and tester F would make a very good pair for hybrid seed production.

Parental lines usually have specific distinguishable morphological characteristics that help to easily identify them in the field. Common distinguishable features include anthocyanin pigmentation in the stem or other parts of the plant as depicted in Figure 5.

Figure 5. Pictorial Identification of Parents. Adapted from Ethiopian Seed Association (2014).

3.0. Field Management Operations for Maize Hybrid Seed Production

Achieving reasonable seed yields on seed plots after choosing the right parents requires paying critical attention to good plant production, protection and post-production management practices. These management operations include:

- Appropriate **site selection**
- Adequate **land preparation**
- Planting **high quality seeds** of parental lines
- Setting the right planting ratio of male and female plants
- Synchronization of flowering
- **Ensuring good soil nutrient** and water management practices
- **Post-planting measures** against weeds, pests and diseases.
- **Detasseling** of female lines in the field before pollen shedding
- **Roguing** of off types to ensure genetic purity
- **Timely harvesting** and post-harvest operations such as shelling, cleaning, sorting, drying, storage and packaging.

3.1. Site Selection

In hybrid seed production, the best field on the farm should be utilized. The important factors that must be considered include the following:

- Choose land with deep well drained loamy soils.
- Avoid planting maize in shady areas.
- Choose gently sloping to nearly flat upland. Low-lying valley bottoms are usually poorly drained and easily get waterlogged; thus, reducing yield.

- Where possible, choose land that has not been cropped to cereals in the previous year. It will help to reduce carry-over of diseases. Avoid planting in fields that were previously sown to maize, for at least one year.

- Moisture and fertility status of selected site must be known.

- It is also desirable to avoid areas with significant movement of people and animals.

- Choose sites with accessible roads to facilitate the delivery of inputs, inspection and the transport of the harvested seed to processing centre/ customers.

- The size of the field must be known due to the time pressure for detasseling in hybrid seed fields. A maximum field size of 1 to 4 ha should be planted at one time, depending on labor availability. Blocks of about 1 ha are most manageable for detasseling and quality assurance. Larger fields may not allow efficient detasseling. However, smaller fields may increase the risk of foreign pollen contamination.

- Field map, in establishing the size of the field, plays a major role in determining isolation distances and for future records.

- Registration of the seed crop: normally seed regulation authorities require seed fields to be registered within a short time of establishment. Ensure that this is done.

3.2. Land Preparation

Land should be ready for planting two weeks in advance in order to allow weed seeds to germinate; it is the first stage of weed control. Off-type plants could easily be identified and rogued out upon re-emergence. Land can be adequately prepared manually or mechanically.

Manual land preparation involves the following operations:

- Slashing bushy weedy fields

- Removal of stumps of shrubs (where possible) to facilitate ploughing

- In some areas (particularly the Guinea savanna zone), hoeing to loosen the soil is done before planting.

Mechanical land preparation requires the use of a tractor or animal traction.

- Slash weedy field before ploughing (do not burn).
  - If previous crop was a legume and vegetation is not thick, plough in the biomass.
  - Plough and harrow to break soil lumps. Sometimes two ploughings may be necessary.
  - Plough across the slope if the field is not level. You can practice contour farming, if the need arises.

Zero/No tillage involves the use of herbicides. Glyphosate has been the herbicide of choice and is applied at the rate of 3 - 4 litres per ha.

- Leave sprayed area for about five days after applying glyphosate.
- Plant into stubble (clear by parting vegetation) i.e. vegetation along planting line.
- Reduce dry vegetation by controlled or cold burning, or physical removal of vegetation from field.

3.3. Plant Establishment

Good seed material is the basic input for increasing seed yield and income. It ensures varietal purity and high crop productivity. Irrespective of cultural practice, poor seed will result in:

- Poor germination
- Poor crop establishment
- Poor plant vigor
- Carry over of diseases and pests
- Low seed yields.

The following are important factors to consider for healthy plant establishment in the field:

3.3.1. Seeding Rate and Germination Tests

A seed rate of about 25 kg/ha is required, but this depends on the seed size and whether it is a female or male line. 10 kg is enough to plant 1 acre and 5 kg for half an acre for female lines. Small seed sizes can give equal germination and yield performance as large seeds. However, small seed should not be planted too deep (i.e., not deeper than 5 cm).

Before planting your seeds, it is good to conduct germination test (10 days before planting) to prevent poor plant stand establishment due to poor quality seeds. To conduct your germination test, follow the steps below:

- Take 100 seeds at random.
- Make a shallow trench of 1-2m long.
- Place seeds evenly in the shallow trench.
- Cover with 3 -5 cm soil and water well for one week but do not soak the soil.
- Observe regularly and water when necessary.
- Count the number of plants emerged after 7 days.

Table 5 shows the number of seeds to plant per hill based on the results of the germination test.

Table 5. Recommended seeding rate after germination tests.

Number of plants counted per 100 seeds	Number of seeds to be planted per hill
85 or more	1 or 2 seeds per hole
70 - 84	3 seeds per hole
50 - 70	Get better seeds
Less than 50	Do not attempt planting, get better seed

3.3.2. Planting Date/Time Based on Agro-Ecological Zone

Ghana has five main agro-ecological zones based on differences in climate, natural vegetation and soil type. These are Rain Forest (Moist and Wet Evergreen), Deciduous Forest, Transitional Zone, Coastal Savanna and Northern Savannah (Guinea and Sudan Savannah) zones (Figure 6).

Figure 6. Main agro-ecological zones of Ghana.

The later maize is planted, the lower the yield under rain-fed conditions. Suggested planting dates based on the major agro-ecological zones in Ghana have been provided in Table 6.

> **In order to practice isolation by time, hybrid seed producers can plant 3 - 4 weeks earlier or later than the suggested dates in Table 6, provided there is an irrigation facility installed at the seed production site.**

Table 6. Suggested planting dates for maize in Ghana.

Agro-ecological zone	Which month to plant	Remarks
Major Season		
Sudan savannah	End-May to early-July	Plant in July through early August after rains have established good soil moisture
Guinea savannah	End-May to end-June	
Transition	Mid-March to end-April	Plant in early March through the third week of March after rains have established good soil moisture (3 rains in a week)
Forest	Early-March to end-April	
Coastal savannah	End-March to End-April	
Minor season		
Transition	Mid-July to early-September	Plant third week of August through the end of September after rains have established good soil moisture (3 rains in a week)
Forest	Mid-July to early-September	

3.3.3. Spacing and Plant Population

The optimum planting density of maize should be adjusted according to local conditions and types of parental lines to be grown. Planting should be done in lines or rows. Ropes or sighting poles should be used to mark the beginning and end of rows to enable you to plant in lines. You will need a minimum of 3 poles of at least 2 meters long for this task. The more poles you use, the straighter your rows will be. Place one at each end of where the first row is to be and the others in between but in line with the two end poles. Seeding rates depend on soil-fertility levels, plant spacing and expected germination rates.

The width of rows and the spacing of plants within the row determines the plant population (Figure 7). The closer the spacing, the more plants there will be per unit area. The recommended number of maize plants per hectare varies from 36,000 to 60,000, depending on the environmental yield potential and parental lines planted.

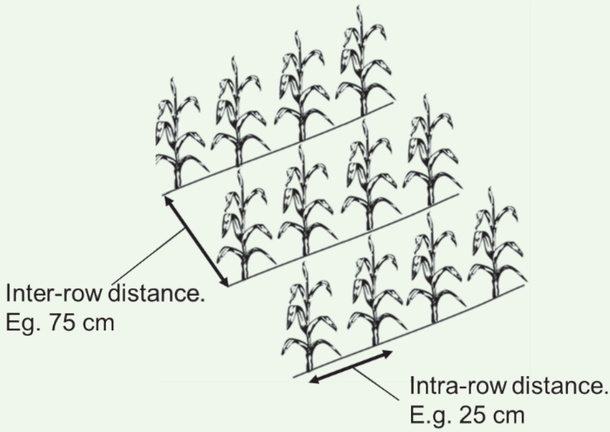


Figure 7. Planting maize in lines at a given inter and intra row spacing.

> **High plant populations are appropriate under high rainfall or irrigated conditions where management is of a good standard.**
>
> **Lower plant populations should be used under dryland conditions, especially in drought prone areas, where a population of about 37,000 to 40,000 plants per hectare is recommended.**

Some female parental lines may be susceptible to lodging under high plant populations. Generally, the taller the parental line, the lower should be the plant population. Short parental lines may be grown at higher plant populations. Whatever the case, the minimum plant population for maize is 36,000 plants per ha. Exceeding the optimal plant population density could have a deleterious effect on maize yields (Figure 8).

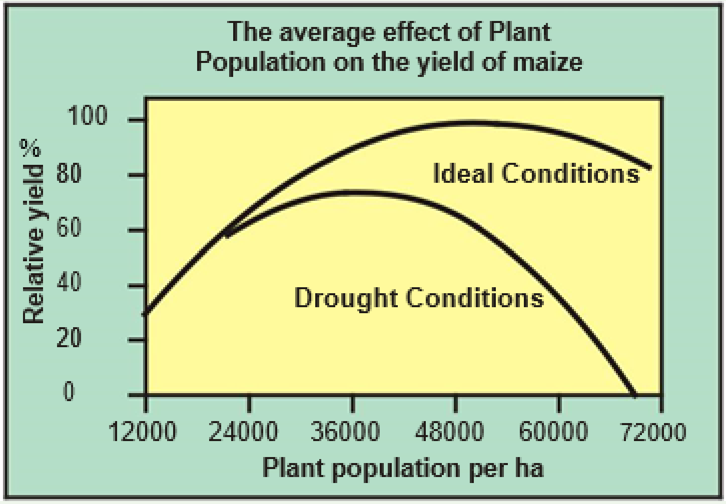


Figure 8. Effect of plant population on the yield of maize.

3.3.4. Planting the Right Female: Male Ratio

One of the most important stages in production of hybrid seed is the establishment of the crop and the female: male ratio set. In hybrid seed production, the female lines are the seed bearers, whiles the male lines' sole purpose is to provide pollen to fertilize the female lines. Thus, the two parent lines cannot have the same number of plants in the field. A balanced female to male plant ratio in the field is therefore of utmost importance.

Setting the right female to male plant ratio involves planting the seed production field to a larger number of the female plants, while at the same time providing an adequate amount of pollen pressure for good seed set in the female lines.

The following points are critical, and it should be well noted in order to set the right female to male plant ratio in the field:

- Ensure the correct parents are assigned to the seed field and that the female and male seed is clearly identifiable.

- Seeding rate depends on female to male ratio. Normally, 3:1 or 6:2 female to male ratio is recommended (i.e. three (3) rows of female parent to one (1) row of male parent) (Figures 9 and 10).

- Spacing should be similar to commercially grown plants thus, 75 cm x 20/25 cm recommended for the female parent (i.e. 53,300 –66,600 plants/ha). Some common recommended spacing is shown in Table 7.

Table 7. Common low and high plant population densities and their planting distances for maize.

Distance between plants/ cm	Distance between rows/ cm	Plant population/ acre	Plant population/ hectare
40	80	12,500	31,250
40	75	13,300	33,300
30	90	14,800	37,000
25	75	21,333	53,333

Plant population per acre or hectare was calculated by assuming one seed per hill. Figures in Table 7 would double if two seeds per hill were used.

- Male parent could be planted at a slightly higher population density to increase the pollen pressure or if the amount of pollen produced is small.

- Avoid mixing seeds for female and male inbred parents – use dyes or colored bags to label seeds for female and male parents.

- Male parent should be planted as border rows to serve as guard rows and for abundant pollen production.

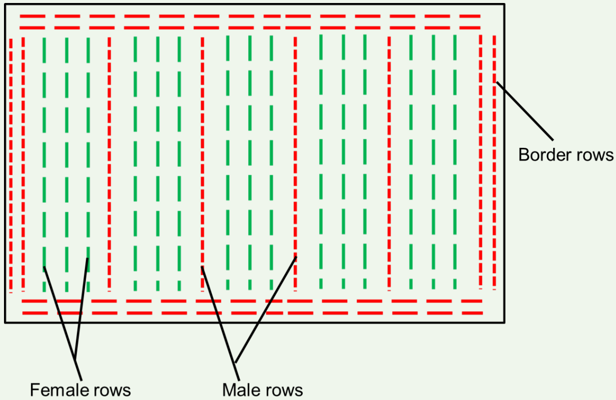


Figure 9. Setting a 3:1 female to male plants ratio in a hybrid maize seed field. Green lines depict female plant rows, whereas red lines represent male plant rows.

Figure 10. Common female to male planting ratio on the field.

3.4. Synchronization of flowering

Obtaining good seed set on the female plants requires an ample overlap in the silking time of the female plants and the anthesis (pollen-shedding) time of the male plants. Thus, synchrony in silking and tasseling between female and male parents is very essential to obtain good seed set.

If the female and male lines differ significantly in their silking and tasseling times by more than 5 days, planting should be staggered during plant establishment for the two parental lines.

Preferably, the male plants should start shedding pollen when the first female silks start showing up and they should shed pollen for whatever length of time that it takes for all the female silks to develop. Notwithstanding, it does not take the same time for male and female plants to reach flowering, because of different growth rate and variations in the environment. Besides, the length of pollen shedding might be shorter than the ideal time for females to reach full silk at emergence. Any confounding of male and female flowering will decrease yields and uncover the female seed parent to contamination from foreign pollen.

Assuming 50% of the male line tassels in 55 days after planting and 50% of the female line silks 63 days after planting, there would be an eight-day gap between silking and tasseling in the field. This flowering interval could greatly affect seed set if the silking and tasseling times are not synchronized. To synchronize the silking and tasseling time using the above example, the female line should be planted at least five days earlier but not later than eight days before the male line is seeded.

3.5. Fertilizer and Irrigation Requirements

3.5.1. Fertilizer Requirements

Maize can be grown successfully on soils with a pH of 5.0 - 7.0 but a moderately acid environment of pH 6.0 - 7.0 is optimum. pH outside this range could result in nutrient deficiency due to unavailability of nutrients, and sometimes mineral toxicity. Normal ear on a well fertilized high-yielding maize weighs about 300g and it has well filled tips. Small ears usually are a sign of low fertility. For better seed yields, amend soil with fertilizers. The three most important nutrient elements for maize are nitrogen, phosphorous, and potassium, but maize on some soils need zinc or boron in trace quantities.

Potash shortage shows up in ears with poorly filled tips and loose chaffy kernels. Phosphate shortages interfere with pollination and kernel fill. Ears are small, often twisted and with undeveloped kernels. Nitrogen is essential throughout the growing season. If plant runs out of nitrogen at the grain filling stage, ears become small with low kernel protein content. Green silks at maturity may be caused by too much nitrogen in relation to other elements. Young maize leaves become marked with reddish-purple colors under phosphorus deficiency (Figure 11 B). Potash deficiency appears as a firing or drying along the tips and edges of lowest leaves (Figure 11 D). Nitrogen deficiency causes yellowing of leaves and severe stunting (Figure 11 A). Magnesium deficiency causes whitish strips along the veins and often a purplish color on the underside of the lower leaves (Figure 11 C).

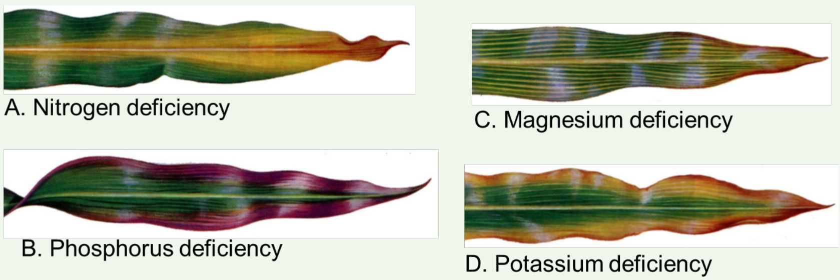


Figure 11. Maize leaves expressing signs of major nutrient deficiency.

3.5.2. Soil Testing

Before planting, take soil samples from the seed production site to the Soil Research Institute or University Laboratories for chemical analysis to know the pH, Nitrogen, Phosphorus, Potassium, percentage Organic Matter, Cation Exchange Capacity and other chemical properties. This information is required to help you formulate a fertilization program for maximum yields.

Follow the procedure described below to collect soil samples for chemical analysis:

1. Divide the field into different homogenous sampling units based on the visual observation and farmer's experience.

2. Remove the surface litter at the sampling spot.

3. Drive the auger to a plough depth of 15 cm and draw the soil sample. A sampling tool should be uncontaminated; approximately uniform in cross section to the desired depth; and provide reproducible sampling units (Figure 12).

4. Collect at least 10 to 15 samples from each sampling unit and place in a bucket or tray.

5. If auger is not available, make a 'V' shaped cut to a depth of 15 cm in the sampling spot using spade (Figure 13).

6. Remove thick slices of soil from top to bottom of exposed face of the 'V' shaped cut and place in a clean container.

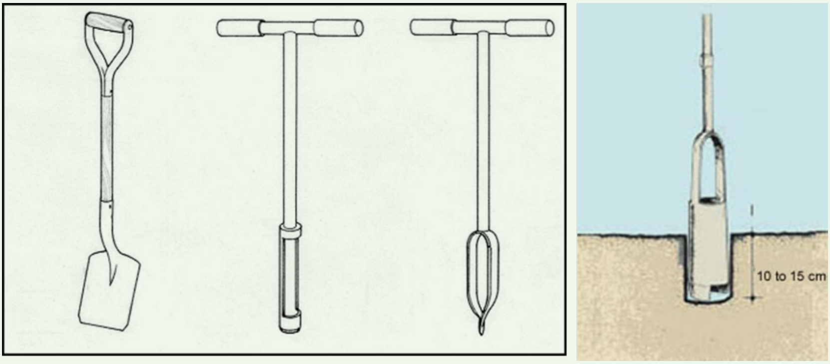


Figure 12. Soil sampling tools showing a spade and an auger.

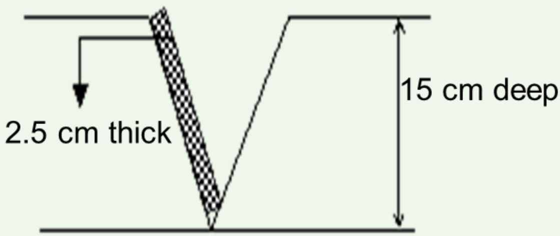


Figure 13. A v-shaped cut made with a spade to collect soil samples.

7. Mix the samples thoroughly and remove foreign materials like roots, stones, pebbles and gravels.

8. Reduce the bulk to about half to one kilogram by quartering or compartmentalization.

9. Quartering is done by dividing the thoroughly mixed sample into four equal parts. The two opposite quarters are discarded, and the remaining two quarters are remixed and the process repeated until the desired sample size is obtained.

10. Compartmentalization is done by uniformly spreading the soil over a clean hard surface and dividing into smaller compartments by drawing lines along and across the length and breadth. From each compartment a pinch of soil is collected. This process is repeated till the desired quantity of sample is obtained.

11. Collect the sample in a clean cloth or polythene bag.

12. Label the bag with information such as name of the seed company, location of the farm, survey number, previous crop grown, present crop, crop to be grown in the next season, date of collection, name of the sampler etc.

13. Send collected samples to an accredited lab for analysis.

3.5.3. Types of Fertilizers

The first consideration for fertilizing maize is the use of organic manure -- it is an excellent source of nutrients and has many other benefits for soils. Inorganic fertilizers should be considered as a supplement to manure if readily available. The addition of manure and ash will greatly improve the response of maize to the applied fertilizer. Under commercial set ups, addition of lime to acidic soils also improve response to fertilizers.

The fertilizer requirements of maize depend on the native soil fertility and seed yield target. Infertile soils require more fertilizer, as does a higher yield target.

Have your farm soil tested to know its fertility status and pH levels as described above. By doing this, you will be informed about the additional amount of fertilizer needed to meet target yields.

The number of bags of each fertilizer needed per hectare depends on the amount of N, P and K contained in the grade of fertilizer you purchase. Each ton of grain produced removes 15.0 to 18.0 kg of nitrogen, 2.5 to 3.0 kg of phosphorus and 3.0 to 4.0 kg of potassium from the soil.

Generally, apply fertilizers /organic manures under rain fed conditions as follows:

- Three (3) 50kg bags of NPK with micro nutrients
    - 25-10-10+6S+3MgO+0.3Zn or 20-10-10+3S or 23-10-5+2MgO+3S+0.3Zn for all agro-ecologies
    - 11-22-21+5S+0.7Zn+0.5B for Guinea Savannah & Forest Transition
    - 15-20-20+0.7Zn for Forest-Savannah Transition & Guinea Savannah
- at first two weeks, and one (1) 50kg bag of Urea (46 % N) per acre at 4 or 5 weeks after planting (i.e. prior to flowering) respectively.
- Spread 0.8 – 1.6 tonnes/acre (20 bags each weighing 50 kg) poultry manure over the field and work into the soil before planting.
- Spread 2.5 tonnes/acre (48 bags each weighing 50 kg) good quality compost over the field and work into the soil before planting.
- N fertilizers levelled up to 120 kg/ha are recommended for application in degraded soils. 60 kg P_2O_5 and 60 kg K_2O per hectare can also be applied.
- Green manuring can also be practiced. Plant mucuna at a spacing of 60 cm x 40 cm as a pre-maize cover legume in major season and harrow it into the soil after 3 months, before planting maize in minor season.
- Nitrogen easily leaches through the soil including sandy soils, therefore, the total amount of nitrogen fertilizer required should be split between two in-crop using the split top-dressing applications to ensure nitrogen availability throughout the critical growth stages of the crop for improved yields. In most cases, all the P and K and about two-thirds of the N are applied basally, with the rest of the N top-dressed later.

3.5.4. Modes of Fertilizer Application

Broadcasting of fertilizer to maize crop is wasteful and usually not recommended. Recommended method of fertilizer application to maize is the localized methods as shown below.

- **Localized placement** – with special reference to the seed or plant. This method requires more labor.

- **Band placement** - fertilizer is placed in bands to one or both sides of the seed or plant. This is usually done in a definite space relationship to the plant or seed – usually 2-3 inches (5 – 7 cm) to the side and 2 inches (5cm) below the seed or plant (Figure 14).

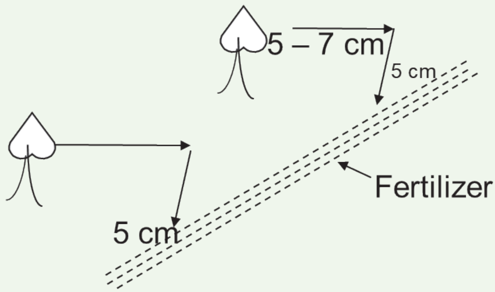


Figure 14. Band placement of fertilizer to plants.

- **Ring placement** – fertilizer is place as a ring around each plant stand at a definite distance from the plant.

- **Point placement** – fertilizer is place at single points about 5 cm away from each plant stand (Figure 15).

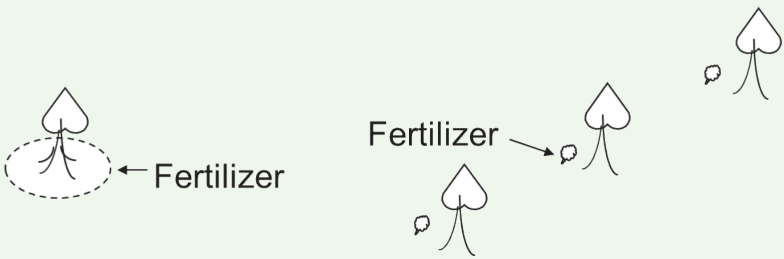


Figure 15. Ring and point placement of fertilizer to plants.

3.5.5. Time of Fertilizer Application

Fertilizer application should be carried out after weeding so that weeds do not benefit from applied fertilizers. Apply N-P-K compound fertilizer (60-60-60 kg/ha as

N, P_2O_5 and K_2O) within 7-10 days after planting and top-dress with 30 kg N/ha at 4-6 weeks after planting 4 weeks for early maturing lines or 6 weeks for intermediate to late maturing varieties. The basal fertilizer must be applied before or at the time of planting**.** Planting with basal fertilizer application is recommended at the same time. Basal fertilizers which contains zinc are recommended for application every two to three years on sandy soils. The eight-leaf stage is the correct stage to apply a fertilizer as side dressing. Weather conditions and residual N in the soil will also determine when most N should be applied.

3.5.6. Irrigation Requirements

Maize produces very high yields under irrigation. It is therefore one of the most efficient grain crops in terms of water utilization. It can produce from 80 to 100 tons/ha green material and 16 to 21 tons/ha of dry material within a relatively short period (100 to 120 days) under irrigation. It is strongly recommended that maize hybrid seed be produced under full irrigation in order to obtain the highest yields.

Maize grows best where total seasonal rainfall exceeds 500 mm. Maize is susceptible to both drought and waterlogging. Drought during the four-week period spanning flowering (silking and tasseling) can cause serious yield losses, especially in the drier areas (Figure 16).

Maize needs 500 to 800 mm of water per growing period, depending on the maturity period in the Forest and Transitional agro-ecological zones. In the Savannahs in the north, maize needs 600 – 900 mm of water per growing period.

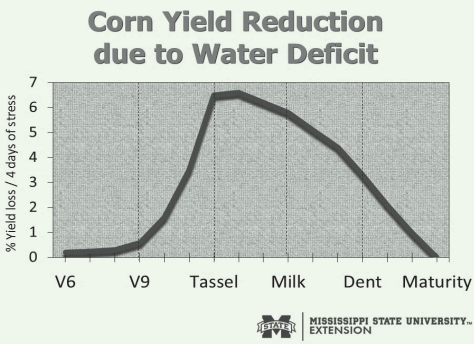


Figure 16. Maize yield reduction due to water deficit.

For a growing period of 90 – 120 days at a spacing of 75 cm x 25 cm, each maize plant would have used about 100 – 140 liters of water in the Forest and Transitional agro-ecological zones (equivalent to 6 mm of water per day). In the savannahs, the water requirements for maize would be 8 mm per day at a growing period of 90 -120 days and a spacing of 75 cm x 25 cm.

Border irrigation can also be used for maize, but furrow or sprinkler irrigation is best used for irrigating row crops such as maize (Figure 17). Table 8 shows some recommendations on the type of irrigation method to use based on the soil type and the net irrigation application.

Table 8. Selection of an irrigation method based on the depth of the net irrigation application.

Soil type	Rooting depth of the crop	Net irrigation depth per application (mm)	Irrigation method
Sand	shallow	20-30	short furrows
	medium	30-40	medium furrows, short borders
	deep	40-50	long furrows, medium borders, small basins
Loam	shallow	30-40	medium furrows, short borders
	medium	40-50	long furrows, medium borders, small basins
	deep	50-60	long borders, medium basins
Clay	shallow	40-50	long furrows, medium borders, small basins
	medium	50-60	long borders, medium basins
	deep	60-70	large basins

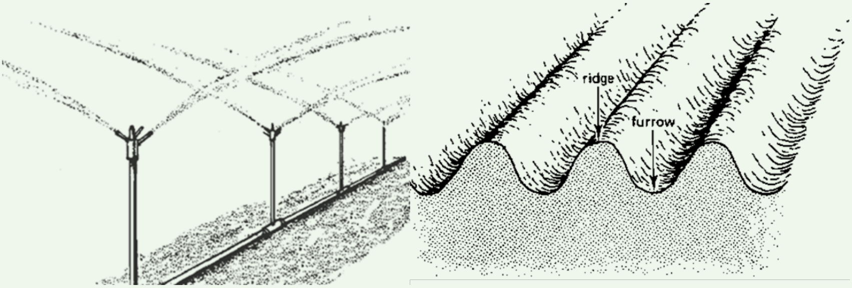


Figure 17. Sprinkler and furrow irrigation system for maize.

3.6. Weed Control

Weeds' presence would increase competition for nutrients and space with the maize crop therefore, effective weed control can be done mechanically, manually or chemically (using pre- and post-emergence herbicides). Control weeds, pests and diseases on time to avoid competition for plant nutrients.

Manual /Mechanical Weed Control

Weeds are removed or collected from crop fields by hand pulling or hoeing. For good manual weed control:

- Start hand weeding when weeds are large enough to grasp.
- Repeat the weeding once or twice.
- Never allow weeds to flower and set seeds in a crop field.
- Weeds are controlled using a rotating hoe (rotary weeder) to uproot and bury emerging young weeds between rows of maize plants.
- Start using a rotating hoe when emerged weeds are young (2- to 4-leaf stage).
- Repeat the hoeing one or two more times. Remove the weeds near the plants manually.

Chemical Weed control

Chemical liquids, granules or gases are used to kill germinating or growing weeds, or even weed seeds. This method of weed control makes use of herbicides. Generally, the type of herbicide used is determined by the type of weeds present (either broad-leaved or grassy weeds).

- You can use **selective herbicides** (e.g. atrazine) to control broad-leaved weeds in your maize farm. A selective herbicide kills certain plants but not others.
- You can also use **pre- or post-emergence herbicides** (Table 9)**.** A pre-emergence herbicide kills weeds as they germinate (sprout) from seeds. A post-emergence herbicide will control existing weeds but will do nothing to stop new weeds from germinating from seed.
- For all herbicide application, **follow the instructions on the label**.
- **Carefully dispose of** the empty containers after use.
- When in doubt, consult the local AEA for advice on available herbicides and their dosages.

Table 9. Common herbicides for controlling weeds on maize fields.

Name of herbicide	Type of herbicide
Atrazine	Pre-/Post-emergence
Alachlor + Atrazine	Pre-emergence
Diuron (Karmex)	Pre-emergence
Triclopyr (Garlon 600)	Post-emergence
Oxadiazon (Ronstar 25 EC)	Pre-/early post-emergence
Pendimethalin (Stomp 500)	Pre-emergence
Bentazon (Basagran)	Post-emergence
Glyphosate (Round-up)	Pre-emergence
Paraquat (Gramoxone)	Pre-emergence

Striga Control in the Savannah Regions

Striga hermonthica, commonly known as witchweed, is a serious parasitic weed in many parts of the Guinea and Sudan savannah zones of Ghana (Figure 18). The presence of a maize crop stimulates the germination of dormant *Striga* seed. Young Striga plants attach themselves to maize roots to draw moisture and nutrients, thereby inhibiting the maize plant. In severe cases, Striga can cause death to maize plants. If *Striga* infestation occurs, pull out *Striga* plants before they flower and produce seeds, or rotate maize with non-susceptible crops like soybean, cotton, groundnut or sunflower.

Figure 18. A maize field infested with *Striga*.

3.7. Common diseases and their control

Maize Streak

The maize streak is the most damaging disease of maize in Ghana. Maize streak virus is a foliar disease transmitted by the leafhopper.

Symptoms:

- Early symptoms include very small, round, scattered spots in young leaves.
- The number of spots increases with plant growth and elongates causing leaf chlorosis with broken yellow streaks along veins contrasting with dark green of normal leaf.
- The disease can cause severe stunting and barrenness of affected plants.

- 
- 

Maize streak

Management

- Chemical control of leafhoppers and
- Cultural practices
- Use of streak resistant varieties
- Also plant early in the recommended planting window of the area

Common rust by *Puccinia* species

Symptoms:

- Oval or elongated brown pustules/spots on upper and lower surfaces of leaves;
- Pustules may appear on tassels and ears and leaves may begin to yellow;
- In partially resistant corn hybrids, symptoms appear as chlorotic or necrotic flecks on the leaves which release little or no spore.

Management:

- Plant resistant hybrids
- Application of appropriate fungicides

Smut by *Ustilago zeae*

Symptoms:

- Galls on plant tissues which are initially green-white and turn into powdery dark brown or black spores
- Galls are common on ears, tassels, shoots or midrib of leaves

Maize smut

Management:

The only method that is completely effective is to grow resistant maize hybrids.

Downy Mildew disease (*Peronosclerospora* spp.)

Symptoms:

- The disease appears as early from two weeks after sowing resulting in chlorosis and stunting.
- In older plants the leaves show mottling, chlorotic streaking and lesions and white striped leaves.
- Usually the leaves are narrower and more erect when compared to healthy plants and are covered with a white, downy growth on both surfaces.

Maize downy mildew

Management:

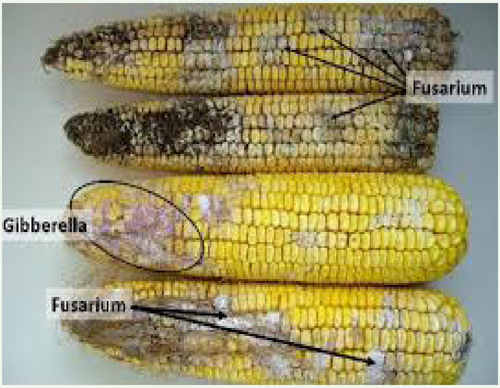
- Grow available resistant varieties and hybrids.
- Follow crop rotation with non-host crops.
- Use suitable systemic fungicide for both seed treatment and foliar spray.
- Keep the fields free from weeds.
- Drying seeds before sowing reduces the disease incidence.

Stalk and Ear rot

Symptoms:

- Plants wilting and leaves changing color from light to dull green
- Lower stalk turns straw yellow;
- Black fungal fruiting bodies may be visible on the stalk, often at internodes
- If fungal infection affects the ears, it produces a red mould at the tips of the ear
- Early infection may result in the ear being covered in pink mycelium which causes the corn husk to adhere to the ear.

Maize stalk rot



Maize ear rot

Management:

- Stressed plants are more susceptible to the pathogen so providing adequate fertilization and irrigation can help reduce incidence of disease
- Control insects, especially stem and ear borer

Useful tips to manage pest and disease in maize

- Be aware of the pest and diseases common in the area where the crop is to be grown, and plant varieties that are resistant or tolerant to them.
- Start scouting field for pest infestation immediately after emergence of seeds and monitor their levels regularly to determine whether they are causing economic damage to warrant their control.
- Plant early to avoid the high pest pressure that are experienced with late plantings.
- Maize rotation with legumes can help with reducing weed, insect and disease pressure, enhance soil fertility and improve yields.
- Under severe pest infestation, use pesticide judiciously.

Integration of all the methods above is critical for better disease and pest management

3.8. Common Insect Pests of Maize and Their Management

Seedling Pests

Slugs and snails (Mollusca: Gastropoda) - Giant terrestrial snails (*Achatina* spp.)

- Consume the foliage of very young seedlings
- **Control: lime/ash**

Grasshoppers – Defoliate plants

- **Control: chemical**

Crickets (Gryllidae) - cut maize seedlings at ground level

- **Control: preplant chemical treatment**

Cutworms

- Larvae nocturnal and feed at night
- Burrow into soil during the day
- They cut stems of young plants and feed on fallen plant e.g. *Agrotis segum*
- Eggs are laid on leaves
- 1st and 2nd instars feed on leaves
- Matured 2nd instar drops to ground to cut stems

Cutworm on maize

Damage symptom of cutworms

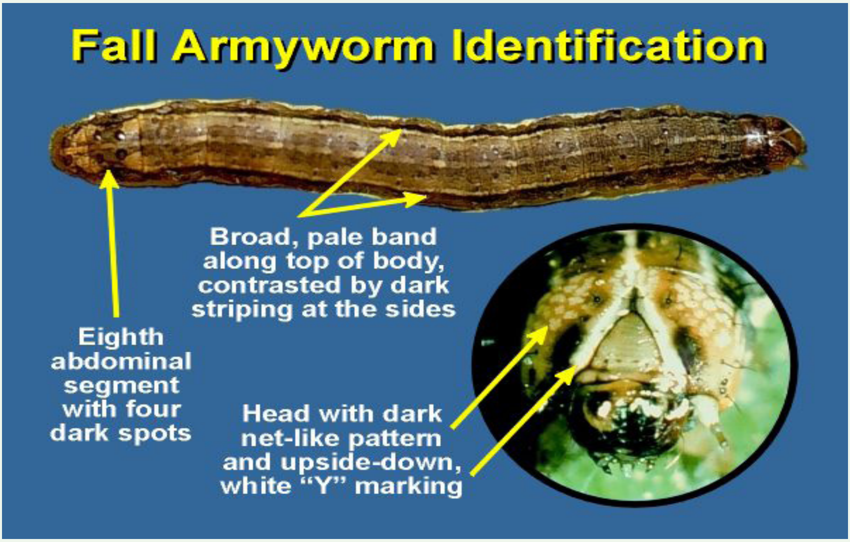
Management of Cutworms

- Maintain good sanitation especially weed-free farm to reduce egg laying by pest
- Include cover cropping to reduce weed competition
- Handpick pests if numbers are low
- Apply diatomaceous earth around plants
- Apply recommended insecticides late in the afternoon for best results

Other field insect pests

Armyworms

- Until recently not a serious pest in West Africa but now very important especially when rains come early in the year: examples include *Spodoptera exempta, S. exigua, S. frugiperda*
- Most important is Fall armyworm, *S. frugiperda*



- Females can lay ca. 300-700 eggs on grasses (cereals)
- Larva is the destructive stage
- Larval emergence is synchronized, and egg can diapause and hatch only when conditions are ripe.

Damage caused by armyworms

- Early stage larval feeding causes "windowpane" and shot holes in leaves
- Late-stage larval feeding causes elongated, ragged holes (see photo below).
- Larva may cut leaves in half
- Larva injures developing tassel at later stage and plugs whorl with wet, yellowish-brown frass

Symptoms of Fall armyworm

Management of Fall armyworm

- Vigorous monitoring of early signs of the pest
- Early or late planting
- Mass-trapping of males using pheromones
- Use of recommended insecticides to spray eg. Bypel, Emamectin benzoate, etc
- Rotate active ingredients
- Spraying should be done early morning or late afternoon and should target the whorl
- Ensure good sanitation on the farm
- Grasses near farms should also be targeted during spraying
- Use resistant varieties if available

Stem Borers

- Important pests of maize and cereals in general
- Can infest up to 70% of monocrop e.g. *Sesamia* spp., *Busseola fusca, Eldana saccharina*


Busseola fusca Maize stem borer damage symptoms

Stem Borer Damage

- Initial symptom is rows of oval or round or oblong perforations in very young leaves as a sign of feeding of young larvae on inner whorl
- All larvae finally bore into maize stalk
- Deep feeding in the whorl or young stems destroys the growing point or apical bud resulting in death of innermost whorl: Dead heart = Death of plant
- Dead heart can be easily pulled out
- When attack is late larvae feed on destroy developing tassels within its whorl

Management of Maize Stem Borers

- Vigorous monitoring of early signs of the pest
- Ensure good sanitation on the farm
- Avoid leaving maize stubbles on the farm after harvesting

- Early or late planting (timely planting)
- Use recommended systemic insecticides to spray: rotate active ingredients
- Use push-pull strategy involving use of legumes as push and suitable grass such as Elephant grass as pull
- Use resistant varieties

Leafhopper (*Cicadulina mbila*)

- Attacks maize and transmits maize streak virus (MSV)

Leafhopper (*Cicadulina mbila*)

Management of Leafhoppers

- Apply diatomaceous earth to plants
- Spot-treat plants with insecticidal soap to keep pest populations under control - **t**horough coverage of both upper and lower infested leaves is necessary for effective control.
- Apply recommended insecticides

Maize Stalk Borer

- Damage characterized by wilting and/or dying of the upper leaves or by ragged irregular holes chewed in the newly unrolled leaves
- Dead-heart can occur: the “dead heart” is caused by the insect boring into the stalk at the soil level and tunneling upward
- Destroys maize stalk

Maize stalk borer

Management of Maize Stalk Borer

- Use a combination of cultural practices (mostly intercropping and the 'push-pull' system)
- Ensure good farm sanitation
- Use recommended synthetic insecticide or botanical such as neem powder (but only at the early stage, before the larvae have bored into the stem)

Corn earworm (*Helicoverpa zea*)

- Larvae feed on the leaves and sometimes destroying the inner whorl of the maize plant
- Such infestations can result in stunting of plants
- Can destroy many of the plants but usually <50% of the plants
- Destroy the corn ear

Corn earworm (*Helicoverpa zea*)

Management of corn earworm

- Spray or inject silks weekly with recommended insecticides to control larvae
- If corn earworms persist, apply *Bacillus thuringiensis* or spray Spinosad to silks at 5-10% formation and continue weekly until tassels turn brown
- Applying mineral oil to the silk where larva bores into the ear - the oil suffocates the larva

Storage Insect Pests

Storage Coleopteran Insect Pests of Maize

General Damage Caused By These Insect Pests

Direct damage

- Can cause severe losses in stored maize
- Infestation usually starts from the field: field-to-store pests
- *Cause mechanical damage leaving holes in maize grain because adults emerge through these holes as larvae are internal grain feeders*
- Leave living and dead insects, cast exuviae and faecal matter in grains
- Grains can be reduced to powder

Indirect damage

- *Damage* increases the efficacy of fungus infestation in their presence under storage
- Infestation increases heating and moisture content of grains due to metabolic activity of the insects and results in:
- caking and spoiling of grain
- stimulate seed germination
- decreased germination and seedling vigour
- spread of disease organisms throughout grain
- reduced grain and food/feed quality

Maize weevil (*Sitophilus zeamais*) Rice weevil (*Sitophilus oryzae*)

Damage on maize by weevils (Others cause similar damage)

Larger grain borer (LGB)

(*Prostephanus truncatus*) Lesser grain borer (*Rhyzopertha dominica*)

LGB prefers maize on cobs

Tribolium castaneum

Lepidopteran Insect Pests of Stored Maize

Angoumois grain moth Indian meal moth

(*Sitotroga cerealella*) (*Plodia interpunctella*)

(Causes webbing of grains)

Management of Insect Pests of Stored Maize

- Promptly harvest maize
- Remove infested grain/sort maize before storage
- Clean and vacuum all cabinets or closets where insects have been found in warehouse
- Dry maize to <13% moisture content before storage
- Inspect storage area before storage and Clean storage area/ maintain good sanitation in the store
- Examine grain regularly so that infestation can be detected early
- Fumigate maize in storage if infested in warehouse
- Use hermetic storage bags to store maize

3.9. Rogueing

The removal of undesirable and off-type plants of the same crop from the field planted to a desired variety/line. Regularly inspect the field for pests, weeds and diseases during the vegetative growth of the seed crop 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 distinctive qualities of the parents must be accessible from the developer of the inbred lines, and will incorporate viewpoints, for example, angle of the leaf blade to the stem, coloration of the leaf sheath and stem, and the state of the tassel. People who conduct rogueing must get comfortable with these features so that just off-type plants are removed or destroyed totally. Be careful that at times, after cutting the off-type plant at the base, side shoots may develop and create an undesirable cob and tassel. Along these lines, it is ideal to uproot off-type plants. It must be done early to avoid cross contamination or shattering of the undesirable seeds. Parameters for rogueing include deviations from:

- Uniformity in plant height
- Uniformity in tasseling or silking
- Color or shape of leaves, tassel or silk
- Presence or absence of other morphological pigments
- Seed color

3.9.1. When to Rogue

Rouging ought to be directed before genetic or physical contamination happens and during times favorable for visual identification.

- Rogue volunteer plants: these are effectively distinguished by size and position out of the rows (post emergence).
- During vegetative advancement, remove off-type plants that go astray from the given genotype regarding root and stalk development, plant type, pigmentation, leaf and stem pubescence, etc. Rogueing effectively, during this period will help decrease the remaining task during the critical flowering period.
- Significant agronomic and morphological qualities can undoubtedly be distinguished at the flowering stage. This is the basic stage to avoid genetic contamination of the crop. Rogueing on male plants must be finished before pollen shedding starts. Rogueing on female plants ought to be done not long after silk-emergence.

3.10. Detasseling

In production of hybrid maize seed, detasseling of the female plants must satisfy the necessary guideline and be led in a convenient manner. Any deferrals in detasseling or insufficient detasseling that outcomes in decoration stubs or missed plants will genuinely lessen the genetic purity of the hybrid seed and may bring about dismissal for certification. The following should be noted:

- Start detasseling immediately the top 3-4 cm of the tassel is visible above the leaf whorl.
- Timely detasseling (removal of the male reproductive part) in female rows is the most critical in producing genetically pure hybrid maize seeds (Figure 19)
- Tassels in the female rows must be removed prior to the shedding of pollen and silk emergence.
- Flag leaves of female plants should not be removed during detasseling – it could significantly reduce seed yield.
- 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, particularly when the female is a single-cross hybrid, are hard to detassel. In top-cross or varietal cross hybrids, where the female is an open-pollinated variety, time of tassel exertion in the female populace will change. In conclusion, with certain parents, silks emerge much earlier or later than pollen shed. Every one of these circumstances, might be exacerbated and make for difficult detasseling supervision and potential administration issues. Close supervision of the field is vital.

Figure 19. Detasseling of the tassel from female plants before pollen shedding. Adapted from Ethiopian Seed Association (2014).

3.11. Male Removal

Remove the males from the field as soon as possible after pollination. 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 (Figure 20). 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.

Figure 20. Removal of male plants after pollination. Adapted from Ethiopian Seed Association (2014)

3.12. Harvesting and Post-Harvest Processing

- Harvest mature grains only from female rows at physiological maturity or when the black layer forms.
- Field must be free from all known contaminants.
- If harvesting is done mechanically, farm implements must be thoroughly cleaned to prevent mechanical admixtures

Post-harvest operations include:

- Drying of harvested cobs to attain required moisture content, MC (12 % MC on fresh weight basis)
- Sorting to remove damaged or diseased ears (Figure 21)
- Shelling of sorted ears
- Cleaning and grading to remove inert materials, undersized seeds, broken seeds, weed seeds etc. seed grading machines are normally used to grade seeds based on their size and shape.
- Seed treatment with chemical protectants before seed storage and bagging – fungicides, fumigation and insecticides are usually used

- Seed packaging
- Tagging or labelling of bagged seeds– labels should be prepared in duplicates (one is placed inside the bagged seeds and the other is attached to the seed bag)

Figure 21. Sorting of cobs on the field or at shelling site. Adapted from Ethiopian Seed Association (2014)

3.12. Seed Bagging and Labelling

In the conditioning process, bagging is the last step. Several essential functions are achieved by seed packaging, these include:

- 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. Transparent plastic bags are preferred in some areas because farmers can see the seed. However, the use of plastic bags may be risky if seed is exposed to the sun and warm temperatures, resulting in accelerated respiration and likely damage. 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 which should include the following:

- Name of the producer
- Name of certifying agency
- Crop species
- Name of the variety and class of seed
- Germination percentage
- Purity percentage
- Year/Date of production
- Net weight in kg
- Batch or identification number
- Moisture content in percentage

3.14. Seed Storage

Hybrid maize seed is stored for a number of reasons and for various durations. The two most critical storage conditions are temperature and moisture content. The moisture content of stored seed equilibrates with the relative humidity in the storage environment. For seed storage, high humidity is the enemy. High humidity promotes the rapid growth of microbes (fungi and bacteria) and insects. Generally, at low humidity below 35%, both microbes and insects do not grow (Figure 22). Cold storage facilities should be installed for proper storage. If cold storage facilities are not available, the principle is to make the seed dry, and then keep it dry using water-proof packaging materials and desiccants. The seed can be stored longer with minimal damage, if the air temperature and the relative humidity is low. Ideally, store seed in a shed to protect it from rain and heat, while providing security. Seeds should not be stored in jute bags, as they are not waterproof. Inexpensive electronic meters for measuring relative humidity should be installed in the storage room. Alternative, relative humidity indicators (humidicators) paper that changes color in response to the ambient relative humidity could be used in seed stores (Figure 23). Bags or packs containing seeds should be arranged gently and tenderly in the storage room and should never be dropped from any height to the ground (Figure 24).

Cob may store maize seed temporarily, 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. Kernels and the cob will be in moisture equilibrium only at about 13% moisture content. When the seed moisture content is high, 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.

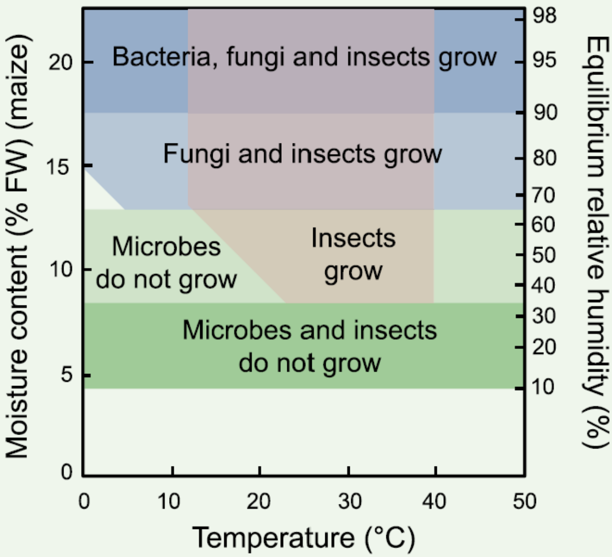


Figure 22. Diagram illustrating the combinations of temperature and MC (or ERH) at which different organisms can grow in storage for maize. Moisture

contents at corresponding ERH values approximate those for cereal grains. Below 65% ERH, products are safe from fungal growth, and below 35% ERH, neither microbes nor insects can grow. Storage life will increase exponentially as ERH and temperature decrease, but even at 65% ERH, dry food products can maintain quality for up to a year at ambient temperatures. Adapted from Bradford et al. (2018).

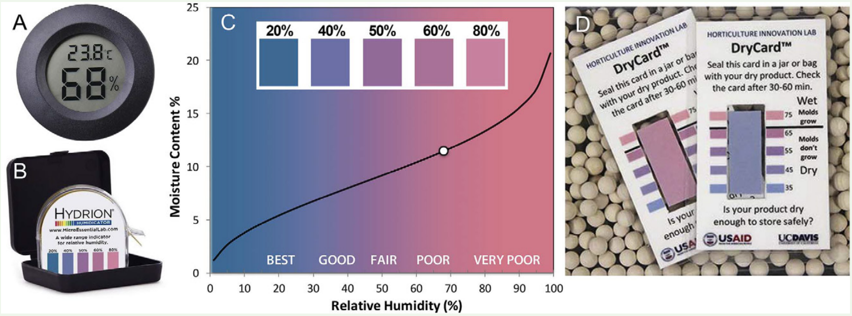


Figure 23. Measurement of relative humidity (RH) and its relationship to product moisture content (MC) and storage potential. Adapted from Bradford et al. (2018)

(A) Inexpensive electronic meter to measure temperature and RH. (B) RH indicator (Humidicator) paper that changes color in response to the ambient RH (www.microessentiallab.com). (C) Graph showing an example of an ERH versus MC isotherm with the Humidicator indicator strip scale superimposed on it. (D) The DryCard™ has a laminated RH indicator strip with an adjacent RH scale for durability and convenience.

Figure 24. Stored seed in labelled bags in well-constructed stacks on pallets with a bin card to monitor stock quantities. Adapted from Ethiopian Seed Association (2014)

3.15. Bulk Storage of Seed

The benefit of mass stockpiling of seed is that it requires less space, since the thickness of seed in mass is about 0.75 t/m^3. Besides, with well-constructed silos and conveyors seed misfortunes are decreased, less work is required for taking care of the seed and the expense of capacity bags is removed. Mass stored seed is likewise simpler to disinfect. The demerit is the high capital expense, in spite of the fact that this might be balanced after some time with the saving in bags. Storehouses ought to consistently be filled and discharged from the inside to maintain a strategic distance from over the top weight developing on one side of the storehouse. The angle of rest of seed of most field crops is about 25°.

3.16. Record keeping

Several steps are involved in hybrid seed production, most of which are affected by the environment such as; air temperature, rainfall, soil type and management. When producing a hybrid for the first time, it is improbable that everything will turn out well and there is normally a steep learning curve with each new hybrid created. Thus, it is useful to keep far-reaching records of all phases of production and to utilize these records to improve production in following seasons. Notwithstanding these records, records for precipitation, funds, work and seed stocks will enhance management of all farm resources. The utilization of a day-page diary in which day-by-day undertakings are needed to be done, contacts made, and outstanding occasions recorded will give a significant record of each season. Such record keeping will supply significant verifiable historical information valuable for present and future seed production

4.0 Conclusion

Farmers' productivity increases when hybrid seeds are grown, but this might be conceivable if the seed meets high genetic, physical and phytosanitary measures. Good management of hybrid seed fields and adherence to seed regulations guarantee quality seed production. Starting with the right source seed, a series of steps are involved to produce quality maize hybrid, each dependent on the success of preceding steps. This manual has laid out the fundamental procedures of each step. By following these in a convenient and efficient way and conforming to the required guidelines, the final certified seed will be marketable, and farmers will achieve good yields that will contribute to profitability and improve standard of living.

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