Innovations To Help Our Country Grow

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ACKNOWLEDGEMENTS

This Manual on Maize Production in Ethiopia is intended to service mainly grass root extension staff who work directly with smallholder farmers.

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The information herein presented was assembled by combining research and empirical data by the author who has been a researcher, breeder-pathologist cum and commercial maize grower for over 30 years.

In addition of the references cited in the text, other sources of information were consulted such as Wikipedia on the Internet and FAOSTAT. However and most importantly, we wish to acknowledge with thanks the use of information taken from IFA 1992 World Fertilizer Manual which contribution is highly appreciated.

DISCLAIMER: Any mistakes, inaccuracies or omissions are solely the responsibility of the author.
I. INTRODUCTION

Maize originated in the Americas. Scientific evidence is clear that it was first domesticated in Mexico where a great diversity of the crop still exists today. The Mexican indigenous inhabitants were growing maize 8,500 years before Columbus went to America for the first time in 1492 (1; 2).

In Ethiopia, maize production is of recent history. It was probably introduced to this country from Kenya during the 17th Century. Since its introduction it has become an important food crop and at present covers over 2.0 million ha; second only to tef in area; but first in total production. The national maize dry grain yield average is relatively low, standing at around 23q/ha, well below the world average of 50q/ha. However, the crop is planted mainly for self-consumption and significant proportion of it, is harvested as green maize on the cob during the “hungry period” (from May to August depending on the region) which brings the dry grain yield average lower.

This cereal crop has remained mainly as a food crop, eaten either solely or in admixtures with other cereals such as barley or tef for injera production. Also, in the rural areas, dry maize grain, is used for the production of local brews. Still maize has a very high and unexploited potential in the feed industry for dairy, and meat production, in both small and big ruminants, as well as for the poultry industry.

Africa and Ethiopia in particular, grow mainly white dent or semi-flint white grain maize. White flint maize is grown in Central America and South America, Asia and Southern Europe. Overall white grain maize occupies only 10% of the world maize production [(3), FAOSTAT 2010]. The majority of the areas around the world plant yellow maize, and a very small fraction of other grain colors such as black, red, violet, green-blue and other grain colors (Fig 1).

1. Produced by: Dr. Marco A. Quinones, Senior Director Implementation Agricultural Transformation Agency (ATA)
Yellow dent maize is primarily produced as livestock feed. Lesser amounts are grown and harvested (the entire above the ground biomass) at physiological maturity to be made into green silage for animal feed. Recently, some large areas of maize production have been dedicated for the production of biofuel like ethanol.

Sweet maize was developed to be harvested as immature green on the cob for human consumption. Popcorn is used primarily for human consumption as a freshly popped snack food.

Plant population per ha varies considerably around the world, depending on cultivars, rainfall, soil fertility and other challenges. In very dry environments (below 500 mm rainfall) plant densities ranging from as low as 15,000 to 25,000 plants/ha can be found, However, on more favorable environments or irrigated areas, populations between 50,000 to as high as 100,000 plants/ha give the optimum grain production. Maize is usually planted in rows with spacing between rows usually ranging from 50-to-100 cm, although in some countries maize still is broadcasted (Fig 2).
The crop will grow well under any soil type with pH ranging from slightly acidic to slightly alkaline (pH range of 5.8 to 7.5). Adequate drainage is needed to allow for the maintenance of sufficient oxygen in the soil for good root growth and microbial activity, as well as water holding capacity to provide adequate moisture throughout the growing season. Maize does not do well when the temperature during the growing cycle averages below 19°C or above 40°C.

II. THE MAIZE PLANT

II.1. The germinating seed

The maize seed possesses three to six seminal roots primordia (buds). Usually bigger seeds will produce more seminal roots as compared with smaller seeds.

The dormant seed will absorb moisture to approximately 40% of its own dry weight before the process of germination starts. Minimum soil temperature at seed depth for germination to start, is 10°C or above. Below 10°C soil temperature, the seed usually remains dormant and above 30°C soil temperature germination also is negatively affected. When planting during cool or warm season, it is recommended that we increase the seed rate to compensate for reduced germination and higher mortality rates. Once the germination process starts, seedling emergence will take approximately one week, but can sometimes be delayed for up to two weeks when soil temperature is cool.

Seeding depth for maize can fluctuate from around 2-4 inches. Deep seeding tends to reduce seedling emergence and can produce uneven stands. On the other hand, shallow seeding can also reduce germination by sprouting and desiccation of the seed before the germination process is completed, and enhances lodging due to poor crown root development.

During germination, the radicle and seminal roots extend first, followed by the enlargement of the coleoptile. When the coleoptile emerges from the soil, its growth will cease and the first true leaf pushes through its tip and expands. The initial root system from the seed serves to anchor the seedling to the ground and absorbs moisture from the soil to provide the growing plant. Eventually it also will absorb nutrients for the developing plant. Before the new seedling becomes photo synthetically functional, the small plantule depends on energy and nutrients provided by reserves in the seed. Accordingly, bigger seeds produce healthier, more vigorous seedlings since they store more nutrients. The first node will appear below the soil surface, immediately below the coleoptile. The nodal roots will initiate from here. Figure 3 gives the sequential process of germination and seedling establishment.
The first node usually is located below the soil surface and it is the site where the coleoptile begins. This node also is the site where a diffuse root system will begin to form soon after seedling emergence (Fig 4). Usually only one node will form below the ground, however with very deep sowing, more than one node may develop and each one bearing roots.

The total number of roots formed is associated with the number of leaves on a culm. Roots begin to form after the first three leaves have appeared, which normally happens 18 days after sowing the seed (assuming seedling emergence takes place after 7-8 days from sowing the seed).
Some of the challenges that extension staff may encounter when supervising a maize plantation at this early stage are presented in Table 1.

### Table 1. Challenges which may be detected at the early stage of seed germination

<table>
<thead>
<tr>
<th>Specific symptoms</th>
<th>Possible cause(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed not sprouting</td>
<td>• Soil too dry</td>
</tr>
<tr>
<td></td>
<td>• Embryo was dead</td>
</tr>
<tr>
<td></td>
<td>• Too many clods during seedbed preparation</td>
</tr>
<tr>
<td></td>
<td>• Fertilizer burned the germinating seed</td>
</tr>
<tr>
<td></td>
<td>• Seed damaged by soil-borne insects</td>
</tr>
<tr>
<td>Seed swollen but not sprouting</td>
<td>• Soil too wet and cold for germination to proceed</td>
</tr>
<tr>
<td></td>
<td>• Fertilizer burnt</td>
</tr>
<tr>
<td>Rotten seeds</td>
<td>• Fungal seed rot</td>
</tr>
<tr>
<td></td>
<td>• Seed not viable</td>
</tr>
<tr>
<td>Seed hollowed out/dug up</td>
<td>• Seed damaged by soil-borne maize insects</td>
</tr>
<tr>
<td>Sprouts twisted, leaves expanding underground</td>
<td>• Seeds planted too deep</td>
</tr>
<tr>
<td></td>
<td>• Cloddy seedbed</td>
</tr>
<tr>
<td></td>
<td>• Soil crusting, compaction</td>
</tr>
<tr>
<td>Uneven emergence</td>
<td>• Irregular planting depth</td>
</tr>
<tr>
<td></td>
<td>• Unfavorable soil temperature for germination</td>
</tr>
<tr>
<td>Seedlings purple in color</td>
<td>• Phosphorous deficiency</td>
</tr>
</tbody>
</table>

### II.2. From emergence to knee height

Under optimum growing conditions, the newly emerged plant will unfurl leaves from the whorl at a rate of approximately one leaf every three days. About one week after emergence the new maize seedling should be well established with two leaves fully expanded. The radicle (below the ground) and seminal roots should have many branches and root hairs. The leaves will start feeding the plant as the seed exhausts its food supply.
By the time the 3rd leaf is fully expanded, the maize plant has begun to create the root system and leaf structure that will be used to later support the ear and grain formation. The radicle and seminal roots grow very little after this stage. The permanent root system begins to form from the crown node near the soil surface and will soon support and nourish the entire plant. These roots begin to branch and form root hairs to accomplish this task (Fig.5)

With 8 leaves fully expanded, the maize plant enters into a stage of extremely rapid vegetative growth. This is the period of rapid leaf enlargement, root growth and stem elongation. The maize plant is now determining how many rows of grains the new ear will have. This determination cannot be increased later in the growing season. The growing point by now is located 2-3 inches above the soil surface with ear shoots and tassel beginning a rapid development. Enlargement of the stalk and the development of nodal roots have torn away the lowest two leaves. Moisture and nutrient deficiencies from this stage on will influence the growth and development of the ears (Fig 6).
II.3. Management considerations

- The maize plant at all the stages described above, is a very poor competitor. Therefore, care must be taken to prevent unwanted stress such as weed competition. Early weeding should be practiced when weeds are 3-5 leaf stage. Avoid late weeding in order to reduce root pruning of the maize seedlings. Usually two weeding operations are necessary. The first one at 18-20 days after planting at the three leaf stage, and the second weeding at 2-3 weeks after first weeding.

- Rapid nitrogen uptake by the maize plant begins about 5 weeks after germination (30-40 days) and will continue for about 4-6 weeks. Nitrogen fertilizer needs to be available during these stages.

- During the early stages of plant growth, seedling mortality can lead to serious yield losses due to reduced plant population. Insect attack can be a serious threat and result not only on seedling deaths, but also weakening the plant which can lead to lodging later on. Be aware of black cutworms before and immediately after seedling emergence; as well as early infestation of any of the three species of stalk borers. Migratory pests such as armyworms may also produce heavy damage when the attack comes at an early plant growth stage, since the total
plant biomass still it is not large and the insect pests can remove large chunks of leaf tissue in a short time.

II.4. From knee height to pollination

Beyond the 8th leaf stage, the maize plant enters a stage of extremely rapid and steady growth, placing heavy requirements on the root system to supply water and nutrients. New leaves unfurl at a faster rate of 1 every 2 to 3 days and brace roots begin to form at the first node above the ground. The tassel begins to develop rapidly with multiple ear shoots in 6 -10 above the ground nodes. The stalk also continues a constant growth through the elongation of the internodes with each internode elongating before the one above it. Although the number of grain rows per ear has already been established, the determination of the number of grains per row will not be completed until one week from silking during pollination.

As the plant nears pollination, upper ear shoot development has surpassed that of lower ear shoot development and leaves will unfurl even at a faster rate of 1 every 1-2 days. By the time the tassel is fully emerged and the tips of the ear shoots are visible, the plant begins to slow down its rate of growth. The plant has now reached its maximum size. The corn plant now begins to transition from vegetative to reproductive development (Fig 7).
Pollen shed normally begins 2-4 days after tassel emergence and generally continues for 5-8 days. Silks usually appears 1-2 days after pollen shed begins, emerging first from the butt of the ear and last from the tip of the ear. Each silk will grow from 1-to-2½ inches every day and will continue to elongate until fertilized. Pollination is not a continuous process, with pollen released for only a few hours each day when the tassel is dry, usually before noon. Upon contact with the silt, the pollen grain germinates and it will take approximately 24 hours to grow down the silk to the ovule where fertilization takes place and the ovule develops into a kernel or grain. Generally 2-3 days are required for all silks on a single ear to be pollinated. On a well-developed ear, there are 650 to 1000 potential grains arranged on an even number of rows around the cob. Each tassel produces and sheds several million pollen grains. Under normal conditions, 95 percent of the pollen grain falling on a given ear will have originated from another different maize plant.

II.5. Management considerations

Grain number and ear size are determined at this stage of pollination. Since early maturing varieties progress through this stage faster as compared to late maturing varieties, they usually produce smaller ears. Higher plant populations are therefore needed for intermediate and early maturing varieties to produce comparable yields to full season varieties.

II.6. Pollination to maturity

After pollination the silks will begin to dry, wilt and turn brown as the cob continues to grow. This is the beginning of a very rapid and constant increase in grain weight. Relocation of nutrients from vegetative to reproductive plant parts has begun. The growth of the plant is now based exclusively on grain development. The grain development goes into successive stages that can be described as follows:

- **Blister stage**: Within two weeks after pollination, the grains are white on the outside and resemble a blister in shape. The kernels contain 85 percent of moisture. The cob is at full size.

- **Milk stage**: Three weeks after pollination, the kernels contain a milky fluid due to starch accumulation and are approximately 80 percent moisture.

- **Dough stage**: Starch accumulation continues into the fourth week and the milky inner fluid now thickness to a pasty consistency. The kernels reach 70 percent moisture and have accumulated half of their dry matter weight.
• **Dent stage:** When half the kernels per ear are dented and usually after the fifth week, they contain 60 percent of moisture. The grain now starts to dry from the top and advancing downward to the base of the grain. The interface between the hard starch and the fluid-like below is called the milk line. By the sixth week the kernels contain 55 percent moisture and are 3 to 3 1/2 weeks to maturity. When the milk line is half way down the kernel, the moisture stands approximately at 40 percent.

• **Physiological maturity:** The hard starch layer has advanced completely to the cob with a brown or black abscission layer developing at the tip of the grain. This black layer formation occurs progressively from the grains at the tip of the ear to the basal grains. The average moisture content ranges from 28-35 percent depending on environmental conditions. The grain has now reached full maturity and will dry at a rate of approximately 1 percent per day.

• **Harvesting:** Should be done at 16-18 percent moisture

• **Shelling:** Shelling the grain from the cob should be done at about 13-14 percent moisture. In Ethiopia, maize is traditionally shelled by beating the maize ears with sticks. The challenge is that a significant proportion of the maize grain is damaged (ranging from 15-30 percent) either broken, or fractured. These damaged grains can easily be attacked by storage insect pests such as weevils, and cause further damage to the entire maize grain stock. Currently there are a number of very efficient maize shellers in the market and service providers who can provide the service for a fee. It is recommended to use such mechanical shellers instead of the traditional way of shelling by beating with sticks the maize ears (Fig 8).

Fig.8: Mechanized maize shelling. Grain damage can be significantly reduced to less than 2 percent of the total shelled maize
• **Bagging and storage:** Bag the grain at 13 percent moisture or below. If grain is to be stored for a month or more before marketing; it is recommended that it be treated before bagging with an insecticide such as Actellic super, or Malathion 5% powder to protect against damage by storage insect pests.

### III. SOIL MANAGEMENT AND CONSERVATION AGRICULTURE

In the past, tilling the soil was recommended in order to accomplish several tasks, namely; 1) to incorporate plant residues in the soil to allow for residue decomposition and release of nutrients as well as building up soil organic matter, 2) improve soil aeration, 3) improve water infiltration, 4) destroy and bury weeds that may have germinated during the fallow period, 5) to work out the soil with several passes of a disk harrow or equivalent farm implement in order to pulverize the soil to produce a fine seed bed for uniform seeding depth placement and even germination, and in general, 6) improve the physical, chemical and biological properties that collectively govern the root environment of crops. Some of the assumptions above are still valid today, while others have been challenged as we learn more about soil management and new agricultural practices. For example, with the advent of conservation agriculture (CA) practices, we now know that cereals in general and maize in particular can successfully be grown under no soil disturbance referred to as “no till” or minimum soil disturbance (minimum till) practices. Under conservation agriculture it has been amply demonstrated that under no till agriculture coupled with mulching or crop residue management, there is higher rain water infiltration, organic matter accumulation, and better aeration by increasing porosity and enhancing on the biological properties of the soil. From the many options that conservation agriculture (CA) affords, minimum till is perhaps most appropriate for Ethiopian smallholder farmers. CA has three important pillars:

- Minimum tillage
- Crop-residue application
- Crop rotation

In addition, amongst the benefits that CA delivers, the following can be highlighted:

- Stopping/minimizing soil erosion,
- Greater rain water infiltration and soil moisture retention,
- Creation of soil organic matter,
- Control of weed infestation,
- Beneficial to women-headed households since it reduces labour constraints.
- One area of concern, which can be addressed by research, is about residue/nutrient management since some of the N nutrient can be diverted by soil microbial for decomposing crop residues.
If and when farmers are practicing CA, the first operation to remember is that the soil should not be disturbed. On mountainous or hilly areas where farming is practiced, it is important to protect the soil from erosion. On these areas, CA can be practiced in combination with agroforestry, the growth of hedge rows made of trees and grass such as Vetiver or Napier grasses as well as in association with some degree of terracing. In situations where tall and woody perennial weeds or shrubs are grown on the farmland, they should be slashed with a cutlass in order to promote new growth. Wait for the first heavy rain (usually accumulation of up to 20mm of rain in 10 consecutive days will be enough) to promote weed growth. Apply glyphosate (preferably the original Round up since generics are not equally effective) at a rate of 3 lt/ha if weeds are moderate to high in numbers and are actively growing; or 4 lt/ha if weed population is very high. Use 200 lt/ha of clean water (not muddy or silty). Wait for 10-12 days after herbicide application to allow weeds to die out before sowing the maize crop. Make shallow furrows for depositing the seeds and basal fertilizer before planting as described above, without disturbing the soil between furrows.

One of the challenges which CA addresses result from tilling the land too many times and pulverizing the soil before sowing, which can accelerate soil erosion under heavy rains. It has also been amply demonstrated that under CA practices coupled with mulching or crop residue management, there is higher rain water infiltration, organic matter accumulation, and better aeration by increasing porosity and enhancing on the biological properties of the soil. Soil clods are also important to reduce soil water erosion on sloppy fields by allowing the rain water to penetrate and prevent runoffs. Soil aggregation will decrease as the number of tilling operations increase. Excessive tillage degrades soil structure stability, which renders the soil more susceptible to particle dispersion by rain drops, water runoff, and surface sealing or soil crusting. Also, wind can easily transport finely pulverized soil. Figure 9 presents four stages on CA on maize after maize crop.
III.1. Seed bed preparation

For farmers that still have not adopted CA, seedbed preparation must be location specific. Soil should be prepared to allow for optimum germination and crop growth. Also, ensuring that nutrients and moisture are available within the first 30-40 cm of the topsoil, since 95 percent of the maize nodal or crown roots will grow within this soil profile.

Seedbed preparation must be rather location specific and compatible with specific soil-site characteristics since the number of tilling operations is directly influenced by soil types, the quantity of crop residue present at the time of the tilling operations, as well as the degree of the slope on the land. For example, excessive tilling operations that destroy soil aggregates (clods) on bare unprotected soils may be counterproductive to soil protection. Soils protected by crop residues will help in increasing dry aggregate size and stability; reduce water erosion by slowing runoff and increase water storage by enhancing water infiltration.

One of the problems that result from tilling the land too many times and pulverizing the soil before sowing is that it can accelerate soil erosion under heavy rains. Soil clods also are important to reduce soil water erosion on sloppy fields by allowing the rainwater to penetrate and prevent runoffs. Soil aggregation will decrease as the number of tilling operations increases. Excessive tillage degrades soil structure stability, which renders the soil more susceptible to particle dispersion by raindrops, water runoff, and surface sealing or soil crusting. Also, wind can easily transport finely pulverized soil.
Prior to sowing during the last tilling operation, the soil should be worked out to smaller aggregates, not big clods, neither totally pulverized.

As much as possible, land should be levelled, with good drainage in order to avoid water logging. The soil should be worked out in furrows before planting. Make contour furrowing on the land at about 2-5% gradient when sloppy in order to avoid soil erosion and ensure good drainage. The distance between furrows for sowing the seed should be done at either 75cm between furrows, or 80 cm between furrows depending on farmers’ preferences. Never make furrows following the slope.

Excessive tilling operations that destroy soil aggregates (clods) on bare unprotected soils may be counterproductive to soil protection (Fig 10).

![Fig. 10. Excessive tilling of the soil can lead to accelerated soil erosion by rain water](image)

Soils protected by crop residues will help in increasing dry aggregate size and stability; reduce water erosion by slowing runoff and increase water storage by enhancing water infiltration (Fig. 11)
IV. RESEARCH RECOMMENDATIONS ON THE MAIZE PACKAGE

IV.1. Management Considerations

During the entire growing season, the maize crop is exposed to a large number of biotic and abiotic challenges that can affect the plant growth and development. It is therefore important to be aware of these conditions and to be able to detect any irregularity that may appear during plant growth and development which may signal a potential problem.

General management considerations can provide the background for profitable maize production. As specific problems usually occur at different plant growth stages, the cause of a problem can be addressed as it occurs on the field. The following paragraphs are presented with this in mind.

Fig.11. Farmers should ideally leave some of the crop residues on the soil in order to protect it from erosion, as well as to produce soil organic matter after decomposition.
IV.2 Current research recommendations

a) **Seed rate:** Research recommends the use of improved, certified seed as a guarantee of high percentage of germination and yield performance. Seed rate stands at 25 kg per hectare with at least 90% germination.

b) **Fertilizer recommendation:** Use UREA for top dressing and DAP or DAP+S+Zn = (NPS) + Zn as basal at planting. Depending on location, fertilizer recommendations to be fine-tuned based on soil fertility maps developed by EthioSIS. However, minimum application of DAP or DAP+S should be one quintal/ha. Zinc can be added as Zn sulphate (23% Zn) at a rate of 5-10 kg/ha mixed with the DAP or DAP + S at time of basal application. As for N nutrient (Urea) the dosage can vary depending on yield expectations and moisture availability. For high production potential areas, the highest grain yield can be achieved with N dosage of 2.5 - to 3.0 qt/ha Urea application. When 2.5 quintals or more of urea/ha are to be used; urea can be split by using half a quintal mixed with DAP and applied basal. The balance of Urea can be applied as top dressing at 35-40 days after planting immediately after weeding the plot. Urea should be placed on site or micro dose application in the soil at 7-10 cm depth and cover by soil to avoid N loss to the air as ammonia gas.

In the absence of site-specific fertilizer recommendation, Urea application can be reduced to the minimum of one qt/ha during top dressing (under rainfall regime of 800 mm or above during crop cycle).

Up until now, only two sources of nutrients are recommended by research, namely Urea (46% N) and DAP – Diammonium phosphate- (18% N + 46 P2O5). The recommendation for these nutrient levels vary from place to place and also depending on amount of rainfall. In areas with long history of cultivation, and rainfall above 800 mm during the crop season, most likely the optimum level of fertilizer application will be in the range from 200 – 300 kg/ha of Urea (92-138 kg of N/ha) and 100 kg/ha of DAP for optimum grain yield. However, if farmers find these levels to be high and difficult to afford, then 100 kg/ha of each Urea and DAP can be applied with the understanding that grain yield will be somewhat reduced but still attractive provided they use (apply) the inputs efficiently.

**Fertilizer recommendations in areas where soil fertility is known**

- **DAP...** One quintal/ha (100 kg/ha) and
- **Urea....** Two quintals or 2.5 qt/ha (200-250 kg/ha).
- **DAP** must be all applied basal at time of planting and deposited deep in the soil.
where roots are going to grow since it is not mobile. DAP can be applied on site or hills (lumped on small amounts of 3 to 3.5 grams per hill) at distance of 0.40 m between hills on the same row and 0.80 m apart between rows preferably; and placed at about one to two inches apart from the seeds. Alternatively, if DAP is to be broadcasted on the soil before sowing, it must be incorporated in the soil with a pass of a disk harrow, or maresha, depending on farmers practice and resources (Figure 12).

As for Nitrogen, if the recommended dosage is for two quintals of Urea all applied as top or side dressing at about 35 to 40 days after planting. This operation must be done immediately after a comprehensive weeding in order to remove competition of the weeds and the crop for the nutrients. Also, Urea the same as DAP must be incorporated in the soil, not left on the soil surface, to prevent N loses due to volatilization. The best way to apply Urea is by site or hill application same as DAP by making a small hole in the ground at about 10-15 cm away from the maize seedlings and placing the urea in the hole, then covering it with soil in order to avoid N loses (Fig. 13).

Fig. 12. Planting maize in hills at 0.80 m distance between rows and 0.40 m distance between seeds, with two seeds per hill. DAP is applied as spot on the bottom of furrow and seeds placed on the side, nearby
Fig. 13. Diagram on the top dressing of Urea fertilizer. Urea is placed at 40 cm distance one hill from the next, and 80 cm distance between rows.

The amount of urea per hole should be 7.5 grams if two seeds are planted per station and two qt/ha of Urea is applied as top dressing (equivalent of applying two coca cola caps filled with urea). The hole where urea is to be placed can be approximately 3-4 inches deep and after the fertilizer has been applied, the farmers shall scoop soil on top to prevent ammonia gas volatilization from the fertilizer. If farmers are using only one quintal of urea per ha, only one coca cola cup should be applied instead of two.

c) For sowing the seeds. There can be different approaches. The final objective is to have a uniformly distributed plant population within the land. Since maize is planted in lines or row planted, the inter row spacing as well as intra row plant spacing can be variable depending on the selected planting method(s) as depicted in table 1.

Maize can be planted at different spacing between rows. In order to reach the same plant population irrespective of row spacing, the number of plants per meter will need to be adjusted. Table 4 gives some practical example:

Table 1. Number of plants on every 10 m. in order to attain the targeted plant population

<table>
<thead>
<tr>
<th>Row spacing cm</th>
<th>No of rows in 100 m</th>
<th>No of plants/10 m at targeted plant population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50,000 plants/ha</td>
</tr>
<tr>
<td>50</td>
<td>200</td>
<td>25</td>
</tr>
<tr>
<td>60</td>
<td>166</td>
<td>30</td>
</tr>
</tbody>
</table>
When the maize crop is to be planted by hand as it is customary with smallholder farmers in Ethiopia, the most preferred method is to make rows 80 cm apart and place the seeds at the bottom on the furrow. Normally, two seeds can be placed together every 45 cm to attain a seed rate of 55,500 seeds/ha for late maturity varieties, or at 40 cm for a seed rate of 62,500 seeds/ha for intermediate maturing varieties. Then DAP can be placed on the side of the seeds at about 1-2 inches apart, but never seeds and DAP should be in physical contact with one another. Sowing two seeds together instead of one individual seed can save time and efforts to farmers. Seed rates can also be influenced by soil type, fertility level, yield expectations and variety selection. Under planting may put a ceiling on yield, but overplanting can also limit yield by barrenness, increase disease pressure and standability (lodging).

Ideally, the crop should be sown by using a seed planter or driller. However, since there is not any equipment available that is oxen-driven in the country, farmers need to rely on hand sowing the crop and oftentimes covering the seed with a pass of the maresha. This operation it is not very efficient and as the result, seed is placed at uneven soil depths leading to irregular germination across the field. To avoid this challenge, it is recommended to cover the seed by foot or alternatively increase the seed rate at sowing by 10 percent above current research recommendations.

d) Weed control: The maize crop must be free from weed competition during the first 40 days (from germination up to knee height). After this, weeds should not represent a bigger challenge. Usually two weed control operations are required, one early weeding at about 18 – 20 days after planting at 3 leaf stage of the maize plant and a second weeding at about 35 - 40 days and prior to the top dressing with N fertilizer (Urea).

e) Pest control: Maize can be severely affected by different insect pests during the early crop establishment and subsequent early growth. The most important insect pests to be considered are:

- **Cut worms:** When maize is planted under heavy mulch or presence of crop residues, the germinating seedlings can frequently be affected by cut worms which cut and kill the germinating seedling at the ground level. Farmers should constantly inspect their fields during germination and identify if some of the...
germinated seedlings are being killed out. If one seedling every 5 meters is found dead across the field, it requires chemical control. Usually the worms cannot be found by the naked eye during the day, since normally they burrow into the soil during the day and become active during the night. They can be controlled by applying insecticides such as Diazinon, in combination with Pyrethroids such as Allethrin, Permethrin, Cypermethrin and others. The application of the insecticide should be done late during the afternoon, in absence of rains for the next 4 hours after the application. Also, it is important to use clean water for the dilution of the insecticide. Muddy water reduces the effectiveness of the active ingredient. Regional plant protection departments are the best option for securing the best applicable product and dosage in use in the market.

- **Stalk borers:** Stalk borers are equally destructive and must be controlled if the infestation comes early and it is heavy. Usually when few plants are affected on the land (such as two to three plants in a row), they can be ignored; but on occasions the infestation can become very heavy (one or two plants every five meters) especially when the environment becomes dry due to absence of rains and need to be controlled by chemical insecticides. The chemical products are usually the same as described above, but the time and mode of control are different, since the chemical must go into the whorl of the growing plant. Usually stalk borers become serious threat when the crop is between 20 – 40 days after germination and need to be controlled. After 40 days, all insect pests can be ignored.

- **Migratory pests such as army worm:** Army worms when they appear in large numbers are another very important threat to maize and other crops as well. Usually when they appear as migratory pest, they are controlled by federal intervention as part of the migratory pest control campaigns of the government.

### IV.3. Planting Depth

Maize should be planted at a soil depth which will allow sufficient heat and moisture for rapid and even germination. For most conditions, a two inch depth for dry planting is ideal. Planting in moist soil should not exceed the following (table2):

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Maximum Depth (cms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Clay</td>
<td>7</td>
</tr>
<tr>
<td>Light Clay</td>
<td>9</td>
</tr>
<tr>
<td>Heavy Silt</td>
<td>9</td>
</tr>
<tr>
<td>Light Silt</td>
<td>10</td>
</tr>
<tr>
<td>Sandy</td>
<td>12</td>
</tr>
</tbody>
</table>
IV.4. Planting order
Research has shown that full season (late maturity) varieties usually respond better when planted early as compared with shorter season varieties. Short season varieties show less yield reduction due to late planting and can be compensated by increasing the plant population. So, the logic is to plant the late maturity varieties first, and then intermediate and the early maturity varieties last.

IV.5. Plant population

Plant population per ha depends very much on the variety, fertility of the soil and availability of soil moisture. Under optimum conditions, the plant population for each class of varieties is presented in Table 3 below:

Table 3. Recommended seed rate/ha depending on maturity of varieties

<table>
<thead>
<tr>
<th>Maturity Class</th>
<th>Name of variety</th>
<th>Optimum seed rate/ha</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early maturing or Short season</td>
<td>Melkassa 2</td>
<td>62,500-to-66,500 seeds/ha</td>
<td>Extra early varieties such as Katumani can be planted at higher seed rate/ha.</td>
</tr>
<tr>
<td>110-130 days to maturity</td>
<td>Melkassa 4</td>
<td></td>
<td>Assuming germination &gt;90%</td>
</tr>
<tr>
<td></td>
<td>Melkassa 6Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MH 138Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MH 130</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pioneer Shala</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planting at spacing of 0.80 m x 0.40 m between rows and two seeds per hill; or at</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.75 m x 0.40 m two seeds per hill for higher population</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assuing germination &gt;90%</td>
<td></td>
</tr>
<tr>
<td>Intermediate maturity</td>
<td>BH 543</td>
<td>62,500 seeds/ha</td>
<td>Assuming germination &gt;90%</td>
</tr>
<tr>
<td>140-160 days to maturity</td>
<td>BH 540</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BH 545Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BH 546</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BH 547</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OP Gibe 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pioneer Hybrid Shone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Agar</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Shone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planting at spacing of 0.80 m x 0.40 m between rows and two seeds per hill</td>
<td></td>
</tr>
<tr>
<td>Full season or late maturity</td>
<td>AMH 760Q</td>
<td>55,500 seeds/ha</td>
<td>Assuming germination &gt;90%</td>
</tr>
<tr>
<td>170 up to &gt;200 days to maturity</td>
<td>BH 660</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BH 661</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BH 670</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>highland available are:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Argene, Wonchi and Jibat</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pioneer Hybrid Shone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Planting at spacing of 0.80 m x 0.45 m between rows and two seeds per hill</td>
<td></td>
</tr>
</tbody>
</table>
V. PLANT NUTRITION

V.1. Fertilizers and their efficient use

Fertilizers supply plant nutrients to the crop or correct soil fertility deficiencies. Fertilizer use is most effective on soils with high natural fertility, but even on low fertility soils, crop growth and grain yield can be substantially improved. Fertilizers are used in order to supplement the natural nutrient supply in the soil, especially to correct the yield limiting minimum factor. Some fertilizers, either mineral or organic, can be used directly as plant nutrients, but most must be chemically processed in order to adapt them to plant needs such as it is the case of chemical fertilizers.

The dosage of fertilizer to be applied should be based on diagnostic methods graded according to the content of available nutrients in the soil. Another approach is by plant analysis that can reveal hidden minimum factors which can be eliminated by additional fertilizer application. The upper limit of fertilizer use from the production side is determined by the limit of economic return.

Fertilizer should be distributed in such a way that all crop plants in the field obtain an adequate amount; this is generally achieved by broadcasting granular fertilizers, band application or spot application. Irrespective of the fertilizer applied, the product must be worked into the soil or left for slow penetration by rain water (when fertilizers are water soluble). Fertilizer use will give the optimum result to farmers when they are applied in accordance with the latest concepts and recommendations.

V.2. Why to use fertilizers?

Use of fertilizer is needed for a long-term production strategy. Its use is the same whether is in cool or tropical climates:

- To supplement natural soil nutrients supply in order to satisfy the demand of crops with high yield potential
- To compensate for the nutrient lost by the removal of plant products or by leaching, erosion, etc.
- To improve unfavorable or maintain good soil conditions for cropping.

V.3. Nutrient required by plants

Plants contain practically all (92) natural elements, but need only 16 for normal growth. Thirteen of these are essential mineral nutrient elements. They must be provided by the soil, by manures or mineral fertilizers. Some mineral nutrients such as Na+, Si++, Co+ are beneficial to some plants but are not essential. The
other three elements are Carbon (C), Oxygen (O) and Hydrogen (H) which plants take from the air. Table 5 provides a list of essential and beneficial plant nutrients required for healthy plant growth.

Table 5. Essential and beneficial mineral nutrients required for healthy plant growth

MACRONUTRIENTS (6)

**A. Primary macronutrients (3)**

- **N = Nitrogen.** Taken up by the roots of plants as NO₃⁻ or NH₄⁺
- **P = Phosphorous.** Taken up as H₂PO₄⁻
- **K = Potassium.** Taken up as K⁺

**B. Secondary macronutrients (3)**

- **Ca = Calcium.** Taken up as Ca²⁺
- **Mg = Magnesium.** Taken up as Mg²⁺
- **S = Sulphur.** Taken up as SO₄⁻

MICRONUTRIENTS (7) of which the critical content in plants ranges from 0.3 to 0.5 mg/kg of dry matter.

**C. Heavy metals (5)**

- **Fe = Iron.** Taken as cation (++)
- **Mn = Manganese.** Taken as cation (++)
- **Zn = Zinc.** Taken as cation (++)
- **Cu = Copper.** Taken as cation (++)
- **Mo = Molybdenum.** Taken as MoO₄⁻ (Molybdate)

**D. Non-metals (2)**

- **Cl = Chlorine**
- **B = Boron**

**E. Some beneficial nutrients (useful for some plants)**

- **Na = Sodium.** Taken as Na⁺
- **Si = Silicon.** Taken as silicate for strengthening stems on cereals to resist lodging
- **Co = Cobalt.** Needed for N fixation on Rhizobium bacterium in legumes
- **Cl = Chlorine.** Some plants require greater than essential for osmotic regulation
- **Al = Aluminum.** Perhaps beneficial on tea?

_1= From IFA World Fertilizer Use Manual 1992 ___
The amount of nutrients which needed to be added as mineral or organic fertilizers, depend on:
• The nutrient requirement of the crop for the desired yield level
• The nutrient supply in the soil

No fertilizer or manure should be applied if the uptake of nutrients from the soil does not lead to significant depletion of the soil reserves (for example micronutrients). Fertilizer use should concentrate on those which actually limit the yield according to the law of the minimum.

V.4. Diagnosis of fertilizer requirements

Rates of fertilizer application can sometimes be based upon local, practical evidence. This method can certainly be useful for obtaining at least a minimum yield level, but it is not very effective, nor economic. Therefore, it remains necessary to assess empirically the nutrient status of the soils and plants in order to provide guidelines for effective fertilizer use. The diagnostic methods are briefly discussed in table 6 below:

Table 6. Methods to diagnose the nutrient status of soils and plants

<table>
<thead>
<tr>
<th>Method</th>
<th>Reading Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical</td>
<td>• (In plant observations)</td>
</tr>
<tr>
<td></td>
<td>• Extent of deviation from full green color</td>
</tr>
<tr>
<td></td>
<td>• Identify deficiency symptoms</td>
</tr>
<tr>
<td></td>
<td>• Growth differences compared with control plots with no fertilizer</td>
</tr>
<tr>
<td>Chemical</td>
<td>• Soil testing (content of available nutrients)</td>
</tr>
<tr>
<td></td>
<td>• pH, Salinity, etc</td>
</tr>
<tr>
<td></td>
<td>• Plant testing (leaf or plant extracts)</td>
</tr>
</tbody>
</table>

V.5. Nutrient removal by maize

Much research has been done in understanding the soil processes involving nitrogen, phosphorous and potassium in relation to plant nutrition. It is well known that when adding N as fertilizer, plant roots absorb only the inorganic forms (NO₃⁻, NH₄⁺) irrespective of the fertilizer source being organic or inorganic. Common forms of N contained in fertilizers and fresh manures include ammonia, urea, ammonium and nitrate.

Ammonia (NH₃), a gas, reacts rapidly with soil water to form the positively charged ammonium (NH₄⁺) cation.
Urea (CO(NH₂)₂) is rapidly converted from the solid or liquid form by the urease enzyme to the ammonia form by soil micro-organisms. When urea or fresh manure is applied to the soil surface, N loss as gaseous ammonia is possible, especially with warm, dry conditions and a soil high pH. If incorporated or watered into the soil, urea is changed in rapid succession to ammonia and on to ammonium. The positive charged ammonium ion is held by the negative charges of the soil. This prevents ammonium leaching except in low CEC soils.

As for P and K as water soluble fertilizers, a portion of that fertilizer will become fixed in the soil, thus, not immediately available to the plant roots. However, these nutrients are not lost forever; the soil will release them back in small amounts over a prolonged period of time [(4), IFA Fertilizer Manual 1992].

If P and K residual in the soil are beneficial, then, to what extent should residues be increased economically? Most crop plants exhibit predictable P and K demand for every ton/ha produced on above the ground biomass. Table 6 gives an indication for nutrient demand by the maize crop under two different yield levels. Once the critical levels of P and K have been attained, farmers should add every year an amount equivalent to the level removed by the crop they grow (nutrient level maintenance). If nutrients are not restored, yield will fall.

Table 7. Macronutrients and Cl removal by the maize crop under two yield levels*

<table>
<thead>
<tr>
<th>Yield q/ha</th>
<th>Part</th>
<th>Macronutrients and Cl. Kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Variety A</td>
<td>Grain</td>
<td>100</td>
</tr>
<tr>
<td>6.3 t/ha</td>
<td>Stover</td>
<td>63</td>
</tr>
<tr>
<td>Variety B</td>
<td>Grain</td>
<td>129</td>
</tr>
<tr>
<td>95 t/ha</td>
<td>Stover</td>
<td>62</td>
</tr>
<tr>
<td>Average kg/t/ha</td>
<td>A=</td>
<td>25.8</td>
</tr>
<tr>
<td></td>
<td>B=</td>
<td>20</td>
</tr>
</tbody>
</table>

*=IFA World Fertilizer Use Manual 1992

Table 8 presents the macro nutrient demand by the maize crop during the first stages of development.
Table 8. Macro nutrient demand by the maize crop during the early stages of development

<table>
<thead>
<tr>
<th>Plant age Days from germination</th>
<th>Nutrients absorbed (kg/ha/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>20-30</td>
<td>1.7</td>
</tr>
<tr>
<td>30-40</td>
<td>6.7</td>
</tr>
<tr>
<td>40-50</td>
<td>8.3</td>
</tr>
<tr>
<td>50-60</td>
<td>5.3</td>
</tr>
</tbody>
</table>

*=IFA World Fertilizer Use Manual 1992

Potassium the same as ammonium have a single positive electromagnetic charge. The remaining cations have two or more positive charges. The higher the charge of a cation, the more strongly it is attracted to the negative charge sites of the soil. This means that K+ and NH4+ can be displaced from their electromagnetic linkage with the soil by Ca++, Mg++ etc, which have more than one positive electromagnetic charge. When the sum of the positively charged nutrients exceeds the soil’s capacity to hold nutrients, K+ and NH4+ will leach before nutrients such as Ca++ and Mg++.

VI. QPM MAIZE

QPM maize is a new kind of maize which basically carries the same protein level as of normal maize varieties, but the quality of the protein is entirely different. The difference between the two types of maize (normal vs QPM) rests on the chemical composition of the protein fraction in the grain, not on the level of protein. QPM has double the amount of two essential amino acids, namely Lysine and Tryptophan which normal maize varieties are deficient on. These two amino acids are essential in human nutrition especially for growing children below five years of age and also for pregnant and lactating mothers.

When these two amino acids are not eaten in enough quantities; growing children (below five years of age) become stunted in physical body growth, but most important, their brain development also is impaired and as the result, they also become slow in learning abilities. In extreme circumstances, protein deficient children can even die from the deficiency. It is very important to stress that the impact on the protein quality of QPM is on children below five years of age and on pregnant or lactating mothers only, because the final adulthood physical growth of a child and his/her brain intelligence level are decided during the period beginning at six months of pregnancy, when still in the mother’s womb up until before the five years of age. Undernourished mothers will necessarily give birth to an undernourished child. Figure 13 presents a composition of young children affected by protein deficiency on top and healthy children who had been on QPM diet on the bottom of the composition.
Until very recently in Ethiopia, another new opportunity has become available in the maize production value chain with the advent of high yielding maize QPM varieties available and presented in table 9 below.

Currently, there is limited supply of QPM seed in the market, but this seed will be used by the regions for extensive demonstrations and in collaboration with ATA, CIMMYT and other collaborators, awareness campaigns will be instituted for popularization of QPM. At the same time, the regional seed production enterprises can go in further expanding the production and supply of seed for anticipated future demand.

When at the peak of commercial production (two to three years from now if an aggressive production campaign is instituted), QPM can become an important marketable commodity grain for domestic school feeding programs at kinder garden level. Also as a food security crop, and even as an export commodity for maize consumption in deficient producing countries such as Kenya, Somalia and for some time to come Southern Sudan.
Table 9. QPM varieties recommended in Ethiopia

Normal maize and QPM varieties otherwise are essentially the same (except for the nutritional contribution of QPM) and the agronomy and overall management along the value chain can be considered the same. Table 9 presents the QPM varieties available and recommended for planting in Ethiopia. There is a range on maturity from the full season variety AMH760Q to the early maturity variety Melkasa 6Q.

VII. Potential future changes in the agronomy of maize value chain

The grain yield on maize can significantly be improved from current level by applying small but important changes in the management of the crop. For example, the recognized world record on maize yield production stands above 20 ton/ha by using a population density of 86,000 plants/ha. Recent yield record claim of 39.6 ton/ha under a population density of 120,000 plants/ha has been reported in USA but not yet officially validated. The author has tested high population densities in Nigeria and Ethiopia during the 2004-05 crop seasons and found out that planting up to 100,000 seeds/ha on intermediate maturing varieties (such as BH 540), the final plant population achieved on per ha basis ranged between 85,000 to 96,000 plants/ha. Also, the yields went up from 80 qt/ha to 140 -150 qt/ha; but also the nutrient level needed to be increased accordingly. The potential to increase present maize yield is a reality and can be achieved by fine-tuning this technology (initially farmers can start by increasing 10 percent current seed rates by small changes in the field design, such as reducing distance between seeds on the same row). On late maturing varieties such as BH 660, AMH760Q and others, seed planting can be increased up to  62,000 /ha to achieve plant population >55,000 plants/ha by planting at 0.80 m between rows and 0.40 m between hills, two seeds per hill. Likewise, for intermediate maturity varieties, the plant population can be increased to >62,000 plants/ha and grain yields will definitely significantly increase. These increases in seed rate do necessarily entail similar increases in N nutrient level in
order to provide the necessary nutrition for increased grain yield. As a general rule, N nutrient dosage should be provided as twice the amount of Phosphorous as P2O5.

Another technology which is on the pipeline is the use of urea super granules (USG) on maize production. USG is pelleted normal commercial prilled urea which is compressed to produce pellets of different sizes and weights. By using USG in substitution of normal urea, the efficiency of N uptake by the crop is significantly increased and yields will concurrently increase as well; due to its slow N release attribute. This technology affords the opportunity for reducing cost of production for the farmers as grain yields are increased. In Bangladesh, where this technology was first tested, more than 600,000 farmers are presently using it on rice production and the country has reduced by 40% the importation of urea and rice production has increased more than 20%. In Ethiopia USG has been tested on wheat, tef and maize production and it has been found that it works the same as in rice in Bangladesh.

Finally, new fertilizer formulas are being tried with the objective of identifying other nutrients that might be missing from the present NP recommendations. Already, a widespread deficiency on SO4= (sulphate) has been found on most soils. Other soils also are reacting to K applications and on highly alkaline soils such as those on the Rift Valley and in Tigray, MAP (monoammonium phosphate) and AS (ammonium sulphate) should be used in place of DAP and Urea respectively. Also, as far as micronutrients are concerned, deficiencies in Zinc, and Boron have been detected. When all these mineral deficiencies are removed, surely smallholder farmers will enjoy a frog-leap increase in their productivity and production, towards a much needed agricultural transformation.

REFERENCES
