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A photograph showing a dense field of tropical maize plants. The plants are silhouetted against a bright, golden-yellow sky, likely during sunset. The light creates a strong contrast between the dark green plants and the bright background.

**IDENTIFYING PRODUCTION
PROBLEMS IN TROPICAL MAIZE**

A FIELD GUIDE



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H. R. Lafitte

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PREFACE

The purpose of this guide is to help agronomists identify, in a simple, stepwise fashion, maize production problems in the field. The guide may also contribute to improved consistency in agronomic observations and to identifying important questions for farmer interviews. Once problems are diagnosed, the lists of possible solutions may help in identifying factors to include in experiments.

The information presented represents the collective knowledge of many experienced maize scientists. The diagnostic procedures found in this guide are not intended to replace experimentation but rather to help improve the efficiency of problem identification and the appropriateness of experiments designed to generate agronomic recommendations. Readers are encouraged to interpret and, when necessary, modify the diagnostic guidelines presented to match more closely their particular agronomic and environmental circumstances. Please feel free to send comments to CIMMYT headquarters on the guidelines and procedures.

I wish to acknowledge the many experts who generously reviewed this guide, among them: M. Bell, G. Edmeades, A. Violic, and S. Waddington. Contributions were also provided by H. Barreto, J. Bolaños, J. Mihm, H. Muhtar, A.F.E. Palmer, J. Ransom, B. Renfro, A. Tasistro, and J. Woolley. A draft version was used by participants in CIMMYT agronomy courses during 1989-1991; their helpful comments are acknowledged. Finally, I thank Mike Listman and Alma Mc Nab for editorial support and Eliot Sánchez P. and Miguel Mellado E. for layout and design, respectively.

H. R. Lafitte

HOW TO USE THIS GUIDE

This guide is divided into four sections:

Section 1 *Field Observation Guidelines:*

Describes some conventions used in the guide regarding parts of a maize plant, maize growth stages, and gives some basic techniques for sampling in the field.

Section 2 *Problem Identification Checklists and Keys:*

Brief descriptions of useful observations and possible symptoms of problems that may exist in a maize field during various growth stages.

Section 3 *Problem Descriptions and Solutions:*

Describes maize response to problems, evidence required for diagnosis, and possible solutions. This section should help identify which problems are most important in limiting yield.

Section 4 *Measurement Procedures and Calculations:*

Provides details on how to make various measurements in the field to obtain further evidence of specific problems.

The normal procedure for using the guide to diagnose problems in a maize field is as follows:

1. Determine the growth stage of the plants in the maize field (see Section 1).

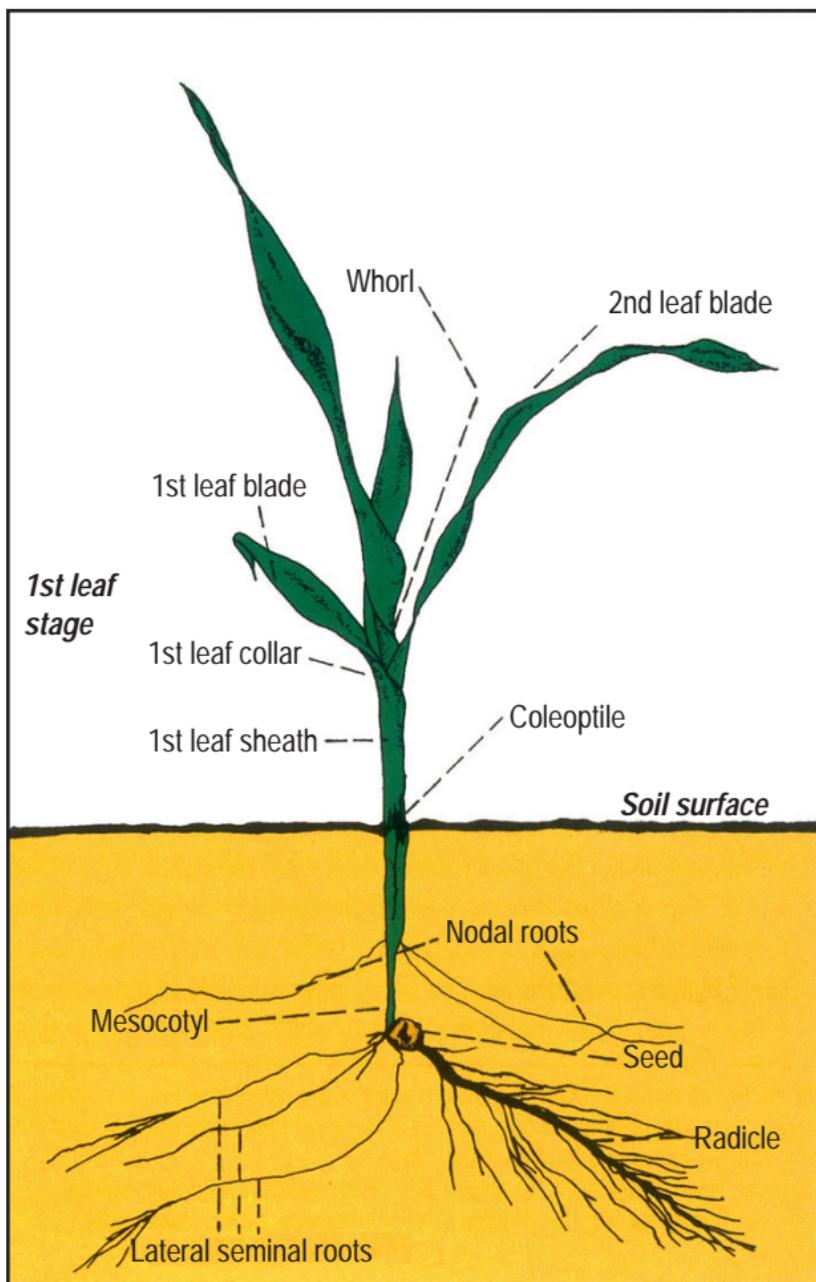
2. Make the appropriate observations as described in the checklists in Section 2 at various sampling locations as described on page 3. Even if one problem is readily apparent, it is usually worthwhile to review all observations listed on the checklist, since more than one problem may be present. You may wish to make copies of the field observation sheets found on pages 114-121 in order to collect all data more easily.
3. Collect further evidence of the problem using the keys or the pages indicated on the checklists or keys.
4. Confirm your diagnosis and possible causes and solutions to the problems in Section 3.

At various times as you follow the above procedure, you may need to make additional measurements in the field. Instructions for making those measurements are detailed in Section 4. In some cases you may find it convenient to skip the diagnostic keys and lists and go directly to the detailed problem descriptions in Section 3.

SECTION 1. FIELD OBSERVATION GUIDELINES

PARTS OF THE MAIZE PLANT

This guide employs certain names for maize plant parts, as illustrated below.



MAIZE GROWTH STAGES

In order to relate observations to problems, you need to be able to identify maize growth stages accurately. The system of growth stages used in this guide is detailed below:

Growth stage

- VE** Coleoptile emerges from the soil surface.
 - V1** The collar of the first leaf is visible (the first leaf always has a rounded tip).
 - V2** The collar of the second leaf is visible.
 - Vn** The collar of leaf number "n" is visible.
("n" is equal to the final number of leaves the plant has. "n" is usually between 16-22, but by flowering the lower 4 to 5 leaves will have been lost.)
 - VT** The last branch of the tassel is completely visible.
Note that this is not the same as male flowering, which is when pollen shed (anthesis) begins.
 - R1** Silks are visible on 50% of the plants.
 - R2** Blister stage. Kernels are filled with clear fluid and the embryo can be seen.
 - R3** Milk stage. Kernels are filled with a white, milky fluid.
 - R4** Dough stage. Kernels are filled with a white paste.
The embryo is about half as wide as the kernel.
 - R5** Dent stage. The top part of the kernels are filled with solid starch and, if the genotype is a dent type, the grains are dented. A "milk line" will be visible when the kernel is viewed from the side in both flint and dent types.
 - R6** Physiological maturity. The black layer is visible at the base of the grain. Grain moisture is usually about 35%.
-

Note: Not all plants in a field will reach a stage at the same time. For this reason, it is best to say that the crop reaches a particular stage only when at least 50% of the plants in a field are at that stage.

Source: "How a Corn Plant Develops", S.W. Ritchie and J.J. Hanway, Special Report No. 48, Cooperative Extension Service, Ames, Iowa. 1984.

SELECTING SAMPLING POINTS FOR FIELD OBSERVATIONS

For general observations such as plant density, weed density, or estimates of yield, it is important to be sure that the sampling points where you collect your data are representative of the entire field. To ensure that your data are representative, make observations or measurements at a number of random places in the field. If you consciously select places which you think are "representative", you will almost certainly bias your results. Generally, the data collected in an individual field are averaged to describe that field. If the field has a lot of variability, you may want to make separate sets of measurements in the different sections of the field and estimate the percent area which falls into each classification. In all fields, you should make a note of uniformity to aid in the interpretation of your data. Once you identify areas which are affected by a specific problem, you may need to make further observations in those areas to identify the cause of the problem.

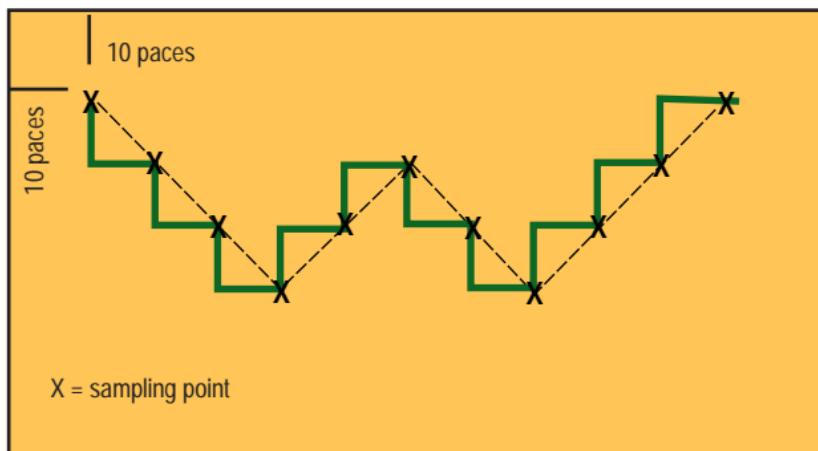
Data collection using the "zig-zag" method

While the number of data collection locations per field generally depends on the type of data needed, it is often advisable to select at least 5 to 8 separate locations in a given field. Many agronomists have found it useful to select locations while walking through the field in a zig-zag pattern as illustrated on the following page. Try to cross the field on a diagonal path about 4 times, while moving from one end of the field to the other.

When selecting sampling locations in a field, decide on the distance between sampling points before you enter the field, and take your measurements from the plant which is nearest your foot when you stop walking. If the maize is planted in rows, it is usually easiest to walk down the row for a specific number of paces, and then walk across a specific number of rows. Sampling points should not be within 10 paces of the edge of the field. It is not necessary for these distances to be exact, so don't worry too much about minor differences in the size of each pace.

If the field is small or irregularly shaped, you will need to adjust the number of paces between each point. The important things to remember are that you should not purposely select either good or bad areas to take measurements, and that you should cover the field completely.

A sheet for recording data at the different sampling points is essential. Examples of field data sheets are included on pages 114-121.



SECTION 2. PROBLEM IDENTIFICATION CHECKLISTS AND KEYS

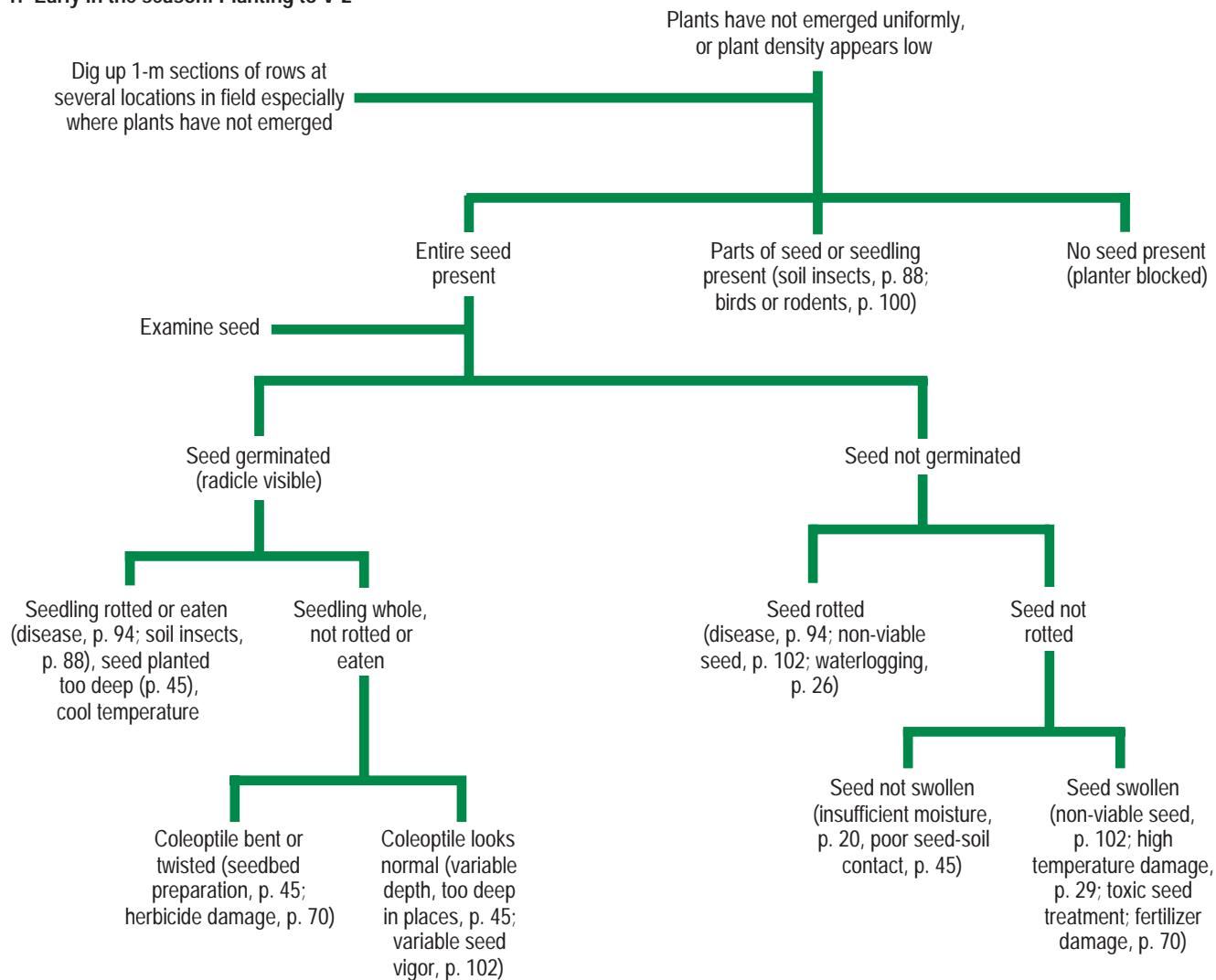
This section includes a checklist of observations to be made at four different stages: just after the crop has emerged, before flowering, after flowering, and at harvest. When you visit farmers' fields, turn to the correct page in this section for the growth stage of the crop, and try to make observations for all of the points listed. Some observations will lead you to a key for identifying probable causes for the symptoms in the field. The keys will then refer you to pages in the section that describe problems and solutions. You can turn to the indicated pages to get more information on the problem you have observed in the field and to find other types of evidence that you should collect.

If the crop growth stage is:	Use checklist:
Planting to V2	1
V2 to VT	2
VT to R6	3
Ready to harvest or after harvest	4

Checklist 1: Planting to V2 stage

Observations/questions	Key in Section 2 or description in Section 3
1. Is there uneven emergence (a quick walking survey of the field reveals >10% of area with thin, bare patches)? Low percent emergence?	Key 1
2. Are weeds larger than maize?	Planting problems, p. 45 Weed competition, p. 76

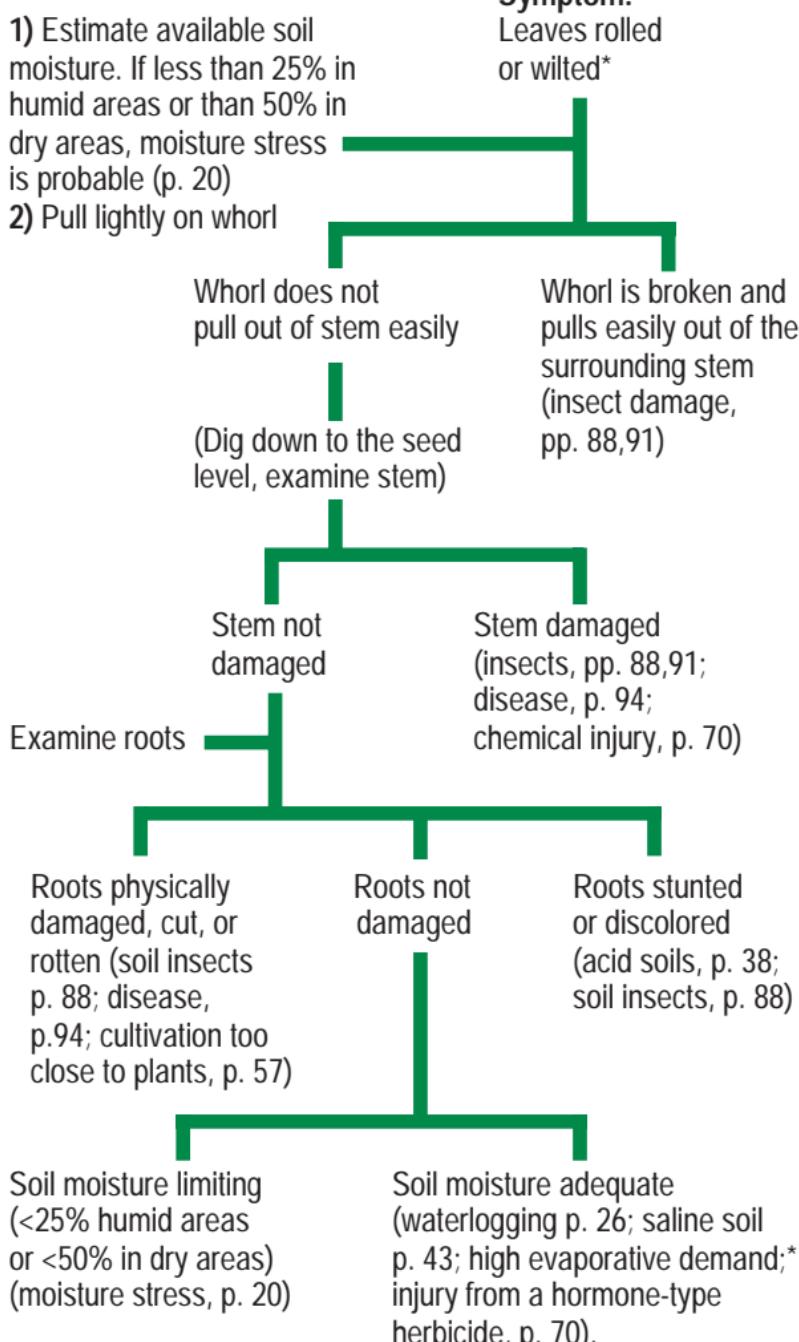
Key 1: Early in the season: Planting to V-2



Checklist 2: V3 stage to tasseling

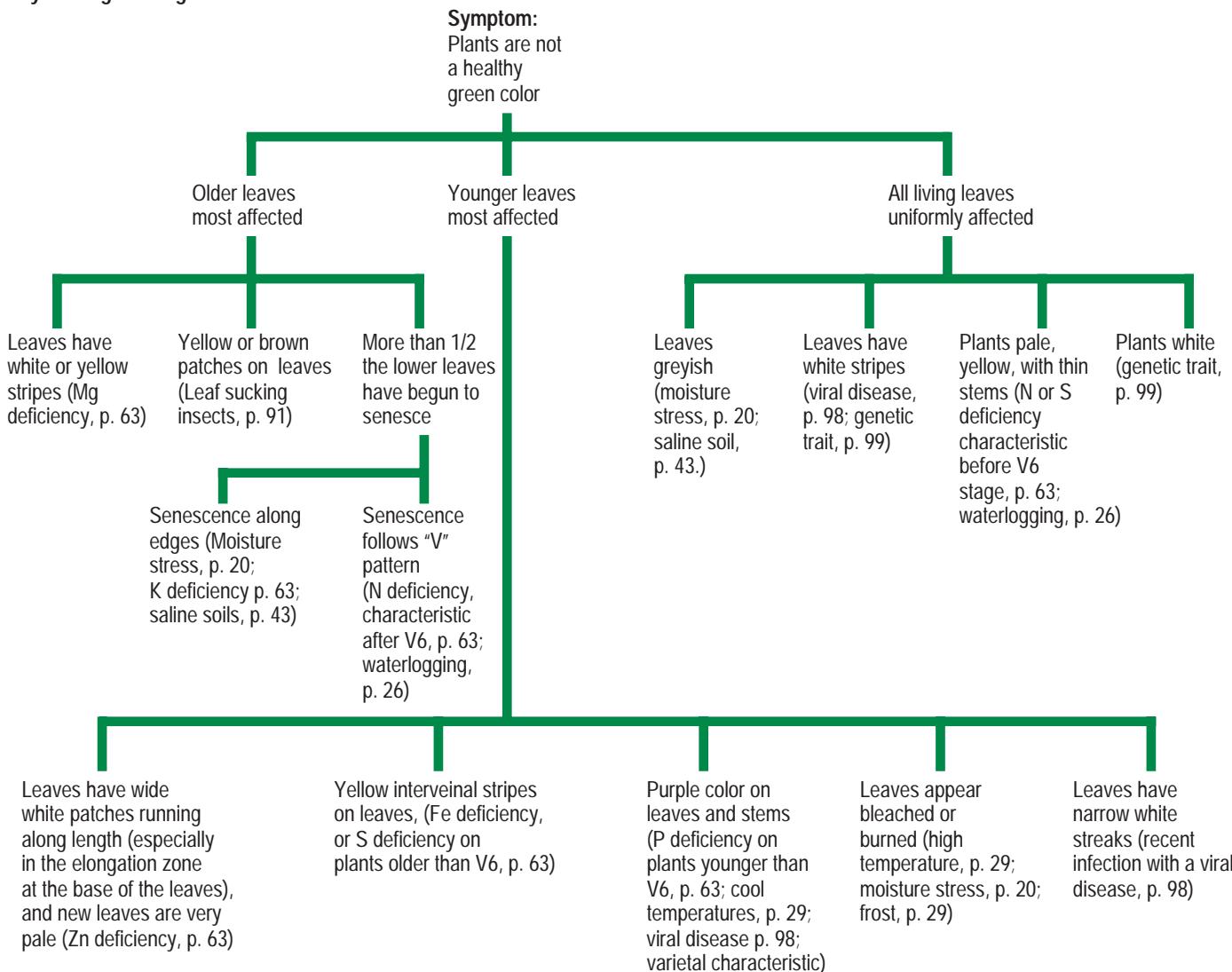
Observations/questions	Key in Section 2 or description in Section 3
1. Assess plant density.	Density, p. 52
2. Assess spatial arrangement.	Plant distribution, p. 61
3. Assess weed competition.	Weed competition, p. 76
Note: For the following points, proceed with using the keys or making counts only if the symptom occurs frequently in the field.	
4. Are plants wilted or leaves rolled?	Key 2a
5. Do leaves not have a healthy green color?	Key 2b
6. Are plants stunted or have thin stalks?	Key 2c
7. Are leaves damaged?	Key 2c
8. Are plants lodged?	Lodging, p. 33

Key 2a. Vegetative growth: V2-V7



* Plants sometimes wilt during the hotter parts of the day even though adequate soil moisture is available if the air is hot and dry; these plants will recover by the next morning.

Key 2b. Vegetative growth: V2-VT



Key 2c. Vegetative growth: V2-VT

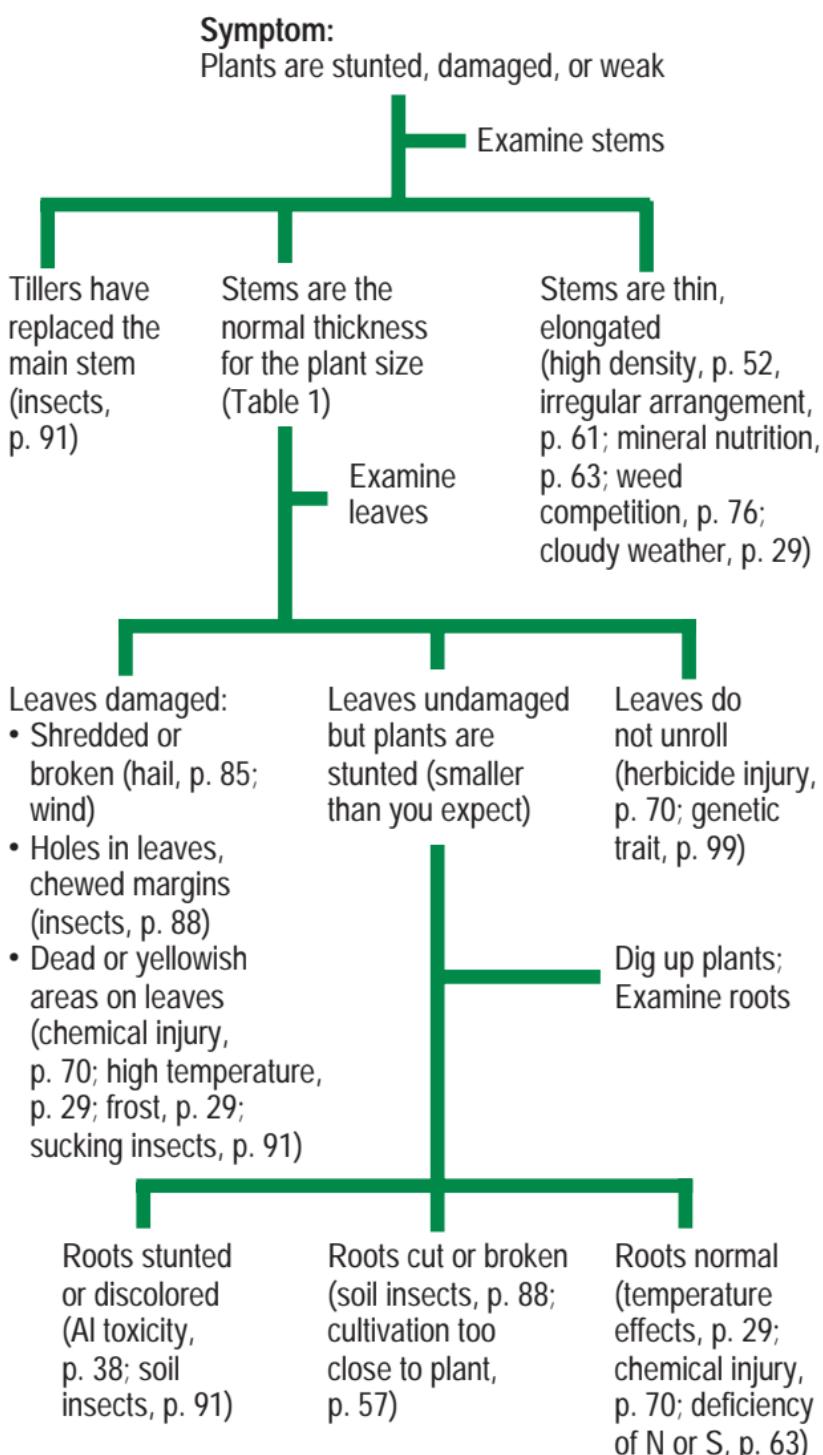


Table 1. Stem circumference at soil level of lowland tropical maize grown with good management, as measured at different growth stages.

Growth stage	Stem circumference (cm)
V5	3.7
V8	6.0
V12	8.1

Source: Growth stage data from S. Chapman.

Checklist 3: Tasseling to maturity (cont'd on p. 14)

Observations/questions	Key in Section 2 or description in Section 3
1. Assess plant density.	Density, p. 52
2. Assess plant distribution.	Plant distribution, p. 61
3. Assess weed competition. (Are weeds shading the crop?)	Weed competition, p. 76
4. Are leaves physically damaged?	Defoliation, p. 85
5. Are plants lodged?	Lodging, p. 33

Note: Points from 1-5 should be checked whenever the crop is between tasseling and maturity. Observations that are useful at specific growth stages should be made in addition to points 1-5 (see following page).

Checklist 3 (cont'd): Tasseling to maturity, observations at specific growth stages

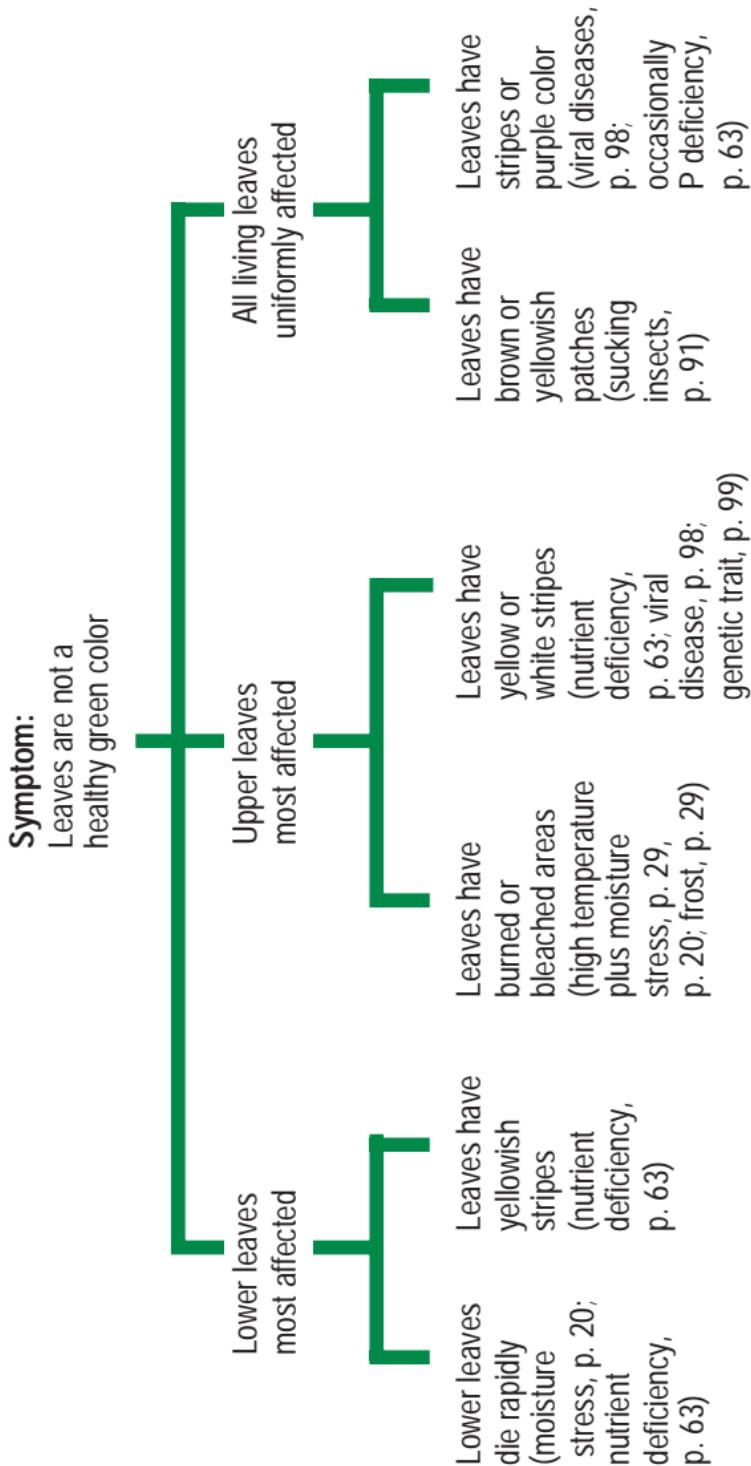
Growth stage	Observations/ questions	Key in Section 2 or description in Section 3
R1	1. Is 50% silking delayed more than 4 days after 50% pollen shed? 2. Are silks eaten by insects?	Moisture stress, p. 20 Density, p. 52 Plant distribution, p. 61 Insects, p. 88
R1 to R4	3. Are leaves not a healthy green color? 4. Are leaves wilted? Are sunlit leaves warm to the touch?	Key 3a Key 3b
R2 to harvest	5. Is the number of ears per plant below 0.9?*	Moisture stress, p. 20 Density, p. 52 Plant distribution, p. 61
R4 to harvest	6. Are ears well filled with grain? 7. Are the tips of the ears uncovered?** 8. Estimate yield.***	Moisture stress, p. 20 Key 4 Density, p. 52

* In counting plants with ears, it is important to distinguish between plants which never had an ear (barren plants) and those where the ear has been removed (due to theft or because the farmer has harvested ears for green maize). Some unimproved varieties have a low number of ears per plant even under good management.

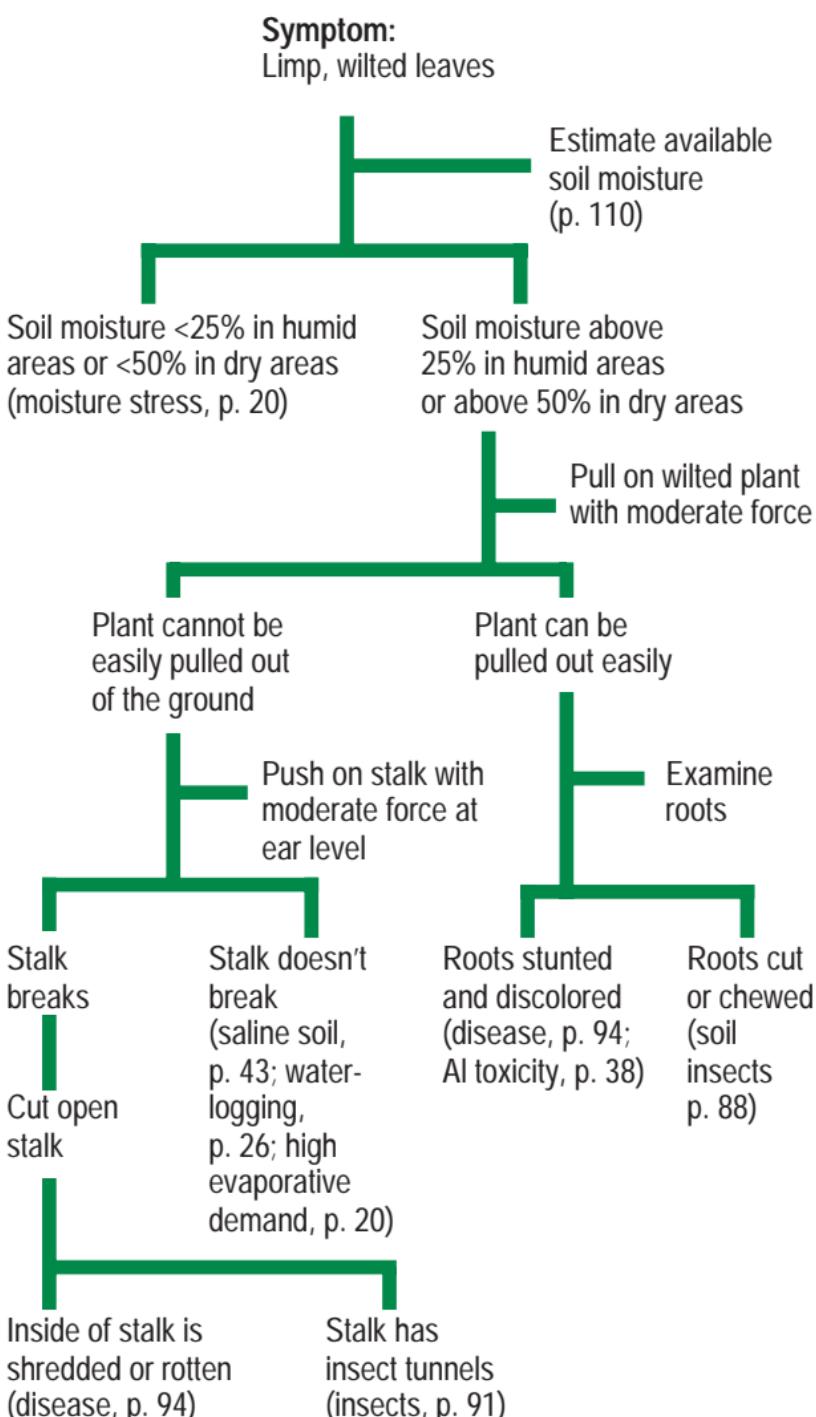
** Cause of poor husk cover may be variety. Husk cover can be of great importance if the farmer stores the grain himself because the ears may come in from the field already infested with insects which will damage the grain in storage.

*** Since the final number of grains per ear has been determined, you can now estimate final yield. See p. 113 for details on this process.

Key 3a. Reproductive growth: R1-R6



Key 3b. Reproductive growth: R1-R6

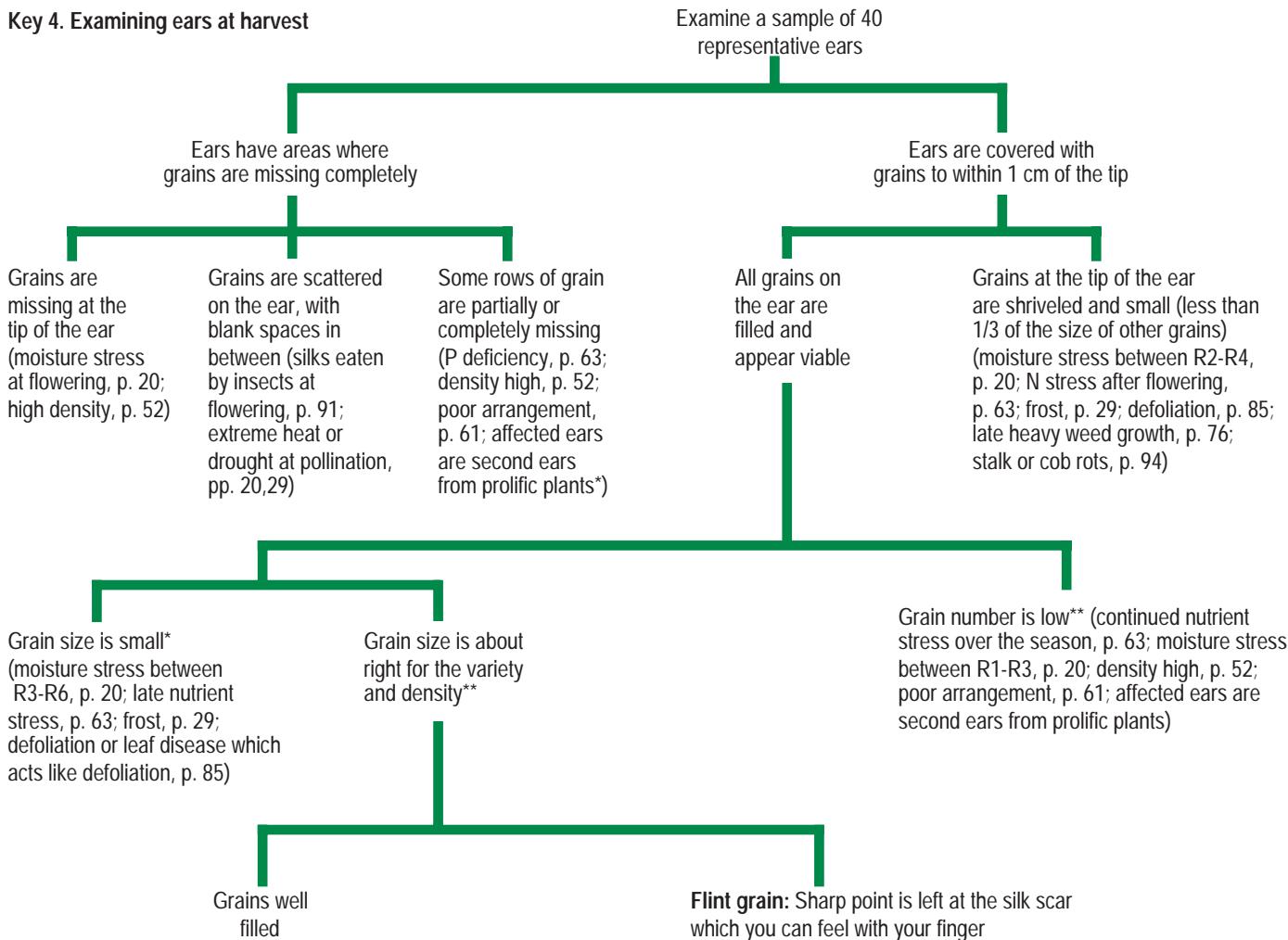


Checklist 4: At or after harvest

Observations/questions	Key in Section 2 or description in Section 3
1. Is the number of ears per plant lower than 0.9?*	Moisture stress, p. 20 Density, p. 52 Plant distribution, p. 61
2. Are ears damaged or rotted?	Lodging, p. 33 Above ground insects, p. 91 Viral diseases, p. 98 Genetic traits, p. 99
3. Are the ears small?	Key 4
4. Are the grains small?	Key 4
5. Is pollination incomplete?	Key 4
6. Are grains of dent varieties dull or wrinkled?	Key 4
7. Do grains of flint varieties have sharp points?	Key 4

* In counting plants with ears, it is important to distinguish between plants which never had an ear (barren plants) and those where the ear has been removed (due to theft or because the farmer has harvested ears for green maize). Some unimproved varieties have a low number of ears per plant even under good management.

Key 4. Examining ears at harvest



* A prolific plant is one which produces more than one ear. The second ears are frequently poorly developed.

** These assessments of "right" or "low" or "small" must be based on your experience.

SECTION 3. PROBLEM DESCRIPTIONS AND SOLUTIONS

CLIMATIC FACTORS AND SOIL CONDITIONS

Moisture stress

Water is the most common limitation to maize production in the tropics. Drought during the crop establishment stage can kill young plants, reducing the plant density. The main effect of drought in the vegetative period is to reduce leaf growth, so the crop intercepts less sunlight. Around flowering (from about two weeks before silking to two weeks after silking), maize is very sensitive to moisture stress. Grain yield can be seriously affected if drought occurs during this period. During the grain-filling period, the main effect of drought is to reduce kernel size.

In general, maize needs at least 500-700 mm of well-distributed rainfall during the growing season. Even that amount of rain may not be enough, however, if the moisture cannot be stored in the soil because of runoff or shallow soil depth, or if the evaporative demand is very large due to high temperatures and low relative humidity.

The occurrence of moisture stress usually varies greatly from year to year. If you observe symptoms of stress one year, you still need to examine weather records and talk to farmers to find out if it is a common problem. If drought is a common problem, it will reduce yield by more than 20% in one year out of four.

Is moisture stress a problem?

Evidence: measurements

Is the plant density low? Inadequate moisture shortly after planting could be the reason. How many ears per plant do you count? Drought near flowering can cause barren plants (ears per plant < 0.9). If you visit the field at the R1 stage, is 50% silking delayed more than 4 days after 50% pollen shed? An increase in the anthesis-to-silking interval is very common when drought occurs near flowering, and yield tends to decline by about 9% relative to unstressed plots for each day that silking is delayed.

Evidence: calculations

You can use soil moisture content and weather data to estimate the probability of moisture stress at the time you are making your observations. Estimate available soil moisture (p.110). If the available moisture is less than 25% in humid areas or less than 50% in dry areas, the crop is probably already suffering from moisture stress. You can also do the following calculation to see approximately how many days the crop can go without stress if no significant rain falls.

Step 1. How much soil water is present to be used before stress begins? This equals (mm current soil moisture) – (mm soil moisture present when the soil reaches 25% available moisture in humid areas, or 50% available moisture in dry areas). This is calculated for the current rooting depth of the crop.

- Step 2. How much water is used by the crop each day? This equals (evaporative demand in mm/day from weather data or Table 2) \times (the crop coefficient for the growth stage from Table 3).
- Step 3. The number of days the crop can go without significant rainfall before stress begins is:

$$\text{Number of days} = \frac{\text{mm water in soil to be used, from step 1}}{\text{mm water plant uses per day, from step 2}}$$

Table 2. Approximate evapotranspiration (ET_0) values for different environments.* Values are in mm/day.

	Average daily temperature ($^{\circ}\text{C}$)		
	10-16	17-23	24-30
Humid tropics	3-4	4-5	5-6
Subhumid tropics	3-5	5-6	7-8
Semi-arid tropics	4-5	6-7	8-9
Arid tropics	4-5	7-8	9-10

* If the area surrounding the crop is dry (without vegetation), add 1 mm/day to the value of ET_0 to account for advective losses.

Source: FAO Irrigation and Drainage Paper 33.

Table 3. Values of the crop coefficient for maize grown at normal densities.

Growth stage	Crop coefficient (kc)
Crop establishment (VE-V5)	0.4
Early vegetative (V6-V10)	0.8
Late vegetative to flowering (V11-R2)	1.1
Early grain filling (R3-R4)	0.9
Late grain filling (R5-R6)	0.6

Source: FAO Irrigation and Drainage Paper 24.

Evidence: observations

1. Are the leaves of the plants rolled (before flowering) or wilted (after flowering)? Do the plants have a dull, grayish color rather than a bright green color? Are there symptoms of photo-oxidation (sections of leaf appear bleached and yellowish) or tassel blasting (Sun and temperature, p. 29)? Are they warm to the touch when in full sun? These symptoms all indicate current moisture stress.
2. Examine the internodes above the ear. Are they much shorter than the internodes just below the ear? This can indicate drought stress in the later vegetative stages, but can also be a symptom of stalk borer damage. Cutting open the stalk will allow you to see if the cause is borer damage.
3. Compare the heights of plants on the edge of the field with those having full competition. The plants with less competition will tend to be taller than the plants which are completely surrounded if drought or nutrient stress occurred.
4. Examine the amount of sunlight which reaches the ground around noon (Density, p. 52). If the density is appropriate for the variety but more than about 20% of the light reaches the soil surface, the leaf area of the crop might have been reduced by drought stress prior to flowering.
5. During the grain-filling period: look at the leaves below the ear. Are they dying more rapidly than you would expect? Senescence due to drought looks somewhat different than normal senescence; in normal senescence, the yellow color

tends to follow a "v" shaped pattern beginning from the leaf tip. When leaves die in response to drought, the yellow color moves along the leaf margins or in a fairly straight line up the leaf, and the leaves rapidly become brown and dry.

Causes of moisture stress	Additional evidence required
1. Insufficient rainfall, or very large environmental demand due to high temperatures and low relative humidity.	Check weather records for rainfall and evaporative demand.
2. Shallow or compacted soils.	Measure soil depth (p. 110).
3. Soils have low water holding capacity.	Estimate soil texture (p. 106) and predicted water holding capacity.
4. Restricted root growth due to soil chemical properties.	Examine roots. Check soil pH.
5. Rain is lost to runoff.	Estimate soil slope. Look for signs of erosion or crusting.
6. Weeds or an intercrop are using the water.	Estimate the percentage of sunlight that is falling on weeds or the intercrop rather than on the maize or soil. At least this proportion of the available water is being used by weeds or the intercrop.

Possible solutions

1. Improve soil water storage by mulching, contouring, or tied ridges to improve infiltration, or by subsoiling. Use conservation tillage to reduce soil water loss.
2. Reduce water demand by the crop by planting at reduced density (Density, p. 52).
3. Plant at a different time of year to reduce the risk of drought, or use early varieties to avoid drought.
4. Lime to make pH more favorable for root growth.
5. Improve weed control.
6. Reduce the density of the intercrop, or plant the intercrop later in the growing cycle.



Maize plants suffering from drought stress. Note the rolled, wilted leaves, early senescence, and the dull, greyish-green color. (A. Violic)

Waterlogging

The maize crop is quite sensitive to waterlogging, that is, to saturated soils. From planting to the V6 stage, waterlogging for more than 24 hours can kill the crop (especially if temperatures are high) because the growing point is below the soil surface at that time. Later in the crop cycle, waterlogging can be tolerated for periods of up to one week, but yield will be reduced significantly.

Is waterlogging a problem?

Evidence: observations

1. If there has been rain recently: Is there water standing in the field for more than 12 hours after a rain? Examine the soil surface in areas where crop growth is poor. Is the soil very wet, perhaps with algae growing on the surface? Are the plants wilted at midday even though the soil is quite wet? These symptoms indicate waterlogging.
2. If you visit the field during a dry period, look for a thin crust of silt on the surface in areas of poor crop growth.
3. Examine the plants. Are there patches of plants which appear nitrogen deficient? Look closely at the lower leaves of the plants in these patches. Waterlogging causes lower leaf senescence, and the dead leaves often have a bronze color. Is weed growth in these patches less, or are the species of weeds different than in the rest of the field? The economic importance of waterlogging will be related to the size of the affected areas and the reduction of yield in those areas.

Causes of waterlogging

Additional evidence required

- | | |
|--|---|
| 1. Field is not level. | Look over the field for low spots. |
| 2. Drainage is poor due to a hardpan. | Measure soil depth in the affected areas. |
| 3. Very heavy rains or excess irrigation. | Check the amount of water received. |
| 4. Inappropriate use of tied ridges or contours. | Examine land preparation methods. |

Possible solutions

1. Level the field, or avoid planting maize in the low areas.
2. Break up the hardpan by subsoiling or by planting a deep-rooted crop for a cycle.
3. Install drainage canals.
4. Plant on wide raised beds, or on ridges.



A young maize plant suffering from waterlogging. Note the pale green upper leaves and the bronze color of the lower leaves, which are senescing prematurely.

Sun and temperature effects

The maize crop can tolerate a wide range of temperatures (from 5 to 45°C), but very low or very high temperatures can have a negative effect on yield. Usually a farmer cannot do much to change the effect of temperature other than shift the planting date slightly or plant a better adapted or earlier maturing variety. Maize varieties do differ significantly in their temperature responses.

The crop is usually not damaged by high sunlight unless it is also under temperature or drought stress. The crop is often affected by low sunlight when extended periods of cloudy weather occur, especially if they coincide with flowering. Again, the farmer often cannot do much to change the amount of sunlight available to the crop, but it is important that you are able to recognize the symptoms associated with these problems so that you do not confuse them with other factors.



Damage due to high temperatures and high radiation, especially when combined with drought stress. Note the senescence along the edges of lower leaves. Upper leaves show yellowing and bleaching due to photo-oxidation. (J. Bolaños)

Evidence: low temperatures

1. Look over the field between emergence and the V3 stage. Are the plants growing slowly, and do they have a purplish color? This symptom can indicate P deficiency, but it can also result from low temperatures even if P supply in the soil is adequate.
2. Look for symptoms of frost damage (see photo).

Evidence: high temperatures

1. Is germination poor? If the soil temperature in the top 5 cm was above 40°C, seed sown at 5 cm or less may have been damaged. The seed is swollen with water, but will not germinate. Deeper planting may avoid this problem.
2. Look for symptoms of photo-oxidation (yellowing or bleaching of the leaves), especially on those areas of the leaves which are at right angles to the sun's rays at midday.
3. Look for sterile tassels, poor seed set, and/or firing of upper leaves. The leaves may be a pale green color due to the effects of high temperatures on chlorophyll formation.

Evidence: low radiation (sunlight)

NOTE: These symptoms can result from many other causes as well. You should check records on the hours of bright sunlight, look at rainfall records, and talk to farmers about the growing conditions during the season before concluding that low radiation was the cause of these symptoms.

1. Look for thin stems and tall, thin (etiolated) plants.
2. Look for a low number of ears/plant (below 0.9) and extensive lodging. This could result from low sunlight at flowering.

Evidence: high radiation

1. Look for symptoms of photo-oxidation. Again, you would expect a problem only if photosynthesis was impaired by drought, micronutrient deficiencies, salinity, low night temperatures, or some other factor.



Frost damage: exposed leaves are most affected, whereas leaves inside the canopy are protected from low temperatures and remain green.



A maize seedling growing at low temperatures. Application of additional P did not correct this purpling, but the symptoms disappeared as the plant grew and temperatures increased.

Lodging

Maize is often affected by lodging, either of the root or stalk. A plant is said to be root lodged if the lower stalk forms an angle of 45° or less with the soil surface. It is stalk lodged if the stalk is broken below the ear and the broken portion forms an angle of 45° or less with the soil. Root lodging and stalk lodging are often poorly correlated; root lodging tends to be associated with environmental factors such as heavy rains coinciding with wind or management factors like high densities or poor plant distribution, while stalk breakage is often closely related to genetic characteristics such as disease and insect resistance, prolificacy, and senescence patterns.

The effect of lodging on yield depends on when it occurs and whether the ears remained in contact with the soil long enough for rotting or germination to occur. Economic loss from lodging also depends on the harvesting method used in the region. If harvest is by machine, many lodged plants will not be harvested. If the farmer harvests by hand, lodging will increase the time required and labor costs.

Is lodging a problem?

Evidence: measurements

Make a count of plant density (Density, p. 52) and include a count of lodged plants. It is often helpful to count root and stalk lodging separately. Note the crop growth stage and whether ears are in contact with the ground. Look over the field, and notice if there are any specific areas which are very badly lodged. If so, estimate the area which is lodged. The coefficient of variation for percent lodging is generally very high. Therefore these measurements should always be made on a number of fields in the area, and they should be combined with observations and discussions with the farmers.

Evidence: questions

Ask the farmer when lodging occurred, and relate the date to a growth stage. If lodging occurs before the R5 stage, yield of the lodged plants will probably be affected due to decreased interception of sunlight. Farmers usually have a good idea of the amount of lodging in an average year, and when it occurs. Ask the farmer how this year compares to other years.

Causes of lodging (principally root lodging)	Additional evidence required
1. The variety is susceptible to lodging due to plant type.	Observe other fields in the area with different varieties. Examine the plant height and ear placement. If the ear height is above 60% of the plant height when growing under good conditions and the plant height is over 2 m, the variety may be susceptible.
2. Heavy rains and wind after stem elongation begins.	Review climatic data, talk to farmers about winds and rains.
3. Lodging caused when the farmer knocked plants over or cut roots while cultivating.	See if lodging occurs in specific areas. Ask the farmer about cultivation.
4. Limited rooting depth because of shallow soils, hardpan, acid soils.	Measure soil factors.



When lodging occurs before flowering, the plant can often recover and yield is not seriously affected.

Causes of lodging (principally stalk lodging)	Additional evidence required
1. The plants lodge due to stalk rots or stem borer damage.	Cut open the stalk and look for brownish, rotten areas or insect tunnels.
2. The density is too high for the variety.	Compare the observed density with the optimum for the variety. Look at the stalks. Are they thin and weak?
3. Too many plants per hill or competition due to weeds or an intercrop.	Count plants per hill. If >3 , this may be the cause. Examine weed or intercrop competition for light. Examine stalks.
4. There was a loss of effective leaf area during grain filling, so the stem reserves of sugar were exhausted.	Look for defoliation due to drought, frost, insects, etc. Check for stalk rots which often infect plants with low stalk sugar concentrations.
5. Excess N applied to unimproved germplasm.	Ask farmer how much fertilizer was applied.
6. Severe potassium deficiency.	Look for leaf symptoms of K deficiency (Mineral nutrition, p. 63). Examine plants for thin stalks.

Possible solutions

1. Change to a shorter variety with lower ear placement.
2. Alter density or spatial arrangement; reduce the density of the intercrop; control weeds.
3. Cultivate earlier in the season to avoid damaging plants.
4. Increase soil depth by subsoiling. The effective soil depth can also be increased by ridging or hillling up around the plants.
5. Control insect pests which lead to lodging.
6. Reduce N application to an unimproved variety, or change to an improved variety which responds more positively to applied N.
7. Correct K deficiency.

Acid or alkaline soils

The maize crop generally grows well over a pH range of 5.5-7.8. The effect of soil pH outside this range is usually to make certain elements more or less available, so toxicity or deficiency develops. Below a soil pH of 5.5, Al and Mn toxicities are frequently problems, and deficiencies of P and Mg are common. At a pH above 8 (or above 7 on calcareous soils¹), deficiencies of Fe, Mn, and Zn tend to occur. The field symptoms of unsuitable pH thus generally resemble those of micronutrient problems. (Figure 1, p. 42)

Is soil pH a problem?

Evidence: measurements

Collect a soil sample and test it for pH. Sample the plow layer and subsoil separately. Kits for doing reliable field tests are available. If pH is below 5.5 or above 7.8, it is probably outside the range for good growth of maize.

¹ A quick test can be used to diagnose the presence of free carbonates in high pH soils. Add a few drops of 10% HCl solution to the soil. If the soil fizzes, the soil is calcareous and deficiencies of Zn, Fe, and Mn are possible.

Evidence: observations

Look over the field for symptoms of micronutrient deficiencies (Mineral nutrition p. 63). If leaf symptoms are present, yield is probably being reduced. If the pH is low, you should examine the roots of some plants for symptoms of Al toxicity. The roots of Al-affected plants will be stunted and short; they will often look like thick clubs rather than like normal, slender roots. The roots may be brownish or black in color. Low pH soils may also exhibit Mn toxicity, causing small reddish-brown spots on older leaves.

Causes of pH problems

1. Inherent property of the parent material/climate combination.
2. Application of acidifying fertilizer.
3. Over-liming to correct a soil acidity problem.
4. Application of alkaline irrigation water.

Additional evidence required

Review soil maps of the area. Problems of low pH are common in aged, highly leached soils with high levels of Al and Fe oxides. Problems of high pH are common to soils which are derived from limestone parent materials. If pH is low, have soil tested for presence of free Al^{+++} .

Question farmer about fertilizer products applied. For example, continued use of ammonium sulfate tends to lower soil pH.

Question farmer about liming practices.

Check pH of irrigation source.

Possible solutions

1. Apply lime to raise the pH of an acid soil.
2. Apply micronutrients to foliage or soil to correct pH-induced deficiencies.
3. Change to a non-acidifying fertilizer source if pH is low, or to an acidifying source if pH is high.
4. Change liming practices to avoid over-liming.
5. Change to a tolerant variety.
6. Apply elemental sulfur to lower soil pH.
7. Reduce irrigation with alkaline water source.



Maize grown in a high pH soil with high levels of free carbonates shows symptoms of severe iron deficiency. (G. Edmeades)

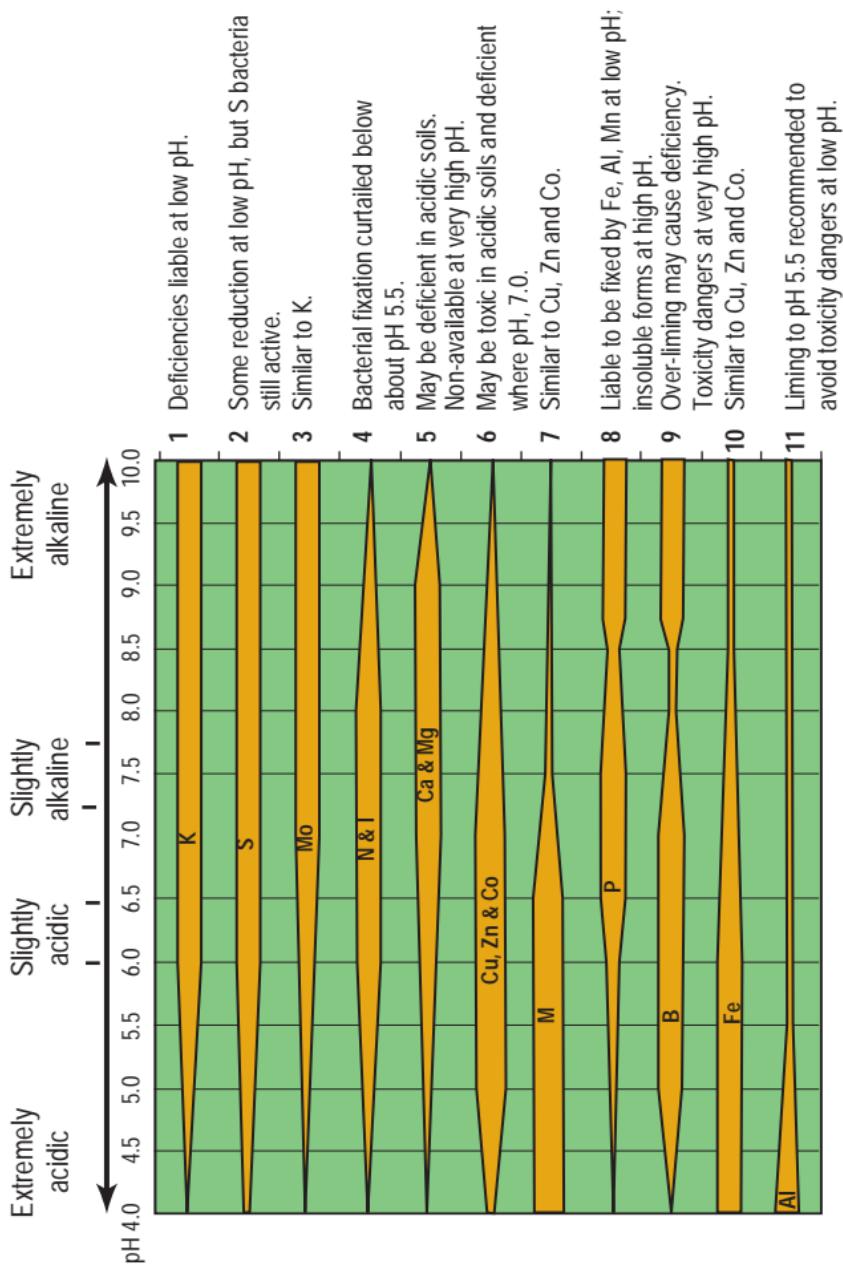


Figure 1. Effect of pH on availability of common elements in soils. The width of the bar indicates the degree of availability.

Source: Booker Tropical Soil Manual, J.R. Landon (editor), 1984, Pitman Press Limited, Great Britain.

Saline soils

Maize is considered sensitive to salinity. When the electrical conductivity of a saturated soil extract is 2.5 millisiemens/cm (mS/cm, same as millimhos/cm), you can expect a 10% yield reduction; a value of 4 is associated with a 25% yield reduction. This yield loss usually results from the fact that the plants cannot extract enough water from the salt-affected soil. In some cases, the salts are actually toxic to the crop.

Is soil salinity a problem?

Evidence: measurements

Collect a soil sample and have it tested for electrical conductivity.

Evidence: observations

1. Look over the field for plants which appear to be wilted, even though soil moisture seems adequate. The leaves may look dull, and the leaf tips or margins may appear to be grayish. If the salt toxicity is severe, the tissue along the leaf margins may become yellow and die.
2. Look for a whitish film of salt on the soil surface, especially on the tops of ridges when the soil is dry in areas where furrow irrigation is used.

Causes of soil salinity	Additional evidence required
1. Irrigation with salty water, or inadequate water applied to meet the leaching requirement for the water source.	Analyze irrigation water.
2. Application of excessive fertilizer in a semi-arid region.	Ask farmer about past fertilizer applications.
3. High water table in a semi-arid region.	Measure depth of water table.
4. Inherently saline soil.	Soil analysis.

Possible solutions

1. Leach the soil with clean water to remove the salt accumulation.
2. Grow a crop which is less sensitive to salinity. Barley, cotton, and sorghum are all more tolerant than maize. Among maize genotypes, some are more tolerant to salinity than are others.
3. Install drainage.
4. Modify irrigation scheduling to have fewer irrigations, but with more water applied at each irrigation.

MANAGEMENT FACTORS

Planting problems: Land preparation and planting methods

There are three types of problems which occur at planting. One is that the land may not be cultivated properly, so that there are clods or crusts which prevent planting at a uniform depth and even germination. Another is that preparation is too long before planting or is patchy, so that the weeds have an advantage over the crop. The third is that the seeds are placed at the wrong depth.

The primary purposes of land preparation prior to planting are to create a soil structure favorable for crop growth, to incorporate residues, and to control weeds and diseases. In many areas, the soil structure is adequate to allow good growth without cultivation, as long as weeds are controlled by other methods. Residues can often be left on the soil surface, if they do not make other field operations difficult.

A good planting method is one that allows seed to be placed at the correct depth and provides good contact between seed and soil. The correct depth of planting is deep enough to allow seed to take up water, to protect it from desiccation or birds, and to prevent it from germinating with light rains, but shallow enough to allow the seedling to reach the surface before depleting its food reserves or being attacked by soil insects or diseases. The suitable planting depth for lowland tropical maize is usually about 5-7 cm, but as deep as 10 cm is often acceptable, if the seed is large and healthy. When planting to use residual moisture, especially in highland areas, farmers

may place seed at depths of 20 cm. However, specialized varieties are needed for planting at such depths if the seed is covered completely. When seed is planted in dry, bare soil in warm areas, the depth should be around 10 cm to avoid high-temperature damage.

Is seedbed preparation or planting method a problem?

Evidence: measurements

Determine if plant density or distribution is a problem (pp. 52 and 61).

Evidence: observations

Note: These observations should be made shortly after emergence, when the maize is at stage V1-V2.

1. Look over the field. Is emergence uniform? If not, dig up seeds in the areas where emergence is poor. Use Key 1 (p. 6) to interpret what you find. If the seeds have germinated, measure the length of the mesocotyl in areas where the plants have emerged and in the areas where the plants have not yet appeared. If the lengths differ by more than 3-4 cm, then the planting depth was quite different in the various parts of the field.

2. Walk through the field. Have the seedlings been pulled out of the ground and eaten? Look for signs that birds or rodents have been in the area. If the seeds have been pulled up, planting depth may have been too shallow or the soil was not firmed adequately over the seed.
3. Look over the field. Are there weed seedlings that are bigger than the crop? If so, the weed control provided by land preparation was not adequate—the crop was probably planted too long after the field had been prepared. Another possibility is that the preparation was not thorough, and weeds were only buried rather than killed.
4. Is the spacing uniform? Mechanical planters can block up, leaving gaps or overplanted spots.
5. Look over the field and note the size of clods left from the cultivation. A seedbed with many clods larger than 6 cm in diameter can cause problems of variable seeding depth, poor contact between the seed and the soil, and physical impediments to emergence.
6. Check for crusting. If a rain has fallen recently, it may not be possible to see the crust in the field. Dig up plants in areas of poor germination, and look for knotted, twisted, pale seedlings which could not break the crust (see photo p. 50). Look for a silt layer on the surface of the soil.

Causes of low quality seedbeds	Additional evidence required
1. Cultivation when soil was not at the correct moisture content, causing clods.	Ask farmer about soil moisture when land was prepared.
2. Excessive secondary cultivation and rain after planting, followed by surface drying, causing crusting.	Ask farmer about land preparation and rainfall after planting.
3. Planting was delayed too long after land was prepared, so weeds had an advantage.	Ask farmer about this.

Possible solutions

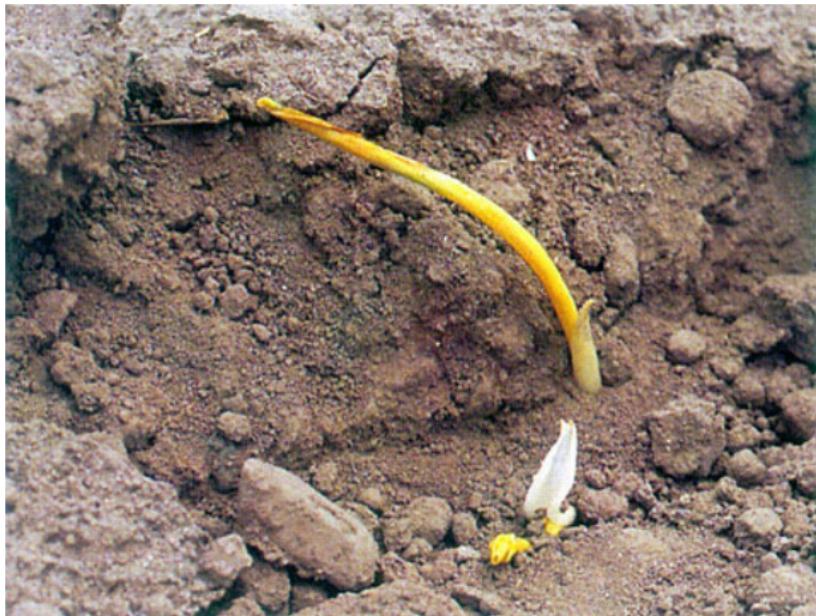
Note: Often the farmer does not own the equipment used to prepare the land, and cannot specify just when cultivation will be done. You need to consider this limitation when you are designing solutions.

1. To reduce clods: develop guidelines for when soil should be worked, based on moisture content. (Table 4, p. 51) Use secondary tillage to reduce the size of clods.
2. To reduce crusting: reduce the number of secondary tillage operations, and leave some crop residues in the upper soil layer. Another solution is light, superficial cultivation to break the crust after planting but before crop emergence.
3. Use reduced or zero tillage to minimize problems of land preparation.

Causes of poor planting	Additional evidence required
1. Soil hard or dusty, so the seeds were placed too shallow. planting	Measure the planting depth (the distance from the seed to the tip of the coleoptile of a normal plant). If <5 cm, was probably too shallow. Ask the farmer about conditions at planting.
2. Seeding device not adjusted correctly, so depth was wrong.	Measure the planting depth. Ask the farmer how planting was done.
3. The soil was cloddy, so the seed-soil contact was poor and seeding depth was variable.	Ask the farmer about clods at planting and the type of tillage used.
4. The seeding was hurried or careless or the planting implement was blocked.	Ask if hired labor was used at planting, or if the seeding was rushed due to other demands on the farmers' time. Examine planting implement.

Possible solutions

1. Change or adjust planting implement or land preparation to provide right depth.
2. Change land preparation to reduce clods and improve seed-soil contact, or add a compaction practice to firm the soil over the seed. Note that if the soil is a clay and if it is wet at planting (>50% available moisture), the soil should not be firmed after the seed is placed in the hole, since the seedling may not be able to emerge through the hardened crust.
3. Perform tillage operations when the soil is in the correct moisture range (Table 4).



This maize seedling could not emerge through the surface crust on the soil.

Table 4. Approximate soil moisture contents appropriate for different tillage operations, based on soil textural class. (See pp. 106 and 110 to identify textural class and to estimate available soil moisture).

Textural class	% available moisture recommended for:	
	Primary tillage operations	Secondary tillage operations
Clay loam (fine)	25% (near wilting point)	Within a day after primary tillage
Loam (medium)	25% - 40%	Within a day (maximum of two days) after primary tillage
Sandy loam (moderately coarse)*	25% - 60%	30 - 50 %
Sandy (coarse)*	Up to 60%	30 - 50 %

* In sandy soils, hard pans due to equipment traffic at incorrect moisture can develop at depths greater than is the case for clay and loam soils.

Source: H. Muhtar, personal communication.

Density

The optimum density under non-limiting conditions will be different for different varieties, and it should be determined for the important varieties in your region. The optimum density could be related roughly to plant height and maturity for CIMMYT lowland tropical germplasm growing in one environment (Table 5, p. 60).

The optimum density at harvest for a variety is that which yields the most grain when the crop is grown under *non-limiting* conditions, which are almost never found in farmers' fields. Therefore, the recommended density at harvest (that which will give the best grain yields in farmers' fields) will be different from the optimum density. In addition, the best density for grain yield in a farmers' field will vary from year to year, depending on the climate and crop management. An agronomist working in an area needs to find the population density which will give the farmer the best return in bad years as well as in good years. It has been shown that a reduction in population density of 30% below the optimum will only reduce yields by about 5% in good years (Figure 2, p. 60), and the lower density should increase yields when stress occurs. Therefore recommended densities are usually about 20-30% below the optimum density.

If drought stress is very common in your region, you may need to adjust your recommended densities downward even more than 30% from the optimum in order to increase the water available to each plant. In semi-arid regions, the risk of crop failure increases sharply as density increases (Fig. 2, p. 60). If the density is reduced to adjust for drought, remember that weed control might also require more attention, since the low density maize will provide less shade.

Once you have decided on a recommended density, you will need to calculate the amount of loss you expect from planting to harvest in order to get a recommended seeding rate.

Compare the harvest density in the area with the number of seeds the farmer plants. In many environments, the loss of plants from planting to harvest is around 20%. Divide your recommended density by one minus the % loss ($1 - \% \text{ loss}$) to get the recommended seeding rate. For example, if you were growing a material with an optimum density of 85,000 plants/ha, the recommended density for farmers' fields might be:

$$85,000 - (85,000 \times 0.30) = 60,000 \text{ plants/ha}$$

However, you would expect about 20% of the plants to be lost between planting and harvest due to insect attack and disease. The recommended seeding rate is thus:

$$60,000 \div (1 - 0.20) = 75,000 \text{ seeds/ha}$$

If there are 3,500 seeds in a kilo, that rate equals 21.4 kg of seed per hectare.

Is population density a problem?

Evidence: measurements

1. If the crop is planted in a row pattern with plants in hills (individual planting stations), count the number of hills in 5-m lengths of row at ten randomly chosen locations in the field. Count the number of plants as well.* At each location, measure the distance between the rows. Now calculate the number of plants per hill (plant distribution) and the number of plants per hectare (population density).

$$\text{Plants/hill} = \frac{\text{number of plants in 5 m}}{\text{number of hills in 5 m}}$$

$$\text{Plants/ha} = \frac{\text{number of plants in 5 m}}{\text{5 m} \times \text{distance between rows measured in meters}} \times 10,000$$

* This procedure should not require more than 30 seconds at each sampling point. Hook a 5-m piece of string to a plant and walk down the row, counting the number of hills you pass until you reach the end of the string. Now walk back to the starting point while counting the number of plants. In this way these important data can be collected quickly and easily.

2. If the crop is planted in rows but not in hills (for example, when a mechanical planter is used), count the number of plants in 5-m lengths at ten randomly chosen locations in the field. At each location, measure the distance between the rows. Now calculate the number of plants per hectare (population density).

$$\text{Plants/ha} = \frac{\text{number of plants in } 5 \text{ m}}{5 \text{ m} \times \text{distance between rows measured in meters}} \times 10,000$$

3. If the crop is planted with no clear pattern (broadcast), count the number of hills and the number of plants in ten randomly chosen 20 m^2 areas.

$$\text{Plants/hill} = \frac{\text{number of plants in } 20 \text{ m}^2}{\text{number of hills in } 20 \text{ m}^2}$$

$$\text{Plants/ha} = \text{number of plants in } 20 \text{ m}^2 \times 500$$

4. Compare the population density with the optimum for the variety. If you do not know the optimum density for your variety, use the estimates in Table 5, p. 60.

Evidence: observations

1. Look over the field. Are the plants uniformly distributed, or are there patches of missing plants? Problems such as soil insects, rodents, and waterlogging can reduce population density in spots that you may overlook in your sampling but which are important for the farmer.
2. Examine the plants carefully at each location where you take your measurements. Are the stems thin and weak? That may indicate a density that is too high (or too many plants per hill).
3. Look at the amount of sunlight which reaches the ground between 11 a.m. and 1 p.m. By flowering, no more than about 20% of the sunlight should reach the ground, (the maize should intercept at least 80%—see photos pp. 58, 59) unless the maize is grown in an environment where drought stress is common or with an intercrop. If the maize is intercropped, most of the sunlight which the maize lets pass should strike the leaves of the intercrop.
4. If the crop is past flowering, look at the number of ears per plant. (Count the number of ears in the sample, and divide by the number of plants.) Is the number of ears per plant below 0.9? The density (or number of plants per hill) may be too high.
5. At harvest: if the average weight of individual dry ears is above 180 grams, the density may have been too low.

Causes of low plant density	Additional evidence required
1. Farmer plants too few seeds.	Ask the farmer how much seed was planted and why. Look at rainfall data to see if drought is common. The farmer may lower density to adjust for drought.
2. Seed planted not viable.	Test seed viability (p. 102). Ask how the seed was stored, and compare with "General rules for seed storage", p. 102.
3. Poor seedbed preparation.	Ask farmer about land preparation.
4. Plants lost after planting (during germination and afterwards).	Look for evidence of disease, pests, waterlogging, drought stress, birds or rodents. Ask the farmer about these problems. If the farmer planted dry, ask how many days after planting the rain came. Examine temperature records for that period. If soil temperatures were above 40°C for more than 2 days, the seed may have been damaged. (Recall that the maximum temperature of bare, dry soil can be several degrees higher than the maximum air temperature.)
5. Farmer destroyed some plants while cultivating.	Ask farmer about cultivation practices. Look for pieces of broken or uprooted plants.

Possible solutions

1. Increase seeding rate.
2. Improve seed quality (p. 102), or do a germination test before planting and adjust the seeding rate accordingly.
3. Improve land preparation or cultivation practices.
4. Fungicide treatment of seed or crop rotation to reduce disease losses.
5. Insecticide treatment of seed to reduce insect losses.
6. Increase planting depth or apply mulch to avoid early drought or high soil temperatures. Improve covering method and/or firm the soil over the seed to improve seed-soil contact in areas with marginal soil moisture. These measures may also reduce losses to birds or rodents (p. 100)
7. Level field to avoid waterlogging.

The sunlight that reaches the ground through the crop canopy is often a good indicator of whether density is adequate. By flowering, the crop should be intercepting at least 80% of the sunlight in most environments where maize is not intercropped and drought is not frequent. The photos show 40, 70, and 90% light interception.



40% light interception. (G. Edmeades)



70% light interception. (G. Edmeades)

90% light interception. (G. Edmeades)



Table 5. Optimum densities and recommended densities (optimum - 30%) for CIMMYT lowland tropical maize.

Plant height (m)	Days to 50% male flowering	Optimum density (plants/ha)	Recommended density (plants/ha)
1.6-1.8	<50	85,000	60,000
1.8-2.0	50-55	78,000	55,000
2.0-2.2	56-60	70,000	50,000
2.2-2.4	>60	65,000	45,000

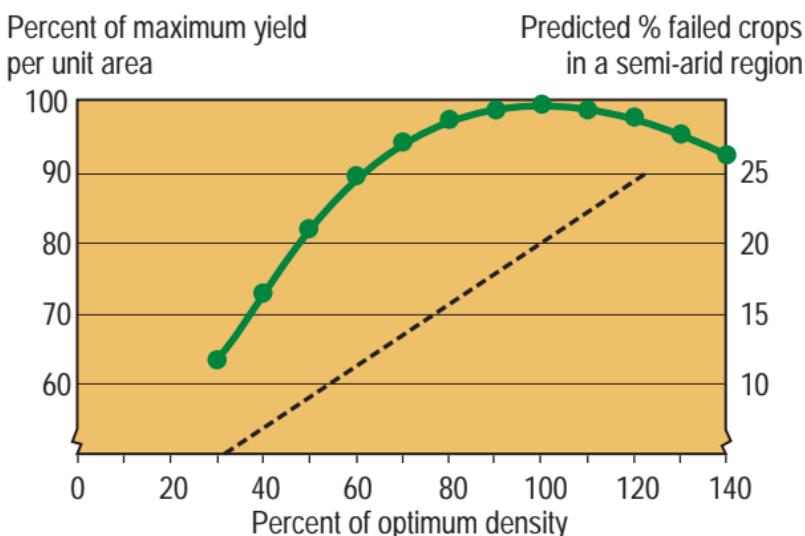


Figure 2. Relationship between grain yield and plant density.

Modified from S.G. Carmer and J.A. Jacobs, 1965. An exponential model for predicting optimum plant density and maximum corn yield. *Agronomy Journal* 57:241-244. Used by permission of the publisher, The American Society of Agronomy, Inc. And from B.A. Keating, B.M. Wafula, and J.M. Watiki, 1992. Exploring strategies for increased productivity—The case for maize in semi-arid eastern Kenya. In: M.E. Probert, ed., *A Search for Strategies for Sustainable Dryland Cropping in Semi-arid Eastern Kenya: Proceedings of a Symposium Held in Nairobi, Kenya, 10-11 December 1990*. ACIAR Proceedings No. 41, pp. 90-100.

Plant distribution

Since hand planted maize is often arranged in hills (individual planting stations) with more than one plant per hill, spatial arrangement can sometimes be a problem, even where density is appropriate. Studies indicate that when more than two plants grow in the same hill, grain yield is affected by competition for water, nutrients, and light. If four or more plants grow in the same hill, one-to-three of them usually do not produce an ear.

Why do farmers often plant many seeds in one hill? When the farmer plants by hand, making more seed holes takes longer. If you recommend that the farmer make more holes per hectare, you need to be certain that the yield advantage will be profitable. In addition, farmers sometimes overplant and then remove plants during the season as forage for animals.

Causes of high number of plants/hill	Additional evidence required
1. The farmer overplants to protect against possible losses from pests or disease.	Ask farmer how many seeds are sown per hill and why.
2. Several seeds are sown per hill to reduce planting costs.	Ask farmer how many seeds are sown per hill and why.

Possible solutions

1. Thin overplanted hills to 2-3 plants/hill when plants are at the V3-V4 stage while maintaining adequate overall population density.
2. Chemically protect seed with fungicide or pesticide to reduce need for overplanting.
3. Demonstrate a yield advantage to planting more hills/ha that compensates for increased labor costs and produces higher profits.

Mineral nutrition

The maize crop needs certain mineral elements in adequate quantities for good growth. These nutrients are generally supplied from the soil and from added fertilizers. Although the maize plant uses 13 different nutrients, only three are required in relatively large quantities: nitrogen, phosphorus, and potassium. These are the nutrients which most frequently limit maize production, but sulfur and some micronutrients such as zinc and magnesium may be important constraints in some areas.

Yield can often be reduced 10-30% by deficiencies of major nutrients before any clear symptoms of deficiency are observed in the field. Even if you don't see symptoms, it is a good idea to calculate a nitrogen balance and analyze soil P levels.

Is mineral nutrition a problem?

Evidence: observations

Walk through the field at different growth stages. If you find the leaf symptoms mentioned below, you can assume that the deficiency is probably important enough to cause some yield reduction. Recall that some diseases can cause symptoms similar to nutrient deficiency. If the cause is nutrient deficiency, symptoms will tend to occur in large areas of the field. If you see the symptoms on isolated plants, they are more likely the result of disease.

1. Before the V6 stage, pale yellow plants with small leaves and slow growth indicate N deficiency or, less commonly, S deficiency. Plants with reddish-purple color along the edges of the leaves can indicate P deficiency (this symptom is accentuated by cool weather).
2. During the period of rapid elongation, lower leaves with yellowing beginning at the tip and moving along the middle of the leaf in a 'v' shape indicates N deficiency. If the yellowing moves along the edges, the problem may be K shortage. At this stage other nutrient deficiency symptoms can also appear, such as pale, chlorotic stripes on the leaves. If this happens on the upper leaves, it can be due to a lack of iron or, in rare cases, copper. Broad whitish bands running along the center of new leaves or in the zone of elongation at the base of leaves may reveal zinc shortage. Yellow striping (chlorosis) on lower leaves may mean magnesium deficiency.
3. What was the previous crop? You can often tell by looking at the residue in the field, or you can ask the farmer. If maize follows a heavily fertilized cash crop, deficiencies of major nutrients are less likely.
4. Compare the heights of plants on the edge of the field with those having full competition. The plants with less competition will tend to be taller than the plants which are completely surrounded if drought or nutrient stress has occurred.

Evidence: calculations

Even if you do not see clear symptoms of nitrogen deficiency in the field, you are not justified in saying that no response to N fertilizer can be expected. Ask the farmer how much N fertilizer he applies, and how much maize he harvests. You can now make some calculations to predict whether nitrogen is limiting.

First calculate the amount of N which is being supplied to the crop by sources other than the fertilizer applied by the farmer. The simplest way to do this is by calculating the N content of an *unfertilized* crop growing in a similar soil and environment when water is not limiting. Try to find a farmer who did not apply N either to his maize or to the previous crops in that field, and ask what yield he obtained when drought stress was not important. Assume that about 25 kg N/ha are required to produce each ton of grain.

$$\text{N supplying capacity of soil/ha/season} = \frac{\text{tons of grain produced/ha}}{25}$$

This N will come from several sources. One important source is soil organic matter, which will be abundant in a recently cleared field or after a long fallow, but which will tend to decline with continuous cropping (see Table 6, p. 67). You can improve your estimate of the N supplying capacity of the soil in your region by finding out maize yields of unfertilized fields and relating them to their cropping histories. The other inputs of N will be from rain, dust, and nonsymbiotic N fixation.

Now add to this amount the N from the fertilizer applied by the farmer. The efficiency of recovery of applied fertilizer will vary, but you can assume for this calculation that about 40% of the fertilizer N applied is available to the plant. The total input of N will be:

$$\text{N from soil} + (\text{fertilizer N applied} \times 0.4)$$

Is this amount as large as that removed by a crop which yields the potential for the area? (Assume that, for a yield level near 4 tons, about 15 kg N/ha are removed for each ton of grain, and add to this another 10 kg N/ha per ton of grain if the stover is removed from the field.) If not, N supply may be limiting.

Evidence: soil analyses

You can use soil analyses to determine whether to expect a response to P or K fertilizer. For these tests to be really accurate, however, they must be calibrated for the soils in the region.

For P. The Bray I test can be used for acid soils. A value of <7 ppm means a P response is likely; 7-20 ppm means P response is possible. If the Bray II test is used, a value of <15 ppm means a P response is likely; 15-30 ppm means P response is possible. The Olsen test can be used for soils with pH over 7. A value of <5 from this test indicates that a response to P fertilizer is likely; values of 5-10 indicate a possible response.

For K. The results should be expressed as milliequivalents of K /100 g soil. Depending on the soil, the sufficiency values vary widely, but in general, a value of <0.2 can be considered low, and a response to K is likely. Sandy soils are more prone to K deficiencies than are clay soils.

Table 6. Approximate amounts of N supplied annually from soil organic matter in different environments.

Environment	History	kg N/ha/yr
Lowland tropical forest	Recently cleared	55
	Cropped >4 years	22
High rainfall tropical savannah (1,250 mm/year)	Long fallow	15
	Short or no fallow	5
Low rainfall tropical savannah (850 mm/year)	Long fallow	4
	Short or no fallow	2
Tropical highland forest	Recently cleared	45
	Cropped >4 years	18

Adapted from P.A. Sanchez, 1976, Properties and Management of Soils in the Tropics. J.Wiley and Sons, N.Y.

Causes of nutrient deficiencies	Additional evidence required
1. Not enough fertilizer (NPK) was applied.	Ask farmer how much fertilizer was applied.
2. Fertilizer applied is lost to leaching, runoff, or volatilization.	Ask farmers about fertilizer source and placement, and rainfall events after application.
3. Fertilizer is applied when the crop cannot use it well, or when the crop is already stunted due to factors such as inadequate weed control.	Ask when fertilizer was applied, and about the crop condition when application was made.
4. Waterlogging results in N deficiency.	Check for symptoms of waterlogging (p. 26). Ask farmer about rainfall.
5. There is excessive competition with weeds or intercrop for nutrients.	Check for presence of weeds or intercrop.
6. Soil pH makes certain nutrients unavailable.	Test soil pH. If <5.2 , Mg deficiency common and P may be unavailable. If >8 , deficiencies of Zn, Fe, and Cu are common. (p. 63; Fig. 1, p. 42).
7. The soil contains low amounts of certain micronutrients.	Soil tests are difficult to interpret. Apply foliar solution or soil amendments to a small test plot and look for a change in symptoms.

Possible solutions

1. Increase fertilizer rate.
2. Change fertilizer application method or timing so that less is lost.
3. Improve drainage.
4. Reduce weed competition.
5. Lime to increase soil pH.
6. Apply micronutrients.



Symptoms of nitrogen deficiency at flowering. Note the "V"-shaped yellow areas, which are first seen on the lower leaves.

Chemical injury

Maize can be damaged by the improper use of agricultural chemicals such as herbicides, fertilizers, or insecticides. The damage is usually the result of applying the chemical carelessly, at too high a rate, at the wrong growth stage, or when the plants are under drought or temperature stress.

Usually problems of chemical injury are the result of occasional accidents and are not major limitations to yield in an area, but it is important that an agronomist be able to recognize these problems.

Herbicide injury can cause malformation of young plants and yellowing, burning, and dying of the leaves. The malformation (such as twisted leaves which do not unroll properly, or distorted roots) results from applying herbicides from certain groups such as 2,4-D at the wrong growth stage or at too high a rate. This problem can occur with phenoxy herbicides (e.g. 2,4-D), dinitroanaline herbicides (e.g. pendimethalin), benzoic acid herbicides (e.g. dicamba), and amide herbicides (e.g. alachlor or metolachlor). Leaf chlorosis and death can result from overapplication of triazine herbicides (e.g. atrazine). Leaf burning results from getting a directed spray of a contact herbicide such as paraquat on the maize or from applying too high a concentration of another chemical. You can distinguish herbicide injury from foliar disease by looking for burning which occurs in patterns from the sprayer nozzle and which only affects leaves of a certain age which were exposed when the chemical was applied.

If fertilizers (especially N and K) are placed in contact with the seed or too close to young plants they can cause burning, especially if soil moisture is deficient. If the problem occurs at planting, the seeds may not germinate, or the seedling may emerge and then die. Burned plants may look wilted or stunted. When fertilizer is sidedressed, it should be placed no closer than 10 cm to the stem.

Foliar applied insecticides or fertilizers can occasionally cause burning of the maize leaves. This can be minimized by applying early in the morning or late in the evening, to avoid intense, direct sunlight on the leaves.

Is chemical injury a problem?

Evidence

Estimate the proportion of plants affected by the problem. If more than 10% of the plants are damaged badly enough to reduce yields (that is, if more than 30% of the leaf area on those plants is damaged), a problem exists. It is very important to look at several fields belonging to different farmers to decide if there is a problem with the technology in use or if a specific farmer simply made a mistake during that particular season.

If the injury has reduced the plant stand, measure the remaining population density. If the reduction in stand causes the density to drop below 70% of the optimum for your variety, measured under non-limiting conditions, the injury is important. (Density, p. 52).

Causes of herbicide injury	Additional evidence required
1. The wrong product was used.	Ask the farmer what was used. Check to see if the product is approved for use on maize.
2. The application rate of the product was too high.	Ask farmer how much chemical he used per tank of water. Look at his tank to see how big it is. Calculate the application rate he used. Check this against the recommended rate on the label or in Table 7, p. 74.
3. Timing of application was incorrect.	Ask the farmer when he applied the chemical. Relate this to an approximate growth stage and check against Table 7, p. 74.
4. A nonselective herbicide was applied with no shield or with a shield which did not work. The damage could also be due to drift from adjacent fields.	Ask to see the shield if one was used. Ask if the weeds were taller than the crop when the product was applied.

Possible solutions

1. Change to a safer product or use lower rates. Investigate "safeners" available for use with specific herbicides.
2. Change the timing or method of application of the product.
3. Use a better design of shield. If the weeds were taller than the crop at application, causing problems when the farmer tried to apply a directed spray, this indicates a land preparation problem (p. 45).

Causes of fertilizer burn

1. Product placed directly in hole with the seed.
2. Fertilizer was placed too close to the plant when sidedressed, especially when plants were under moisture stress.

Additional evidence required

- Ask farmer how planting was done.
- Ask where product was placed, what soil moisture was like, and if there was wilting after the application.

Possible solutions

1. Use a planting stick with two points to make a separate hole for fertilizer.
2. Sidedress fertilizer when soil moisture is adequate, and place the product at least 10 cm from the stem.
3. Design experiments to examine the effect of timing on fertilizer application. In some environments the application of fertilizer at planting can be avoided.

Table 7. Common herbicides used in maize, recommended range of concentrations,* and recommended time of application.

Chemical	Recommended rate (kg/ha)	Recommended time of application
2,4-D amine	0.5 - 1.0	From emergence until maize has 6 leaves (30 cm tall).
2,4-D ester	0.3 - 0.6	
Paraquat	0.2 - 0.6	When needed post-emergence but as directed spray. Contact with maize will burn the leaves.
Dicamba	0.25 - 0.36	As for 2,4-D.
Glyphosate	0.34 - 1.12 for annual weeds 1.12 - 4.48 for perennial weeds	Never allow chemical to contact maize. Can be used very carefully as a directed spray to control problem weeds.

* Note that the concentrations given here are as kg of active ingredient per hectare. You will have to calculate the amount of commercial product as:

$$\text{kg of commercial product} = \frac{\text{kg active ingredient}}{\text{fraction of active ingredient in the commercial product}}$$

Table 7. (cont'd)

Chemical	Recommended rate (kg/ha)	Recommended time of application
Atrazine	1.5 - 3	Pre-emergence. Can be applied post-emergence, but if applied with oil and crop is under stress, may damage maize.
Alachlor	1.7 - 4.5	Pre-emergence. Can be applied early post-emergence to crop, before weeds emerge.
Metolachlor	0.6 -1.2	Pre-emergence, or post-emergence before maize is 8 cm tall.
Pendimethalin	0.6 - 2.2	Pre-emergence.

Weed competition

The importance of weed competition in maize depends on four factors: the crop growth stage, the amount of weeds present, the degree of water and nutrient stress, and the weed species. Weeds damage the crop primarily by competing for light, water, and nutrients. Maize is very sensitive to this competition during the critical period between the V3 and the V8 stages.

Before the V3 stage, weeds are usually important only if they are larger than the maize or if the crop is suffering from water stress. Maize needs a period between the V3 and V8 stages when few weeds are present. From the V8 stage to maturity, the crop usually reduces the sunlight reaching the weeds enough to provide good weed control. In the later part of the cycle, weeds are important mainly if water or nutrient stress is a problem, or if a very aggressive weed overtops the maize and shades it, or if the weed has some allelopathic effect. In addition, some weeds make harvesting difficult, and thus increase production costs.

Some weed species cause more damage than others. This can be because the weeds actually produce toxic substances which damage the crop (allelopathy) or because the weeds are very effective competitors for water or nutrients. Some weed species which are reported to be allelopathic are listed in Table 8 p. 82.

Is weed competition a problem?

Note: These observations should be made before the maize reaches the 8-leaf stage. If the farmer controls weeds, you should make the observations just before the farmer cultivates or applies herbicide, and note the crop growth stage. If you visit the field after flowering, it will be difficult to estimate the importance of weeds on yield.

Evidence: observations

Examine a 5-m length between the rows at 10 random locations in the field.

1. Are many weeds larger than the crop? Is the crop shaded by the weeds? If so, the weeds are a problem.
2. Is the crop suffering from drought stress? Estimate the percent of sunlight which falls on weeds rather than the crop or bare ground. That percentage is close to the percentage of the available water which is being used by the weeds rather than by the crop.
3. Note the growth stage of the crop. Between the V3 and V8 stages, weed density should be low to avoid yield reduction.
4. Do maize plants in weedy spots in the field look different from those growing in clean spots? This can indicate severe competition for nutrients, water, and light, and/or allelopathic effects.
5. Compare different areas of the field with the photographs on pp. 80-81. Estimate the amount of yield loss. This comparison should be made around the V8 stage.
6. What are the main weed types present? Narrow or broad leaves? Annual or perennial? This information is needed to identify a method for addressing weed control problems and to know if toxins produced by the weeds might be important.

Causes of high weed competition	Additional evidence required
1. Poor manual weed control.	Ask farmer about the timing, frequency, and methods of weeding.
2. Weeding too late.	Look for large dead weeds lying in the field and stunted maize. Ask the farmer when he controlled weeds.
3. Ineffective herbicide application.	Ask farmer about conditions during application.
4. Planting delayed after land preparation.	Ask farmer for dates of field operations.
5. Problem weed species not controlled by current method.	Identify weed species. The perennials are poorly controlled manually. Most herbicides only control certain types of weeds (Table 9, p. 83).
6. Allelopathic weed.	Identify weed species (Table 8, p. 82).
7. If the land has been used for continuous maize cropping for many years, the load of weed seeds may be very high.	Ask farmer about the history of the field.

Possible solutions

1. Recommend improving the method or timeliness of weed control.
2. Reduce problems of drought or nutrient stress (pp. 20, 63).
3. Increase population density of crop and/or N application rate to get more shading of weeds.
4. Move to another site or rotate with another crop that will allow better control of problem weeds.

Maize at V8 under good, fair, poor, and no weed control. If there were no subsequent weeding, respective yields would be approximately 100, 75, 25, and 8% of potential. In the no-weeding treatment, even if weeds were controlled from this stage on, the crop would already have suffered irreversible damage (note the reduced plant size and early leaf senescence).



Good weed control. Yield = 100%.



Fair weed control. Yield = 75%.



Poor weed control. Yield = 25%.



No weed control. Yield = 8%.

Table 8. Some common weeds reported to have allelopathic properties.

Scientific name	Common name
<i>Abutilon theophrasti</i>	Velvetleaf
<i>Agropyron repens</i>	Quackgrass
<i>Amaranthus</i> sp.	Pigweed
<i>Ambrosia</i> sp.	Ragweed
<i>Avena fatua</i>	Wild oat
<i>Brassica</i> sp.	Mustard
<i>Chenopodium album</i>	Common lambsquarters
<i>Cynodon dactylon</i>	Bermuda grass
<i>Cyperus esculentus</i>	Yellow nutsedge
<i>Cyperus rotundus</i>	Purple nutsedge
<i>Digitaria sanguinalis</i>	Crabgrass
<i>Echinochloa crusgalli</i>	Barnyardgrass
<i>Helianthus annuus</i>	Sunflower
<i>Imperata cylindrica</i>	Alang-alang, Speargrass
<i>Poa</i> sp.	Bluegrass
<i>Portulaca oleracea</i>	Common purslane
<i>Rottboelia exaltata</i>	Rottboelia
<i>Setaria faberii</i>	Giant foxtail
<i>Sorghum halepense</i>	Johnsongrass

Sources: S.O. Duke, 1985. *Weed Physiology*, Vol. 1: Reproduction and Ecophysiology. CRC Press.

E.L. Rice, 1984. *Allelopathy*. Academic Press, N.Y.

Table 9. Selectivity of some important herbicides used in maize-based cropping systems.

Chemical	Species controlled	Species not controlled *
2,4-D	Many annual broad- leaf weeds. High rates can be used on <i>Cyperus</i> sp.	Many annual and perennial grasses
Paraquat	Most annual grasses and broadleaf weeds.	Perennial weeds, also <i>Parthenium hysterophorus</i> .
Dicamba	Many annual broad leaf weeds.	Most perennial weeds.
Glyphosate	Most annual plants (including maize!) and many perennial weeds, including <i>Cyperus</i> , <i>Imperata</i> , and <i>Sorghum halepense</i> .	Species with underground storage tubers may require additional treatments. Weeds should be growing when the chemical is applied.

* When the chemical is applied at the recommended rate.

Table 9. (cont'd).

Chemical	Species controlled	Species not controlled *
Atrazine	Most annual broadleaf weeds, some annual grasses.	Most perennial weeds, many annual grasses.
Alachlor	Many annual grasses and broadleaf weeds.	Most perennial weeds.
Metolachlor	Most annual grasses, some broadleaf weeds.	Most perennial weeds, many broadleaf weeds.
Pendimethalin	Many annual grasses and broadleaf weeds, including <i>Rottboelia</i> .	Most perennial weeds.

* When the chemical is applied at the recommended rate.

Defoliation

Many factors can cause defoliation (loss of green leaves) in maize. Leaf area is often lost due to insect attack, wind or hail damage, or feeding by livestock. In addition, in many areas farmers remove leaves before the crop is mature to use them as fodder. The effect of defoliation on grain yield depends on the amount of leaf loss, which leaves are affected, and the time leaf loss occurs (Table 10, p. 87).

Is defoliation a problem?

Evidence: observations

At what growth stage did defoliation occur? If the crop is younger than V4-V5, defoliation will usually have little effect on yield. After the V6 stage, the effect of defoliation on yield increases as flowering approaches and declines with time after flowering.

Estimate the amount of leaf area lost on 5 plants at 10 different spots in the field. If the crop has not reached flowering, observe the top 10 leaves. If the crop has reached flowering, observe the leaves above the ear. Compare the amount of leaf loss and the stage of development with Table 10, p. 87. If the expected yield loss is more than 5%, defoliation is a problem.

Note: If the fodder is an important part of the maize production system, you should not necessarily worry if leaf removal reduces grain yield somewhat. Try writing a budget for the system, including the value of the fodder, and remembering that green leaves tend to be better quality feed than dry leaves. The farmer needs to get the most benefit he can from the system, and in this case he may be willing to lose some grain in order to harvest more or better fodder.

Causes of defoliation

Usually the causes of defoliation are not difficult to identify. Ask the farmer what caused the loss of leaves. Damage due to hail, insects, diseases, and livestock leave characteristic patterns.

Possible solutions

1. Loss due to insects: apply insecticide; use resistant varieties; change tillage, planting date, or rotation to reduce insect populations.
2. Loss due to disease: change to a resistant variety; change planting date.
3. Loss due to defoliation by the farmer: recommend a shift in the date of leaf removal if necessary.
4. Loss due to hail: some varieties (especially highland maizes) are less damaged by hail than others. If hail is a frequent problem, it may be useful to change varieties or shift the planting date.

Table 10. The % yield loss associated with different levels of defoliation occurring at different growth stages.

Level of defoliation	Growth stage			
	V6	V12	VT	R2
33% area removed ¹	3	7	22	10
66% area removed ¹	3	23	50	26
All leaves removed ¹	2	40	92	80
Leaves below ear removed ²	-	-	-	2
Plants cut off just above the ear ²	-	-	-	45
54% area removed, low density ³	-	-	-	28
51% area removed, high density ³	-	-	-	18
73% area removed, high density ³	-	-	-	37

Sources:

- ¹ C.A. Shapiro , T.A. Peterson, and A.D. Flowerday. 1986. Yield loss due to simulated hail damage on corn: a comparison of predicted and actual values. *Agronomy Journal* 78:585-589. (Temperate maize)
- ² R.F. Soza, A.D. Violic, and V. Claure. 1975. Maize forage defoliation. Paper presented at the XXI PCCMCA Meeting, El Salvador. (Tropical maize)
- ³ G. O. Edmeades and H. R. Laffite. 1993. Defoliation and plant density effects on Maize selected for reduced plant height. *Crop Sci. in press.* (Tropical maize; remaining leaves were close to the ear)

BIOTIC FACTORS*

Soil pests

Soil insects can be particularly damaging in maize because they reduce plant density, and maize cannot easily recover from low densities. These insects, along with nematodes, can also affect the plant roots and cause problems of drought stress or lodging.

Are soil insects a problem?

Evidence: observations

1. Is plant emergence irregular? Dig up seeds in the areas where emergence is poor and use Key 1 (p. 6) to interpret what you find.

2. Are the plants wilted even though soil moisture is adequate? Pull lightly on the plant. Cutworms or white grubs may have eaten through it at the base. Dig up a wilted plant and examine the roots. Look for larvae inside the roots or sections which have been chewed. Cut open the plant all the way down the length of the stem and look for larvae or tunnels where they have been.

Another possible (though not common) cause of root damage is nematodes. These tiny organisms can cause stunted, discolored root systems, but the definitive diagnosis of nematode problems requires laboratory analysis.

* This section does not seek to describe all the disease and insect problems that can affect maize yield. The factors discussed are those which might be confused with agronomic problems, or which might be corrected by a change in agronomic practices.

3. Look for plants that have curved stems or which are root lodged. Pull on the stem of the plant lightly; if many roots are damaged, the plant can easily be pulled out of the ground. Dig up some plants and look for clipped roots and tunnels. Dig up the soil around affected plants—cutworms are often found in the soil near the plant.
4. Look for termite mounds in the fields in areas where termites are common. These insects cut maize roots and can cause lodging at or after the VT stage.

Causes of soil pest problems	Additional evidence required
1. High natural level of infestation, or high level of insects due to constant maize cropping.	Dig up area around affected plants early in the morning. Look for larvae. A laboratory test is required to confirm nematode infestation. Ask farmer about rotation patterns.
2. Poor weed control, or poor incorporation of previous crop residues.	Ask farmer about weed populations during the fallow period and about land preparation. Look over the field for persistent weeds which serve as insect hosts, or for residues on the soil surface.
3. Termites tend to prefer maize over other crops.	Check if maize fields are more severely affected than adjacent fields planted to other crops.

Possible solutions

Note: All solutions require the correct identification of the insect. Use an insect identification guide or request help from an expert if you are uncertain.

1. Treat the seed with a protective chemical or apply a systemic insecticide.
2. Rotate with another crop to reduce the infestation.
3. Change tillage practices to reduce insect populations.
4. Plant a resistant variety if one is available.
5. Move maize away from termite infested fields.



Insects have cut through the whorl of this young plant.
(A. Violic)

Above-ground insects

Stalk borers, which can cause wilting and tillering in young plants and lodging in older plants, are often associated with symptoms that look like moisture stress. Some of the small sucking arthropods that attack leaves can cause damage similar to nutrient deficiencies. Other insects feed on silks, leading to poor pollinations. The main goal of this section is to help agronomists recognize these problems.

This section will not discuss leaf-chewing insects. The damage due to these insects can be easily identified, and economic thresholds for damage will have to be worked out for individual regions. The section in this guide on defoliation will give some idea of economic thresholds for leaf loss (Defoliation, p. 85).

Are above-ground insects a problem?

Evidence: observations

1. *Stalk borers.* Do young plants look wilted? Pull upward on the whorl. Stalk borers often cut through the whorl, and you can easily pull it out of the surrounding stem. Plants that are affected frequently produce tillers if the growing point is damaged. Borers also produce rows of "shot holes" on the leaves of young plants. Later in the cycle, look for small entry holes in the stalk. If plants lodge, cut open the stalks and look for tunnels caused by the larvae. Stalk borers often cause low plant densities and lodging (see pp. 33 and 52 to estimate economic importance), but early infestation can also leave plants severely stunted with low yields.

2. *Sucking arthropods that attack leaves (spider mites and thrips).* Look for silvery or yellow patches on the leaves. In arid zones, carefully examine the lower leaf surface for the tiny insects or for their delicate webs. In humid areas, examine the top surface of the leaf. (These insects are seldom of economic significance; it is simply useful to recognize that nutrient stress, disease, or chemical damage are not the causes for the symptoms.)
3. *Silk-cutting insects.* Examine the crop at flowering. Are the silks eaten away to the husk? Visit the field in the late evening or early morning and look for worms or beetles on the silks. At harvest, look for a high incidence of poorly pollinated ears. If seed set is reduced by more than 20% on more than 20% of the plants, the yield loss is significant.

Causes of insect problems	Additional evidence required
1. Continuous maize cropping allows insect populations to build up, especially where residues are not incorporated.	Ask farmer about rotations. Observe residue management.
2. Maize cycle coincides with the natural annual buildup of insect populations.	Ask farmer about other crops planted earlier in the year which might serve as hosts for insects.
3. Dry weather can cause outbreaks of spider mites.	Review weather records.

Possible solutions

Note: All solutions require the correct identification of the insect. Use an insect identification guide or request help from an expert if you are uncertain.

1. Apply an insecticide.
2. Rotate maize with another crop.
3. Plant a resistant variety if one is available.
4. Plant earlier in the year to avoid high insect populations.
5. Incorporate residues immediately after harvest.



Spider mite damage. Note the yellow patches on the leaves.

Fungal and bacterial seedling diseases*

Many diseases which attack seeds and seedlings reduce plant density and plant vigor. Since plant density is critical to good maize yields, these diseases need to be identified and controlled. In many cases, the impact of these diseases can be reduced by changing agronomic practices. For example, diseases which are unimportant when conditions are good at planting may become lethal if the seed is planted when soil temperatures are low (<15°C).

Stalk rots can kill plants if they attack early in the cycle, and thus reduce plant density. Later in the cycle, stalk rots cause lodging.

Leaf blights cause a reduction in photosynthesizing leaf area. Their initial effects tend to be similar to defoliation, though later the production of toxins may become important. Leaf blights can resemble nutrient stress in the very early stages of the disease, but later in the cycle they can usually be identified using a disease guide.

Are diseases a problem?

Evidence: measurements

Estimate plant density around flowering time (p. 52). Is the density appropriate for the variety?

* Diseases of germinating seeds and seedlings, leaf blights, and stalk rots.

Evidence: calculations

Ask the farmer how much seed was planted. Divide the number of plants by the number of seeds to get the percentage survival. If the seed was good (germination above 90%), you should expect about 80% survival to flowering. (Remember that soil insects and moisture stress can also reduce survival.)

Evidence: observations

1. Before the V4 stage: Look over the field for areas where emergence is poor. Dig up the seeds. Are they swollen with water but rotten or blackened? This is a sign of disease. The economic significance will be related primarily to the decrease in plant density.
2. Before the V8 stage: Look for plants which appear to be wilted, even though soil water seems adequate, or which are turning brown and dying. Pull up the plants and cut them open all along the stalk. Look for brownish spots or areas that appear to be water-soaked. These are signs of stalk rot. The economic significance will be related primarily to the decrease in plant density.
3. Near maturity: Make a count of stalk lodging (p. 33). If lodging is significant, cut open some stalks and look for browning and shredding of the stalk tissues. The main economic significance will be associated with lodging, but if the disease attacked the plant early in the cycle, there may be a significant direct effect on yield as well. Is there significant leaf area above the ear lost to leaf blights? The area affected can be related to losses as in the case of defoliation, for a minimum estimate of damage.

Causes of plant diseases	Additional evidence required
1. Seeds were planted too deep, or in cool weather without fungicide.	Check planting depth, and look at temperature records.
2. The variety is susceptible to important diseases in the area.	Ask the farmer what variety was planted. Ask if other varieties are less affected.
3. An alternate host for the disease is present in the area.	Look for other plants (or crop residues) which can serve as a co-host for the disease.

Possible solutions

Note: All solutions require accurate identification of the disease. Consult a pathologist or a disease guide if you are uncertain.

1. Apply a fungicide as a seed treatment to control diseases of the seed and seedling, and use good quality seed.
2. Plant a variety which is resistant to the problem disease. Considerable genetic variation in resistance exists for most major maize diseases.
3. Change the planting date or rotation.



Stalk rot was an important cause of plant loss in this field.



Extensive leaf blight has largely defoliated the plants on the left, causing an early end to grain filling. (J. Mihm)

Viral diseases

Viral diseases or those caused by mycoplasm-type organisms frequently result in symptoms that resemble nutrient deficiencies. The most common diseases are shown in Table 11, p. 99, along with the nutrient problems with which they might be confused. Many of these diseases are spread by an insect vector. The symptoms may appear only on upper leaves, or over the entire plant, depending on when the infection occurred.

In order to distinguish viral diseases from nutrient problems, ask the following questions:

1. Are the affected plants found in patches where most of the plants have symptoms, or are they scattered around the field? You would expect the disease to affect scattered plants, though the plants may be concentrated along the margin of a field where the vector entered. Mineral deficiency will tend to affect all of the plants in an area of the field. Look for a mottle or mosaic pattern on the leaves which is characteristic of some viral diseases. Generally, streaks or stripes caused by a disease will be centered on the veins, while chlorotic stripes caused by nutrient deficiencies are often interveinal.

2. Is the development of the plant affected? Viral diseases, if they strike early in the season, will often cause the plants to be stunted, with distorted leaves and undeveloped ears. Mineral deficiencies may affect growth, but the development of the plant will usually be fairly normal.

The control of viral diseases usually relies upon planting resistant varieties, attempting to control the insect vector, and/or eliminating alternate hosts for the disease.

Table 11. Diseases caused by viruses or mycoplasm-type organisms which might be confused with nutrient deficiencies.

Disease	Symptom	Mineral deficiency with similar symptoms
Fine stripe, corn stunt	Narrow white stripes	Mg, Fe, S (younger leaves)
Streak	White streaks, especially at base of young leaves	Zn
Maize bushy stunt	Reddish leaf margins	P

Genetic traits

Some genetic traits (mutations) appear similar to mineral deficiencies, virus diseases, or chemical injury. Plants exhibiting these traits are usually found with a very low frequency and tend not to occur in patches.

Birds and rodents

Birds and rodents usually eat seeds or plants, especially early in the season, and thus reduce plant density. They can also damage maize late in the season by eating grain off the mature ear. Rodents can be a more severe problem if lodging has occurred, placing the ear within the animal's reach.

Is bird or rodent damage a problem?

Evidence: measurements

Is the plant density low (p. 52)?

Evidence: observations

1. Before the V4 stage: Look for areas where seeds have been dug up. Often birds will pull the young plant out of the ground and eat the remaining seed. Look for the tracks or droppings of birds or rodents in areas where emergence is poor. The damage often occurs in distinct patches or along the margins of fields where shrubs or trees provide a habitat. The economic importance of this damage will be related to the effect on plant density.
2. Around maturity: Examine the tips of ears in different areas of the field. Are the husks chewed or shredded? Estimate how much of the grain is lost. If more than 20% of the ears are more than 25% damaged, the yield reduction is over 5% and the problem may be of economic importance. Even if the damage is less than this, the problem may cause economic losses by allowing insects and disease to affect the ear.

Causes of bird and rodent damage	Additional evidence required
1. Seed planted too shallow, or soil not firmed over the seed.	Dig up seed and measure planting depth. Ask farmer about planting method.
2. Poor husk cover, so the grain on the ear was easily attacked by birds.	Examine husk cover.
3. Lodging, allowing rodents to reach the ears.	Count lodging.
4. Maize planted out of season, or a very early variety, so it was the only food supply for birds and rodents in the area.	Observe the maturity of the crop and compare it with that of other maize in the area. Check for damage in late-planted fields.

Possible solutions

1. Change the planting method.
2. Apply a bird repellent to the seed.
3. Poison rodents in burrows near the field.
4. Plant a variety with improved husk cover.
5. Double the maize (bend the stalks below the ear after the R5 stage) to limit bird damage.
6. Plant varieties of similar maturity for the region.
7. Employ a bird scarer.

SECTION 4. MEASUREMENT PROCEDURES AND CALCULATIONS

TESTING MAIZE SEED VIABILITY

Poor plant stands (low populations) are often caused by poor quality seed. The primary causes of reduced seed quality are storage under conditions of high relative humidity and/or high temperature, and damage due to insects or overly rapid drying. Some general rules* about storage conditions for maize:

1. For every 5°C increase in the storage temperature over the range from 0 to 50°C, the life of the seed is reduced by half.
2. The relative humidity of the storage area should be below 65%. For the temperature range from 6-30°C, that means that the maize grain should be at a stable (equilibrium) moisture content of 12%. If the relative humidity of the storage area rises to 80%, the grain will absorb water vapor from the air, and the grain moisture will rise to 15%. At that moisture level, fungi can attack the seed and reduce its viability.
3. Storage temperature and relative humidity are related: if the sum of temperature (in °C) plus the relative humidity (in percent) is 80, the seed will begin to deteriorate after 1-5 months. If the sum is 70, you can store the seed safely for 18 months.

* Source: Rules for testing seeds. Association of Official Seed Analysts. Journal of Seed Technology 6:30-35, 1981.

4. Seed quality can be reduced if drying is not done carefully, especially if the seed had a high moisture content at harvest. Seed maize should never be dried with air warmer than 45°C. If the seed moisture is above 25%, the seed must be dried slowly (with air temperature no more than 10°C above ambient) to avoid cracking.

Another cause of poor seed quality is diseases which attack the grain either in the field before harvest or while in storage. The main diseases which affect seed viability are ear and kernel rots.

To test seed viability (germination tests)

1. Collect a sample of seed from the farmer near planting time, not just after the harvest. Ask the farmer how long he stores his seed, and examine the storage area. This will help you interpret the results of the germination test. Ask him if he selects only good seeds for planting, or if he sows without removing damaged seeds. This information will allow you to select seed for the germination test which is similar to the seed the farmer will plant.
2. You will need to collect about 500 seeds. If the grain is already shelled, push your hand well into the bag or pile with your fingers straight, and then close your hand to draw out the sample. Collect samples from five different places in the bag or pile (especially from the center). If the maize is still on the cobs, collect at least ten ears from different places in the pile and take the grain from the central part of each ear.

3. Examine the seed for insects, and for holes, cracks, or other damage. If the farmer sows only good seed, you should test only good seed.
4. Count out 400 seeds and divide them into groups of 50. Moisten a paper towel so that it is damp but water does not drip from it when you shake it. Place the seeds on the paper towel in a line along the middle so that they are not touching. Fold the paper over the seeds, and then roll it up loosely. Place the eight samples of 50 seeds in an open plastic bag with the rolls placed vertically in a place where the temperature stays between 20-30°C. Check daily to be sure that the paper towels do not dry out.

You can also use a dish of wet sand for the test. Plant 400 seeds in groups of 50 about 2 cm deep and be sure that the sand does not dry out.

5. After 4 days, count the number of germinated seeds on each towel or in the dish of sand. You should count only normal seedlings — those which have both roots and shoots. Make a second count on day 6 and your last count on day 7. The percent germination is the total number of seedlings you counted multiplied by 0.25 (because you started with 400 seeds).

6. Remember that the rate of emergence in the field will not be as high as the germination rate, since vigor is also important in allowing the germinating seedling to emerge. Compare the percent germination you observed with Figure 3 to estimate percent emergence in the field, remembering that soil crusting, depth of planting, etc., will also affect the final emergence rate. You can get some idea of field emergence rate by planting seeds in a small box of local soil at the depth the farmers will use.

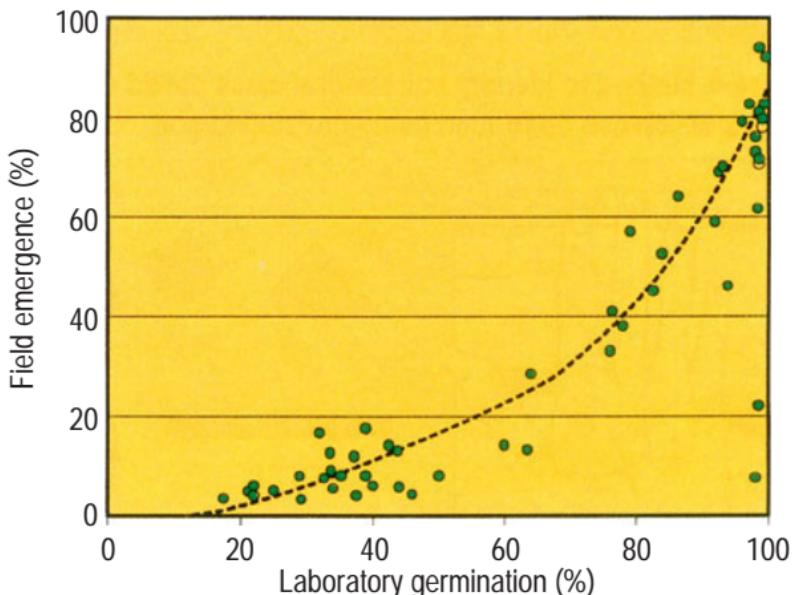


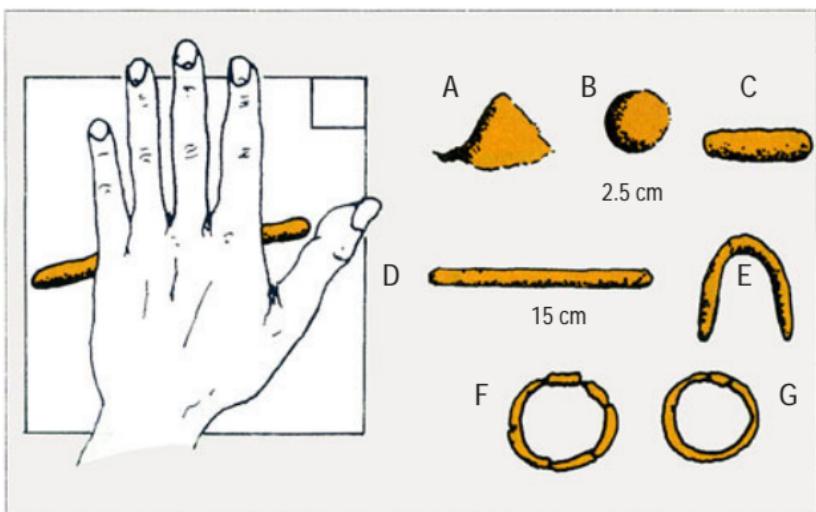
Figure 3. An example of the relationship between laboratory germination and field emergence for maize. Each point represents one of 60 seed lots.

Reprinted from David A. Priestly: *Seed Aging: Implications for Seed Storage and Persistence in the Soil*. Copyright© 1986 by Cornell University. Used by permission of the publisher, Cornell University Press.

IDENTIFYING SOIL TEXTURAL CLASS

The texture of the soil influences the movement of water and nutrients through the profile, and also affects root growth. You can determine soil texture in the field either by forming different shapes with moistened soil (Figure 4) or by feel (Figure 5). Textural class affects water holding capacity: a clay soil can store about 200 mm of available water per meter, a loam can hold about 160 mm per meter, and a sandy soil can store about 60 mm per meter.

Figure 4. Method to identify soil textural class based on the shapes which can be formed using moistened soil.



Place approximately 1 tablespoon of fine, dry earth in the palm of your hand. Drip water slowly onto the soil until it approaches the sticky point, i.e. the point at which the soil just starts to stick to your hand. Next, form a ball about 2.5 cm in diameter. The extent to which the moist soil can be shaped by hand is indicative of its texture.

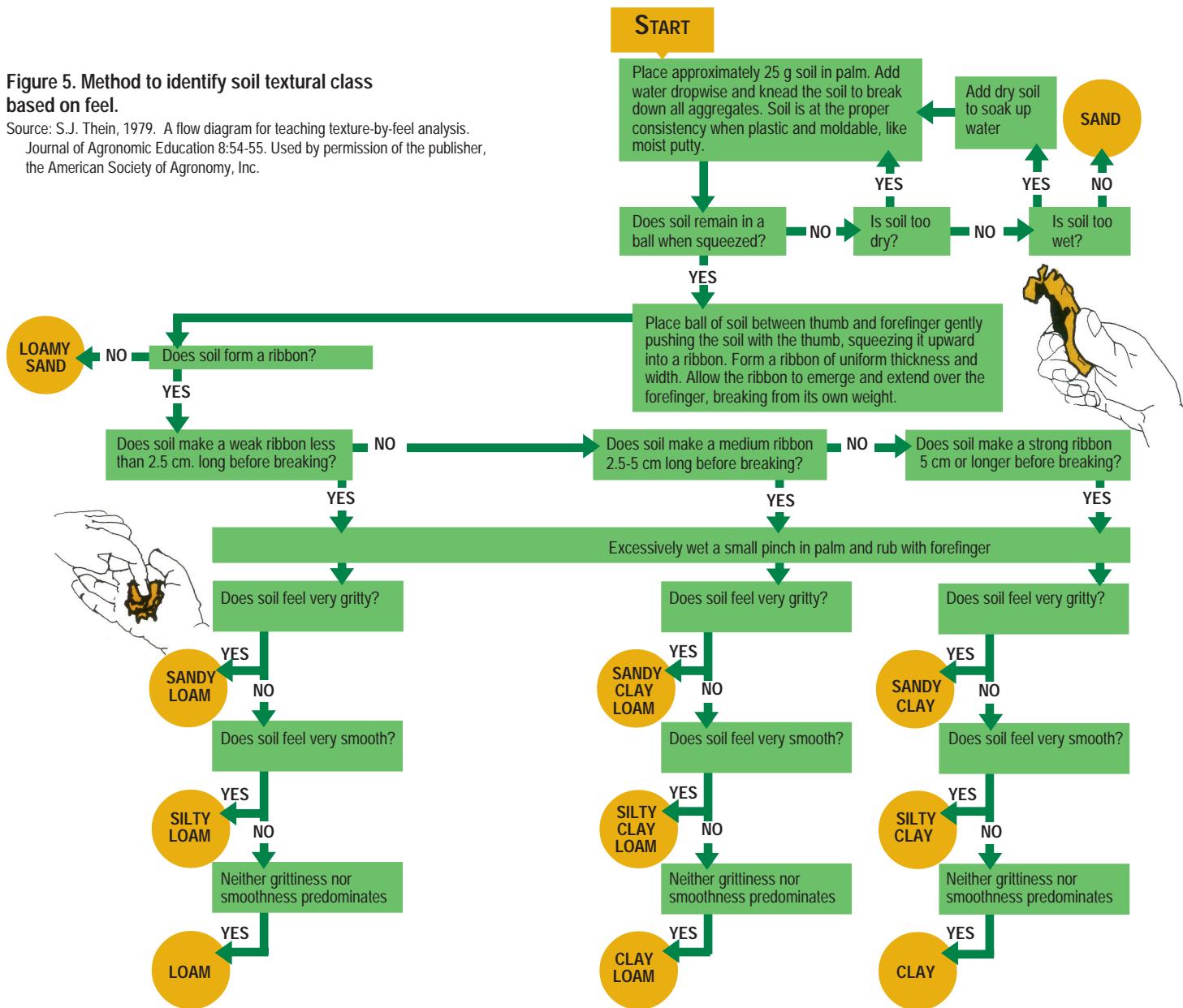
Source: Agricultural Compendium for Rural Development in the Tropics and Subtropics, 1985, Elsevier Science Publishers, The Netherlands.

Textural class:

- (A) Sand - Soil remains loose and single-grained; can only be heaped into a pyramid.
- (B) Loamy sand - The soil contains sufficient silt and clay to become somewhat cohesive; can be shaped into a ball that easily falls apart.
- (C) Silt loam - Same as for loamy sand but can be shaped by rolling into a short, thick cylinder.
- (D) Loam - About equal sand, silt, and clay means the soil can be rolled into a cylinder about 15 cm long that breaks when bent.
- (E) Clay loam - As for loam, although soil can be bent into a U, but no further, without being broken.
- (F) Light clay - Soil can be bent into a circle that shows cracks.
- (G) Heavy clay - Soil can be bent into a circle without showing cracks.

Figure 5. Method to identify soil textural class based on feel.

Source: S.J. Thein, 1979. A flow diagram for teaching texture-by-feel analysis. Journal of Agronomic Education 8:54-55. Used by permission of the publisher, the American Society of Agronomy, Inc.



ESTIMATING AVAILABLE SOIL MOISTURE

Once you know the textural class for the soil, you can use this table to estimate available soil moisture. Note that the amount of available moisture (mm) at field capacity is expressed per meter of soil. If the rooting depth is less than 1 m, the amount of available moisture is reduced proportionally.

MEASURING SOIL DEPTH

The root system of a mature maize plant usually grows to a depth of more than one meter. If some barrier exists in the soil, however, the roots cannot extend, and the crop will often suffer from water shortage in the limited soil volume. A measurement of effective soil depth will frequently alert a scientist to possible production problems.

To measure soil depth

You will need a shovel. A soil corer can be used instead, but a corer can miss hardpans if the user is not familiar with the soils in an area. In addition, a corer can often hit stones in rocky soils, making the user think that the soil is shallower than it actually is.

Table 12. Guide to soil moisture content.

Texture				
	Coarse (sand, loamy sand)	Moderately Coarse (sandy or silt loams)	Medium (loam, clay loam, silty clay loam, silt, sandy clay)	Fine (clay, silty clay or light clay)
At field capacity, contains:	60-100	100-150 (mm available moisture per meter of soil)	150-200	200-250
Soil moisture content				
Above field capacity.	Water appears when soil is bounced in hand.	Water released when soil is kneaded.	Can squeeze out water.	Puddles and water form on surface.
Field capacity.	Upon squeezing no free water appears on soil but wet outline of ball is left on hand.			
75-100% available moisture.	Tends to stick together slightly, sometimes forms a weak ball under pressure.	Forms weak ball, breaks easily, will not stick.	Forms a ball and is very pliable, slicks readily if relatively high in clay.	Easily forms a ribbon between fingers, has a sticky feeling.
50-75% available moisture.	Appears to be dry, will not form a ball under pressure.	Tends to ball under pressure but seldom holds together.	Forms a ball, somewhat plastic, sometimes slicks slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
25-50% available moisture.	Appears to be dry. Will not form a ball with pressure.	Appears to be dry. Will not form a ball with pressure.	Somewhat crumbly, but forms a ball.	Somewhat pliable. Will form a ball under pressure.
0-15% available moisture.	Dry, loose single-grained. Flows through fingers.	Dry, loose. Flows through fingers.	Powdery, dry, sometimes slightly crusted, but easily broken down into powder.	Looks moist but will not quite form a ball.

Source: Irrigation Practice and Water Management 1 Rev. 1, FAO, 1984.

You will usually need to check soil depth in two or three places in a field. One place may be adequate if the crop looks uniform and is on a level area. If the crop looks different in different areas of the field, you will need to measure soil depth in each area.

Pick an area where the plants look uniform, and start digging. It is best to do this when the soil is near field capacity, otherwise digging can be very difficult. Dig until you strike any barrier to root growth through which roots do not penetrate. This can be a plow pan, a hard pan, a rock layer, an impermeable clay layer, an acid subsoil, a water table, or a salt band in irrigated areas. If you are uncertain that what you find is a barrier, examine the roots of the crop to see if they penetrate the area. Scraping along the face of the hole with a pocket knife will often help in detecting a compacted layer. Record this depth.

For maize, you usually do not need to measure deeper than one meter. Since it is difficult to dig holes to this depth, you might dig to about 40 cm, since plow pans usually form above this level. Use a soil corer below that depth, taking several cores from the bottom of the hole you dug in order to avoid possible errors caused by striking rocks. You can break the cores at several places to see if roots are still present at different depths.

Looking at road cuts or quarries in the area can also give you an idea of the soil profile, but it cannot fully substitute for soil depth measurement in the field, since soil depth will vary within a region.

ESTIMATING YIELD BEFORE HARVEST

After the R4 stage, the final number of grains per ear has been determined. At this point it is possible to estimate final yield. As you measure plant density (p. 52), open three ears at each sampling spot and count the number of grains per ear. Use the first, fifth, and tenth plant in the measurement row if these have harvestable ears. If the selected plant does not have a harvestable ear, move to the next plant in the row for the count. It is essential to avoid deliberately selecting plants with large ears, as that will bias your results. Count the number of rows of grain and the number of grains in a representative row. Do not tip kernels which are less than one-half of the size of the kernels in the center of the ear. Multiply number of rows by kernels per row to get grains per ear. You will have to assume a final grain weight, so this is only an estimate of yield. You can assume 3,500 grains per kilo at 15% moisture for many improved varieties. Final yield estimate in kilograms per hectare at 15% moisture is:

$$\frac{\text{plants}}{\text{ha}} \times \frac{\text{ears}}{\text{plant}} \times \frac{\text{grains}}{\text{ear}} \times \frac{1}{\text{number of grains per kilo}}$$

APPENDIX: SAMPLE FIELDS SHEETS

Field Diagnosis - Datasheet 1 (Planting to V2)

Date _____

Field identification - Farmer: _____

Crop growth stage: _____

Location: _____

	Sampling point								Avg.
	1	2	3	4	5	6	7	8	
Emergence good?									
If not, note if seed is germinated, rotted, etc. (p. 11)									

Weeds:

Larger or smaller than crop?

Species present

Sample 1: _____

Sample 2: _____

Sample 3: _____

Sample 4: _____

Sample 5: _____

Sample 6: _____

Sample 7: _____

Sample 8: _____

Summary: _____

Soil Characteristics:

Note soil depth, texture, available moisture

(if necessary), pH, slope, residues, or other comments in 4 locations.

Sample 1: _____

Sample 3: _____

Sample 5: _____

Sample 7: _____

Summary: _____

Comments:

Note pronounced variation within the field, questions

to ask to farmer, other observations, and additional data which need to be collected.

Field Diagnosis - Datasheet 2 (V3 to harvest)

Date _____

Field identification - Farmer: _____

Crop growth stage: _____

Location: _____

	Sampling point								Avg.
	1	2	3	4	5	6	7	8	
Hills/5m									
Plants/5m									
Lodged plants/5m									
After R2: Ears/5m									
After R4: Grains/ear									
After R4: Husk cover (1=good, 5=poor)									

Calculations:

Plants/ha=	Plants/hill=	Ears/plant=	After R4: Estimated yield=
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Crop: At each sampling point, make observations and include what cause you suspect for any symptoms you find.

	Leaves rolled? wilted? warm?	Healthy color? early senescence?	Plants stunted? damaged?	After VT: % light interception.
Sample 1:	_____	_____	_____	_____
Sample 2:	_____	_____	_____	_____
Sample 3:	_____	_____	_____	_____
Sample 4:	_____	_____	_____	_____
Sample 5:	_____	_____	_____	_____
Sample 6:	_____	_____	_____	_____
Sample 7:	_____	_____	_____	_____
Sample 8:	_____	_____	_____	_____
Summary:	_____	_____	_____	_____

General comments on variety: Average plant and ear height, variability, etc.

Weeds: Note the following at each sampling point:

	Size relative to maize	Important species	% light intercepted by weeds
Sample 1:	_____	_____	_____
Sample 2:	_____	_____	_____
Sample 3:	_____	_____	_____
Sample 4:	_____	_____	_____
Sample 5:	_____	_____	_____
Sample 6:	_____	_____	_____
Sample 7:	_____	_____	_____
Sample 8:	_____	_____	_____
Summary:	_____	_____	_____

Pests and diseases: Note significant disease, insect, or animal damage
(include % of plants affected, % of leaf area affected and when damage probably occurred).

Sample 1:	_____
Sample 2:	_____
Sample 3:	_____
Sample 4:	_____
Sample 5:	_____
Sample 6:	_____
Sample 7:	_____
Sample 8:	_____
Summary:	_____

Soil Characteristics: Note soil depth, texture available moisture (if necessary), pH, slope, residues, or other comments in 14 locations.

Sample 1: _____

Sample 3: _____

Sample 5: _____

Sample 7: _____

Summary: _____

Comments: Note pronounced variation within the field, questions to ask the farmer, other observations, and additional data which need to be collected.

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