

# **CHAPTER 13C: AGROMETEOROLOGY AND MAIZE PRODUCTION**

**By Emmanuel Ofori and Nicholas Kyei-Baffour**

**Reviewed and improved by Murray Brown and Chris Coulson, with contributions from Orivaldo Brunini and Kees Stigter (and in an earlier stage from Paulo Caramori and Luiz Marcelo Sans)**

## **I. Importance of the crop in various climates**

Maize is the world's third most important crop after rice and wheat. About half of this is grown in developing countries, where maize flour is a staple food for poor people and maize stalks provide dry season feed for farm animals. Diversified uses of maize worldwide include: maize grain; starch products; corn oil; baby foods; popcorn; maize-based food items; maize flour; forage for animals; maize stalks providing dry season feed for farm animals; maize silage for winter animal feed in cold temperate regions; and maize stalks as a soil mulch where it is in abundance. Maize grain is used as feed for beef, dairy, hog and poultry operations in developed countries. Maize can be classified on the basis of its protein content and hardness of the kernel. These include popcorn, flint, flour, Indian and sweet corn.

In industrialised countries maize is largely used as livestock feed and as raw material for industrial products, e.g. in Australia as feed, silage, breakfast food and processing (breakfast cereals, corn chips, grits and flour), industrial starch and popcorn. In low income countries it is mainly used for human consumption.

In sub-Saharan Africa, maize is a staple food for an estimated 50% of the population and provides 50% of the basic calories. It is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Africans consume maize as a starchy base in a wide variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled and plays an important role in filling the hunger gap after the dry season. However, the yields are low, fluctuating around 1.0 t/ha. Several African countries have focused attention on increasing maize production in the small holding agricultural sectors, but such efforts have been ineffective because of heavy pre- and post-harvest losses caused by diseases, weeds and pests. In South Africa, in addition to the traditional uses, the country is considering maize fuel, an alcohol based alternative fuel produced by fermenting and distilling the starch rich grains of the crop.

According to UN's Food and Agriculture Organisation (FAO), maize yields currently average 1.5 t/ha in Africa, slightly more than 3 t/ha in Latin America, and 1.7 t/ha in India. FAO indicates grain yields have been recorded as follows: 5-6 t/ha (dryland); and 8-10 t/ha (irrigated). Silage, at 68–70% moisture content, yields of 20 t/ha (dryland); and 42 t/ha (irrigated) have been recorded. Maize grain has yielded 5.5-6.3 t/ha in Yugoslavia and silage 35-50 t/ha in France, using high yielding cultivars and intensive cropping practices, and 25–30 t/ha in the United Kingdom.

### **Importance of the crop in the United States**

Maize grain yields have exceeded 12.5 t/ha in the USA and in southern Ontario, Canada, without irrigation, so the value of this crop now exceeds US\$ 20 billion in North America. Corn refineries use 14% of the USA maize crop, producing such

products as: corn oil; gluten for animal feed; corn starch; corn syrup; dextrose (used mainly by the pharmaceutical industry as the starting material for manufacturing Vitamin C and penicillin); alcohol for beverages; bio-ethanol (which accounts for 12% of all automobile fuels sold in the US); high fructose corn syrup (used mainly by the soft drink industry, surpassing the use of sucrose in the US); biodegradable chemicals and plastics; paper; textiles; ready-to-eat snack foods and breakfast cereals; cornmeal grits; flour; and additives in paint and explosives. It is estimated that maize yields 4000 industrial products and that there are more than 1000 items in US supermarkets that contain maize.

### **Yield gap and yield potential**

In the developing world, most farmers have to accept low yields as they are unable to consider the use of improved production methods, because they operate at small scale subsistence levels. Yield gap analyses will draw farmers' attention to lost production potential under the prevailing climatic conditions in their respective environments and what production practices (soil fertility, agronomic, cultivar selection, etc.) need to be improved. Yield differences among regions as shown in Table 1 should provide the incentive to manoeuvre toward yield improvement.

Table 1. Yield potential (t/ha) relative to (*current yield*) in developing world (Prabhu et al, 2000).

Ecological environment	Highland/Transitional	Midaltitude/Subtropical	Tropical Lowland
East and Southeast Asia	5.0(3.5)	8.0(3.0)	5.5(2.2)
South Asia	5.0(0.7)	7.0(2.6)	4.5(1.4)
West Asia/North Africa	-	4.5(3.2)	-
Sub-Saharan Africa	5.0(0.6)	7.0(2.5)	4.5(0.7)
Latin America and Caribbean	6.0(1.1)	10.0(4.0)	5.0(1.5)

Note. *Yield potential refers to the highest yield achievable on farmers fields – with the use of improved seed (high yield, tolerance to diseases and pests) appropriate levels of nutrients, water, and weed control.*

According to Ofori et al. (2004) the difference between the actual and potential yield of a typical maize variety grown, during the major cropping season (April through July), on a farm in Ghana over a 9-year period, was just over 4 t/ha (i.e. actual yield varied from 0.9 to 1.4 t/ha and the potential for that season should have been 5.5 t/ha). The April-July rainfall varied from 570 to 790 mm over this 9-year period.

### Maize Production profile by region in the developing world

In the tropics and subtropics most maize is grown by small-scale farmers, generally for subsistence as part of agricultural systems that feature several crops and sometimes livestock production. The system often lacks inputs such as fertilizer, improved seed, irrigation and labour. In most developing countries there is very little purchased input for the cropping system and essentially depends on the natural resource base. The soil nutrients in the natural resource base are dwindling faster than they are being replaced. Rainfall is the single most important natural resource input under this form of cropping. Increasing population pressure has resulted in an intensification of land use. Nutrients and organic matter in the soil have been depleted and crop yields have steadily decreased. To increase production it will be necessary to replenish soil nutrients and optimise the use of other resources such as seed, water, capital and labour. Land use intensification is only feasible if nutrients depleted during cultivation are replenished. Inorganic fertilizer use in sub-Saharan Africa is generally limited by the lack of financial resources for the farmers. Table 2 shows the dominant constraints to bridging the gap between the actual and potential yield for the developing world.

Most maize-producing countries in the industrialised world employ extensive inputs and highly mechanized crop production systems and hybrid maize seed is commonly used.

Table 2. Dominant constraints to bridging the yield gap between potential and actual yields in the developing world (Mauricio, 2000)

Ecological environment	Highland /Transitional	Midaltitude /Subtropical	Tropical Lowland
East and Southeast Asia	<ul style="list-style-type: none"> <li>a) Limited technological options</li> <li>b) Branded leaf and sheath blight</li> <li>c) Borers(<i>Chilo</i> spp)</li> </ul>	<ul style="list-style-type: none"> <li>a) Drought/moisture stress</li> <li>b) Soil Acidity</li> <li>c) Downey Mildew</li> <li>d) Borer(<i>Chilo, Sesamia</i> spp.)</li> <li>e) Drought/moisture stress</li> </ul>	<ul style="list-style-type: none"> <li>a) Limited Superior early germplasm</li> </ul>
South Asia	<ul style="list-style-type: none"> <li>a) Low and declining soil fertility</li> <li>b) Limited technological options</li> <li>c) Turcicum blight</li> </ul>	<ul style="list-style-type: none"> <li>a) High temperature</li> <li>b) Drought/moisture stress</li> <li>c) Turcicum Blight</li> <li>d) Borers(<i>Chilo, Sesamia</i> spp.)</li> </ul>	<ul style="list-style-type: none"> <li>a) Limited superior early germplasm</li> <li>b) High temperature</li> <li>c) Drought/moisture stress</li> <li>d) Downy mildew</li> <li>e) Borers(<i>Chilo, Sesamia</i> spp)</li> </ul>

West Asia/North Africa		<ul style="list-style-type: none"> <li>a) High temperature</li> <li>b) Drought/moisture stress</li> </ul>	
Sub-Saharan Africa	<ul style="list-style-type: none"> <li>a) Low and declining soil fertility</li> <li>b) Limited technology options</li> <li>c) Turcicum Blight</li> </ul>	<ul style="list-style-type: none"> <li>a) Low and declining soil fertility</li> <li>b) Gray leaf spot</li> <li>c) Streak Virus</li> <li>d) Weevils</li> <li>e) Borers (<i>Chilo</i>, <i>Sesamia</i> spp.)</li> <li>f) Drought</li> </ul>	<ul style="list-style-type: none"> <li>a) Low and declining soil fertility</li> <li>b) Drought/moisture stress</li> <li>c) Striga</li> <li>d) Streak virus</li> <li>e) Borers</li> </ul>
Latin America and Caribbean	<ul style="list-style-type: none"> <li>a) Limited technology options</li> <li>b) Drought/moisture stress</li> <li>c) Ear Rot</li> <li>d) Rust</li> </ul>	<ul style="list-style-type: none"> <li>a) Soil erosion</li> <li>b) Drought/moisture stress</li> <li>c) Turcicum Blight</li> <li>d) Borer(S. W. Corn Borer)</li> </ul>	<ul style="list-style-type: none"> <li>a) Low soil fertility</li> <li>b) Soil acidity</li> <li>c) Drought/moisture stress</li> <li>d) Fall armyworm</li> <li>e) Stunt</li> </ul>

## II Agroclimatology of the crop

Climate is interrelated with other production factors and should be understood either as a resource to be managed or a factor that needs to be manipulated. Sustainable use of soil, capital and labour should be balanced with use of climate and weather information.

The response of the maize crop to climate depends on the physiological makeup of the hybrid/variety being grown. Yield differences are the result of the genetic composition of the hybrid, the environmental conditions under which the crop is grown, and the infestation by crop pests (diseases, insects and weeds). The final yield will depend on: hybrid selection; soil fertility; soil water; and control of crop pests. These factors will be discussed in this order.

Each farmer has to select the *hybrids* that are most suitable for the climatic region in which his farm is located. In temperate regions of the world the length of the frost-free season dictates the hybrids that are suitable, because the maize plant cannot withstand temperatures below about  $-2^{\circ}\text{C}$ . Growing degree-day and heat unit indexing systems have been developed for most temperate regions of the world, so that the maturing time required by each maize hybrid can be matched with growing degree-day or heat unit ratings for the frost-free growing season in each climatic region. In tropical regions of the world it is the rainy season onset that dictates the selection and optimum time to plant maize hybrids. They need to be selected to match

the anthesis period to when the soil moisture is likely to be most adequate, unless there is water available to irrigate the crop when necessary.

The soil fertility needs to have an optimum balance of the three major nutrients, nitrogen, phosphorus and potassium, and the necessary micronutrients, such as boron, calcium, magnesium, manganese and molybdenum. The farmer should have the soils on his farm assessed for the three major nutrients every year or two to determine how much fertilizer should be added to maximize maize production. This is an important management practice in both temperate and tropical regions. The farmer should be aware of fertilization requirements and procedures with respect to the soil nutrient levels, the growth stage, the crop variety, the targeted yield and the agronomic practices.

In order to maximize maize yields soil moisture should be maintained above 50% of the available water capacity in the rooting depth of the soil profile throughout the growing season. This is not always possible in either temperate or tropical climatic regions as rainfall can be very scarce and sporadic in some years. However, it is essential to at least have adequate soil moisture at the time of anthesis in order to have a full set of kernels on the ear at harvest time. This is the time when supplemental water through irrigation would be most beneficial.

Crop infection and infestation by diseases, insects and weeds can significantly reduce yields in both temperate and tropical regions and agrometeorology is important in crop protection. Diseases are best controlled through maize breeding programs that develop hybrids with resistance to such diseases as: leaf blights (of which *Bipolaris*, *Colletotrichum* and *Excesohilum* strains are common examples); root and stalk rots (of which *Phytophthora*, *Fusarium*, *Gibberella* and *Diplodia* strains are representative cases); rusts (of which *Puccinia* and *Polyspora* are plain illustrations); and smuts (such as *Ustilag* and *Spacelothian* strains). Maize diseases are usually not controlled by spraying with fungicide chemicals, except that seed is often treated before planting with a fungicide powder to control soil pathogens that damage the embryo before germination. (These fungi include *Pythium*, *Fusarium*, *Diplodia*, *Rhizoctonia*, *Penicillium* species). Wet and cold soil (<10°C) conditions at planting time are most favourable for these seed diseases.

The problem of disease and pest control among different production levels is particularly acute in the small-scale, resource-poor systems under which maize is typically grown in tropical regions of the world. The most inexpensive control measure for insects is through crop rotation, which ensures that maize is not grown on the same land year after year.

Numerous species of weeds can infest maize crops and cause yield losses in both temperate and tropical regions. The *Amaramthus*, *Panicum*, and *Butilon* species are the most detrimental in temperate regions and the *Striga* species in tropical regions, especially in Africa. Among the 23 *Striga* species in Africa, *Striga hermonthica* is the most detrimental. In temperate regions most of the time weeds are controlled by herbicide application. Since these chemicals are applied shortly after planting maize, when the soil needs to be moist but not too wet, weather conditions play a major role in the success of weed control in temperate climates. Some weed species have developed resistant strains to the 'triazine' chemicals that are usually applied before emergence of maize seedlings, so it is sometimes necessary to apply alternative herbicides after emergence. Herbicides are often too expensive for farmers to use in tropical regions, so other cultural practices, such as crop rotation and hand cultivation, are used to control weed infestations.

Weather conditions play a role too, but are not as critical as for herbicide application. According to several studies around the world (James et al. 2000;

OMAFRA, 2002; Dogan, 2003) the best time to minimize the effect of weeds on maize yields is within 4 to 8 weeks after planting when maize is in the 2 to 8 leaf stage. When weeds are controlled culturally during this initial period of maize growth, then shading by the crop is quite effective in controlling weed growth during the remaining time to maturity.

### III Basic management aspects of the crop in various environments

Promotion of growth and yield will mean that an effort has to be made to reduce the effects of pests, diseases, drought, and frost causing crop losses for both commercial farmers and smallholder resource poor farmers.

*Drought stress* alone can account for a significant percentage of average yield losses and is one of the greatest yield reducing factors in maize production. There are two facets to maize drought resistance:

- a) Affordability of irrigation systems. Not all farmers have access to irrigation systems and the cost of these systems limit their use by resource poor farmers.
- b) Increasing pressure on water resources from other user sectors. As water resources for agronomic uses become more limiting, the development of drought-tolerant varieties becomes increasingly more important (Wesley *et al.*, 2001).

Apart from breeding and soil management, *drought control* measures are:

- i) Timing of cultivation to coincide with the time of adequate soil moisture availability judged on the availability and user appreciation of agrometeorological information
- ii) Reduction of plant population with moisture scarcity (thinning)
- iii) Higher soil fertility to increase plant health and improve resistance to diseases and pests
- iv) Weed control to reduce competition for water between the maize plant and the weeds. Weed control also creates suitable humidity levels for the maize plant environment.

There are a lot of research efforts at both regional and international levels in both developed and developing countries in providing *drought resistance hybrids*. Plant breeding/biotechnology can offer a leeway to drought management under rainfed or dryland maize production. What is important is to characterise the hybrids according to their level of tolerance for easy selection by farmers or farmer groups. Drought resistance hybrids and their composites are often more promising in dryland environments than local maize varieties (Obeng-Antwi *et al.*, 2002).

As a result of the *warming and changing climate* patterns, maize yield is going to be reduced especially among small holder maize farmers, who may lack the resources to cope with these situations. With the effect of climate change resulting in reduced rainfall amounts and increased soil and plant evapotranspiration, one important goal is to enhance drought resistance in maize and other cereal crops, which would greatly benefit regions with less favourable conditions for agriculture. Solutions must go beyond increasing production as increasing the nutrient content of the maize is important as well. Breeding of high yielding, high nutrient varieties with limited water use could provide part of the answer.

It is clear that climate influences *incidence of pests, diseases and weeds*, though their intensities differ between crops and regions depending on climatic conditions, crop resistance and crop management such as cultivation techniques

including fertilization, water supply and crop protection. Protection measures should be targeted at managing weeds, pests and diseases. Can control be put within the reach of the resource poor farmers?

*Weed control* for yield increase can be quite costly to resource poor farmers. Part of the solution is in the use of biodiversity and biotechnology. To put stemborer and striga control within the reach of African farmers, simple, inexpensive measures need to be developed that are tailored to the diversity of African cropping and socio-economic systems. A sustainable solution would be an integrated approach that simultaneously addresses disease, pests and weeds.

Ndema et al. (2002) reported on weed grasses grown as *trap plants* in border rows around maize plots leading to reduced pest densities in maize. This was due to an increase in plant-induced mortality occurring on grass species in both the humid forest and the derived savannah of western Africa. Yields per plant tended to be higher with grasses present, with the highest increase of > 100% observed in Cameroon the second year of the experiment when the grasses were well-established. The most promising grass species identified in the study were *Pennisetum purpureum* and *Panicum maximum*. The latter was the most efficient species for suppressing *S. calamistis* and *M. nigrivenella* infestations and enhancing egg and larval parasitism.

The new approaches utilize the benefits of *biodiversity* of graminous and leguminous plants in the cultivation of maize, and how to manage these plants in order to reduce stem borer and striga infestation and increase stem borer parasitization by natural enemies in cereal cropping systems has been demonstrated. The approaches rely on enriching the biodiversity of plants and the pests' natural enemies in and around the cropping environment. Based on the understanding of the volatile semiochemicals employed by the stemborers in locating suitable hosts and avoiding non-hosts, a novel pest management approach utilizing a 'push-pull' or stimulo-deterrent diversionary strategy has been developed. In this habitat management system, which involves combined use of trap and repellent plants, insects are repelled from the main crop, and are simultaneously attracted to a discard or trap crop. For maximum efficiency, these systems also exploit natural enemies, particularly parasitic wasps, which are important in suppressing pest populations. Plants, which repel stemborers as well as inhibit striga weed have also been identified.

Several plants have been identified which could be used as trap or repellent plants in a push-pull strategy, according to the study. Particularly promising are Napier grass (*Pennisetum purpureum*), Sudan grass (*Sorghum vulgare sudanense*), molasses grass (*Melinis minutiflora*) and the legume silverleaf (*Desmodium uncinatum*). Napier grass and Sudan grass have shown potential for use as trap plants, whereas molasses grass and silver leaf repel ovipositing stem borers. All four plant species are of economic importance to farmers in Africa as livestock fodder and have shown great potential for stem borer and striga control in on-farm trials. Napier grass, a commercial fodder grass, can provide natural control to stem borers by acting as trap plant, and as reservoir for their natural enemies. Napier grass has its own defense mechanism against crop borers. When the larvae enter the stem, the plant produces a gum like substance, which causes the death of the pest.

Sudan grass, also a commercial fodder grass, can provide natural control to stemborers by acting as trap plants for stemborers, and as reservoirs for their natural enemies. Planting Sudan grass around maize fields reduced stemborer infestation on maize and also increased efficiency of natural enemies (Khan *et al.*, 1997b). Molasses grass, when intercropped with maize, not only reduced infestation of maize by stemborers but also increased parasitism particularly by the native larval parasitoid,

*Cotesia sesamae* (Khan *et al.*, 1997a). The plant releases volatiles that repel stemborers, but attract parasitoids that cause no damage to the plants. Such plants with an inherent ability to release such stimuli could be used in ecologically-sound crop protection strategies.

Molasses grass, which originated in Africa, but spread to other tropical areas in the world, is well known to be a valuable pasture and hay grass. The grass also has high anti-tick properties especially when green. The grass is familiar to farmers in eastern Africa and is reported to be preferred as fodder for both dairy and beef cattle. Silverleaf (*Desmodium uncinatum*), a high-value, commercial fodder legume, when intercropped with maize, repelled ovipositing gravid stemborer females, and suppressed striga by more than 40 times.

The habitat management strategy manifests important features which render it distinctively more advantageous than other methods. The first of these features is its suitability to conditions of mixed agriculture, which is prevalent in eastern Africa. The cultivation of the grasses and legumes can increase both crop yield and livestock productivity. A second key feature of the proposed technology is that it introduces practices which are already familiar to farmers in Africa. The approach uses multiple cropping, and it is based on the use of economically valuable plants. For example, the cultivation of Napier grass for livestock fodder and soil conservation, recommended in eastern Africa, is already widespread.

#### IV. Other background information on the crop

##### Growth stage monitoring

The maize plant described in the Table 3 is representative of a lowland tropical variety, flowering in 55-60 days and maturing in 115 days. However, considerable variation exists among varieties in terms of morphology and growth habit. For example, an early-maturing tropical variety may reach a height of only 1.5 m, flowering in 45-50 days and maturing in 90 days. Growth stage in the pattern shown in Table 3 should be prepared as a management guide. It must be emphasized that environmental factors influence the length of the various growth stages and as such information about the environmental factors should also be part of the characterization. Familiarity with the names and locations of the plant parts is helpful in understanding how the plant develops.

Table 3. Growth stages of maize crop

Stage	DAS*	Features
VE	5	The coleoptile emerges from the soil surface
V1	9	The collar of the first leaf is visible
V2	12	The collar of the second leaf is visible
Vn		The collar of leaf number 'n' is visible. The maximum value of 'n' represents the final number of leaves, which is usually 16-23, but by flowering, the lower 4-7 leaves have disappeared

VT	55	The last branch of the tassel is completely visible
R0	57	Anthesis or male flowering. Pollen shed begins
R1	59	Silks are visible
R2	71	Blister stage. Kernels are filled with clear fluid and the embryo can be seen
R3	80	Milk stage. Kernels are filled with a white, milky fluid
R4	90	Dough stage. Kernels are filled with a white paste. The embryo is about half as wide as the kernel. The top part of the kernels are filled with solid starch
R5	102	Dent stage. If the genotype is a dent type, the grains are dented. The 'milk line' is close to the base when the kernel is viewed from the side in both flint and dent types
R6	112	Physiological maturity. The black layer is visible at the base of the grain. Grain moisture is usually about 35%

\*DAS: days after sowing

Table 3 gives the approximate number of days after sowing in the lowland tropics where maximum and minimum temperatures may be 33 °C and 22 °C respectively. In cooler environments, these times are extended. For each variety a phenological characterization such as this can be useful. Planting date should be such as to avoid exposure to increased risk of plant diseases, pests and soil moisture stresses.

### **Growth monitoring –an illustration**

All normal maize plants follow this same general pattern of development, but the specific time interval between stages and total leaf numbers developed may vary between different locations, hybrids, seasons and planting dates. For example:

- a. An early maturing hybrid may develop fewer leaves or progress through different stages at a faster rate than indicated here (Table 3). However, a late maturing hybrid may develop more leaves or progress more slowly than indicated.
- b. The rate of plant development for any hybrid is directly related to temperature, so the length of time between the different stages will vary as the temperature varies, both between and within growing seasons.
- c. Environmental stress such as nutrient or moisture deficiencies may lengthen the time of vegetative stages but shorten the time between reproductive stages.
- d. The number of kernels that develop, final kernel size, rate of increase in kernel weight, and length of the reproductive growth period will vary among hybrids and environmental conditions.

### **Biotechnology**

The use of biotechnology in maize production improvement will mean collaboration of other disciplines with agrometeorologists. This should facilitate the development of suitable maize varieties for drought resistance and improved tolerance, as well as for low nitrogen availability as pertains in most developing countries under rainfed production. The development of maize resistant to pests, diseases and weeds as well as maize varieties with increased starch and protein contents should be a feature of biotechnology advances. The direction of such biotechnology endeavours depends on regional production goals. Is it for poverty alleviation, biofuel or increased protein content? Many such questions may be asked.

Genetic engineering offers new possibilities for plant breeding for increased resistance to pests and pathogens as well as other traits. New varieties resistant to pests, diseases and drought may lessen the dependence on pesticides and fungicides and help secure sufficient crop yields especially among resource poor farmers and in water limiting environments. According to Sankula et al. (2004), there are reported cases of reductions in pesticide and herbicide use, by 62% and 50% respectively, due to the cultivation of biotechnology-derived and herbicide-tolerant maize.

Under different climatic conditions and environments, varietal selection has to be based on a host of factors. For example whether the crop is produced under rainfed/dryland conditions, unimodal or bimodal rainfall patterns, supplementary or fully irrigated or under sufficient or limited rainfall conditions.

## V. Some management details

Agronomic practices that will improve soil fertility will increase yield dramatically. Examples are:

- a) Cultivation practices that will
  - i) destroy the seeds of various weeds
  - ii) encourage healthy plant growth
  - iii) conserve soil moisture

Examples are mulching, residue management, no-till or zero tillage, reduced field traffic, organic matter addition, suitable fertilization rates based on proper soil assessments, etc.

- b) Integrate maize crop with suitable crops for:
  - i) Crop rotation
  - ii) Mixed cropping
  - iii) Sequential cropping

Suitable crops for crop rotation, mixed and sequential cropping should be carefully selected based on their effect on weed, pest and disease control and soil fertility.

Some management issues to consider are:

- a. Selection of hybrids/varieties best suited to climate conditions and management practices;
- b. Plant at the time most suitable to the farming area and at the correct seeding rates;
- c. Use agronomic practices suitable to the soil type;
- d. Fertilize according to soil assessments for the desired production levels;
- e. Use cultural practices most suitable for the control of weeds, diseases and insects;

- f. Follow the recommendations provided by agronomic and agrometeorology extension specialists.

Transfer of improved technology may take place through demonstrations on improved crop production technology and Integrated Pest Management training programs, seed production programs and provision of fungicides, herbicides, insecticides and other inputs.

The maize technology transfer in the Ghana Grain Development Project was based on three types of activities (Morris et al., 1999): building linkages between research and extension, providing support to extension activities and strengthening seed production activity.

Available varieties are continually changing as new ones are being developed, so there is a need to have up-to-date varietal information. The choice of variety depends on market requirements, environmental conditions, socio-economic considerations, whether the crop is irrigated and the levels of disease and pest resistance required. For example, the State of Queensland (Department of Primary Industries and Fisheries, 2004) gives recommendations on factors to be considered as a guide to the selection of maize variety. Time to flowering, cob height, husk cover, disease resistance, “standability”, end use and isolation are mentioned. Hybrid selection should be understood by all and must also have socio-economic components. It is necessary to develop suitable characterization methods for all hybrids that will make the selection process much easier and convenient.

Management information requirements should include communication networks which should be targeted at

- a. Information sharing and communication on hybrid/varietal performance with expert support;
- b. Training for farmers on such matters as seed selection, management practices and agrometeorological services;
- c. Assessing the performance of varieties in a systematic manner;
- d. Agronomic, pest, and soil fertility advisories for farm districts;
- e. Information on newly developed hybrids for farmers;
- f. The response of each hybrid or variety to any of the growth/yield limiting factors;
- g. Information and training on the occurrence of diseases, insects and weeds, including trans-border spread of diseases;
- h. Disease cycle and climatology (e.g. occurrence of humid conditions)
- i. Symptoms of infestation and crop damage

For management purposes pests and diseases should be reported as follows:

The name of the disease/pest (Latin and/or common) with

- a) Crop damage
- b) Symptoms of infections and infestations
- c) Weather and microclimate conditions for their survival and multiplication
- d) Life cycle
- e) Dispersal/spread mechanisms

- f) Management procedures/regimes

## **VI. User requirements for climate information**

The information has to be presented in a language and format which the user understands and has to be issued at the appropriate time. For example studies into the use of climate information for production planning examined rainfall dependability, using coefficient of variation, at some selected centres in Ghana. This showed the months in the year where rainfall can be dependable (Ofori et al., 2004).

### **Information to cope with climatic risk for maize production**

According to a study reported by Unganai (2002) any potential benefits of long range forecast that will benefit farmers has to contain the following information:

- a. Date of onset of rainy season
- b. Date of end of rainy season
- c. Quality of the cropping season rainfall indicated by the rainfall amount using rainfall percentile studies. Rainfall percentile study also allows for good comparison of rainfall among farming centres or within agroecological zones. That also aids in production planning and advisory services. Temporal and spatial distribution of important climate factors.
- d. Probability, frequency and timing of adverse weather events (e.g. dry spells or midseason drought flood, wind storm, frost) within the season. This will include climatic risk zoning to determine adaptation or avoidance mechanisms during the season.
- e. The patterns of rainfall, temperature, evapotranspiration, relative humidity, sunshine hours, vapours pressure deficit and other agriculturally significant climate variables. This will include deviations, anomalies, timing of favourable climatic conditions.
- f. Characterization of ecological zones suitable for climate manipulation and maize production purposes using suitable climate based crop yield or growth models and
- g. Interpretation of the above information in terms of which varieties to plant and when to plant.

Such agrometeorological services may be complemented by comparisons with long term averages and recent seasons and with additional information that was recently shown to be appreciated by farmers and extensionists as exemplified below.

Dry spells that substantially reduce the soil water reservoirs and affect crop yield causing problems for agriculture and other human water needs. Climatic risk zoning must be used to determine the best planting time to avoid or reduce drought effects on crop development. The following determinations/assessments are thus suggested for coping with climatic risk:

- potential suitability of a specific variety for a given region
- probability of drought and frost
- phenological stage most susceptible to drought and frost
- availability of meteorological data
- zoning of production districts based on climatic and edaphic conditions and
- determine water requirement index for each phenological stage.

In addition to the above, water requirement and dryness indices, stored soil moisture and the risk of severe drought must be determined. For example:

$$\text{Water Requirement Index} = \frac{ETR}{ETM} = \frac{\text{actual crop evapotranspiration}}{\text{maximum crop evapotranspiration}}$$

$$\text{Dry index, } DI = \left(1 - \frac{ETR}{ETP}\right) \text{ (Brunini et al, 2000).}$$

Suitable drought monitoring and characterization indices therefore are:

- water requirement index
- drought index
- available stored water
- probability of dry spell
- rainfall anomaly
- soil moisture holding characteristics
- growing period climate characteristics
- maize fertilization - develop a methodology for maize fertilization that will have implications for drought/dry spell management or soil moisture storage and nutrient leaching especially in humid regions.

User requirements for pests and disease management in a climate context are:

- a. Pest and disease identification services
- b. Life cycle and mode of attack/infestation, simplified in chart form
- c. Pests and disease mapping for each locality showing the times of the year when climatic conditions favour their survival and multiplication
- d. Monitoring methods to determine pest and disease presence (visual identification methods must be disseminated)
- e. Assessment of effectiveness of control measures is also vital. This involves
  - o Assessment of why the method worked or did not work
  - o Close consultation with pest advisors or extension officers
  - o “What if” analysis (what if I lose, what if I gain)
  - o Resistance tolerance should be reported and
  - o Environmental influences (rain, humidity, wind, soil, temperature) should be known
- f. Timing of control method application to optimise their effectiveness

- g. Social and economic costs of weeds should be researched and documented

User requirements for weed control in a climate context are:

- a) Weed characteristics including
  - o Rapid vegetative regeneration,
  - o Persistence in the soil for long periods and
  - o Adaptation to varying environments
- b) Impacts of weeds in terms of
  - o Crop yield reduction through weeds competing for light, water and nutrients
  - o Danger to human beings and/or livestock through poisoning
  - o Harboring crop pests and diseases
  - o Increases in the cost of harvesting.

User Requirements for soil and water conservation in a climate context deal with promoting cropping/farming practices such as manuring and crop residue management that increase the organic matter content of the soil. For both rainfed and irrigated maize production the information should contain

- a. seasonal variations in atmospheric water demand
- b. maize crop water use through it's life cycle and for all varieties
- c. irrigation scheduling techniques
- d. soil moisture monitoring techniques
- e. measuring or calculating evapotranspiration using on-site evaporation pan or meteorological information
- f. monitoring crop conditions
- g. training in the "hand feel" method (dig-look-judge-respond) (Moore *et al*, 2005).

Other management considerations should include:

- i) Knowledge of hard pans and of soil moisture holding characteristics
- ii) Knowledge of the crop rooting depths and characteristics, resistance level of hybrids/varieties to drought, disease, frost, etc.
- iii) Water supply. If agriculture is rainfed, assess the sufficiency and dependability of rainfall during the season and identify the months with higher dependability. If irrigated, then assess the reliability of water source.

User requirements regarding timing of farm operations should consider

- a. Timing and application of nutrients especially in humid areas
- b. Weed control

c. Pollination timing effects on kernel and silk receptivity

Tactical application of nitrogen after high rainfall at seeding and flag emergence and application of phosphorus and potassium at seeding increased crop yields by 79% and 100% at two locations, Boscabel and Orchid Valley, according to Hill *et al* (2005). Similar treatment could be done to maize crops at specific locations.

User requirements for resistance/tolerance level of hybrids

Resistance or tolerance evaluation to weed, pest, disease and drought levels of all hybrids under different environments and edaphic conditions should be assessed for their overall potential. This will aid in varietal selection for a particular environment. In some cases resistance or tolerance levels are quantified and acceptable levels developed. Factors to look at are:

- a) Virus resistance level
- b) Insect or pests resistance level
- c) Fungal resistance level
- d) Bacterial resistance level
- e) Herbicide resistance level
- f) Drought or frost resistance level
- g) Weed infestation resistance
- h) Nitrogen use efficiency
- i) Response to nitrogen fertilization.

These levels should be quantified as an aid to farmers and other stakeholders to make decisions on the type of variety to use. Potential for breeding maize with greater nitrogen use efficiency, characterising the nitrogen response to local and improved maize varieties, identifying secondary traits associated with tolerance to low nitrogen stress may be required.

User requirements for agrometeorological information on the crop could be listed as follows:

- a. Maturation periods in days or degree-days/heat units for all maize hybrids/varieties;
- b. Climatic risk zoning to determine the best planting time to avoid or reduce the risk of encountering drought during crop development;
- c. Matching crop water requirement with the season;
- d. Information about the weather factors that are conducive to infestation by insects and infestation by pathogens to allow timeliness of control practices;
- e. Drought/frost stress characteristics of the crop;
- f. Growth stage characterization;
- g. Strengthening farmer appreciation of crop growth/crop yield models;
- h. Development of accurate models to estimate crop performance.

## VII Examples of agrometeorological services related to this crop

Three case studies were identified in the literature, of on-station design attempts of agroforestry systems with maize, as agrometeorological services to farmers in Africa. The first example was an alley cropping design on flat land in the semi-arid Machakos district of Kenya (Mungai et al., 1996). In the alley cropping system studied, every fourth row of maize was replaced by a row of *Cassia siamea* trees and loppings were incorporated into the soil at the beginning of each maize growing season. In this kind of replacement agroforestry it was found that there is more difference between yields in agroforestry systems and the monocropping controls at higher amounts of rainfall and with better rainfall distributions.

This design on flat land proved that it was difficult to increase crop yields considerably by alley cropping in the semi-arid tropics in other years than those with appreciably above average rainfall with a beneficial rainfall distribution. There is even an amount of relatively low rainfall below which the controls often do better. Ever since the late eighties and early nineties it is clear that adoption of such systems by farmers is much lower than expected. This early work made clear why farmers have such negative feelings on alley cropping. Low biomass production that insufficiently improves soil conditions through mulching, and high competition for resources between trees and crops are the main causes. Farmers are thus advised not to apply such systems on flat land in semi-arid conditions. That was the agrometeorological service delivered by this research in the late eighties and disseminated in the early nineties through extension channels of the (then) International Council for Research in Agro-Forestry (Mungai et al., 2001).

In the second case study, *Senna siamea* contour hedgerows with interrow distances of 4m were used “on-station” for erosion control on a 14% slope of an Alfisol at the ICRAF research station in the semi-arid district of Machakos, Kenya. The hedgerows were for one of the two rainy seasons of each year intercropped with maize, without the use of fertilizers. There were four rows of maize in the alleys formed by the hedgerows. Cumulative results for four seasons showed that the most successful treatment for soil loss and run off reduction was the combination of hedgerows and surface spreading of their prunings as mulch, done just before the start of the rainy seasons. This reduced cumulative runoff from close to 100 mm to only 20 mm and reduced cumulative soil loss from more than 100 ton/ha to only 2 ton/ha (Stigter et al., 2005a). This was at the expense of 35% of the maize yields.

These rather high yield depressions were due to greater competition from the now older hedges compared to the younger ones used in earlier experiments, along with fertilizers. The planting of hedgerows alone, without applying the mulch, was appreciably less effective in both soil loss and runoff reduction and at the expense of even more maize yield. Mulch appeared to be the main factor reducing soil evaporation, but under high soil evaporation of between 50% and (an upper limit of) 65% of the rainfall, evaporation reduction was not more than in the order of between a relative 5% and 10%. This is due to the low biomass production in semi-arid conditions (Kinama et al., 2005). Experiments with *Panicum maximum* grass strips (and no mulch) instead of the low trees gave results for runoff and soil loss reduction that were halfway between the values for the hedges with and without mulch application, but yield reductions were the highest of all treatments.

Highlighting the system design consequences for farmers, as an agrometeorological service, it has to be kept in mind that alley farming on sloping land was earlier shown to be only successful if the system was adapted to the

particular needs of the farmers concerned. The grass strips were more effective in preventing soil erosion than the hedgerows because of the compactness and thickness of the grass strips. They are more effective in reducing runoff speed and trapping soil than the thinner and appreciably less dense hedgerows. For lower input farmers, grass strips and highly competitive trees with high biomass density close to the ground, even when less efficient in direct erosion control, may deliver highly needed thatching material and/or fodder and save money for durable erosion control embankment stabilization (Stigter et al., 2005a).

In the third case study, in semi-arid Laikipia District, Kenya, *Coleus barbatus* hedges solved existing wind problems where previously the wind blew off maize stalk mulches and was mechanically shaking the maize. Protection was assisted by *Grevillea robusta* (Silky Oak) trees as used in the demonstration agroforestry plots with maize and beans (Oteng'i et al., 2000). In the demonstration plots the hedge roots were pruned and half of the trees as well. The positive moisture effects were stronger closer to the pruned trees.

The agroforestry intervention with pruned older trees and maize stalks used for mulching did not negatively influence maize yields in the wettest season and showed a positive effect on maize biomass yields in the driest season. Comparison of yield differences in mulched and pruned plots in the wettest season indicated that, for maize, tree pruning was more operational than mulching under these conditions. A combination of the water conservation measures of root-pruning, mulching and minimum tillage was to be preferred for the maize/beans intercrop in this agroforestry system for seasons with very low rainfall. More overlapping of depletion zones of the three root systems would have influenced the pruned plot yields of the intercrop more seriously (Stigter et al., 2005b).

The results learned that under the very difficult semi-arid conditions in Laikipia, the mulched tree cum hedge pruned agroforestry system overall helped to limit land degradation. However, the farming conditions are extremely marginal and economically more viable systems must be developed as (agrometeorological) services to help the migrated farmers concerned (Stigter et al., 2005b).

## References

- Brunini, O., Pinto, H. S., Zullo Jr., J., Barbano, M. T., Camargo, M. B. P., Alfonsi, R. R., Blain, G. C., Pedro Jr., M. J. and Pellegrino, G. Q., 2000: Drought quantification and preparedness in Brazil – The example of Sao Paulo State.
- Cumberland, G. L. B., Honore, E. N. and Farrel, C. A., 1971: The importance of weeds, and the correct timing of weed control measures, in maize. *Proceedings of the 24th New Zealand Weed and Pest Control Conference*, pp. 115-120.
- Dögan, M. N., Ünay, A., Boz, Ö. and Albay, F., 2004: Determination of optimum weed control timing in maize (*Zea mays* L.). *Turkish Journal of Agriculture*, 28, pp. 349 – 354.
- James, T. K., Rahman, A. and Mellsop, J., 2000: Weed competition in maize crop under different timings for post-emergence weed control. *New Zealand Plant Protection*, 53, pp. 269-272.
- Khan, Z. R., Ampong-Nyarko, K., Chiliswa, P., Hassanali, A., Kimani, S., Lwande, W., Overholt, W. A., Pickett, J. A., Smart, L. E., Wadhams, L. J. and Woodcock, C. M., 1997a: Intercropping increases parasitism of pests. *Nature* (London), 388, pp. 631-632.
- Khan, Z. R., Chiliswa, P., Ampong-Nyarko, K., Smart, L. E., Polaszek, A., Wandera, J. and Mulaa, M. A., 1997b: Utilisation of wild gramineous plants for

- management of cereal stemborers in Africa. *Insect Science Applications*, 17, pp. 143-150.
- Kinama, J. M., Stigter, C. J., Ong, C. K., Ng'ang'a, J. K. and Gichuki, F. N., 2005: Evaporation from soils below sparse crops in contour hedgerow agroforestry in semi-arid Kenya. *Agricultural and Forest Meteorology*, 130, pp. 149-162.
- Mauricio, R. B., 2000: Participatory methods in the development and dissemination of new maize technologies. CIMMYT: World Maize Facts and Trends.
- Morris, M. L., Tripp, R., and Dankyi, A. A., 1999: Adoption and impacts of improved maize production technology. *A case study of the Ghana Grains Development Project. Economics Program Paper 99-01*. Mexico, D.F.: CIMMYT.
- Moore, E., 2005: Key drought management tips. *Drought management FACTSHEET No. 2*. British Columbia, Ministry of Agriculture and Lands.
- Mungai, D. N., Stigter, C. J., Ng'ang'a J. K. and Coulson, C. L., 1996. New approach in research education to solve problems of dryland farming in Africa. *Arid Soil Research and Rehabilitation*, 10, pp. 169 – 177.
- Mungai, D. N., Stigter, C. J., Coulson, C. L., Ng'ang'a, J. K., Netondo, G. W. S. and Umay, G. O., 2001: Understanding yields in alley cropping maize (*Zea Mays* L.) and *Cassia siamea* (Lam.) under semi-arid conditions in Machakos, Eastern Kenya. *Journal of Environmental Science* (China), 13, pp. 291 - 298.
- Ndema, R., Grounou, S. and Schulthess, F., 2002: The role of wild grasses in the management of lepidopterous stem-borers on maize in the humid tropics of western Africa. *Bulletin of Entomological Research*, 92, pp. 507 – 519.
- Obeng-Antwi, K., Sallah, P. Y. K., and Frimpong-Manso P. P., 2002. Research efforts at managing production in the lowland tropics. *Ghana Journal of Agricultural Science*, 35, pp.
- Ofori, E. Kyei-Baffour, N. Agodzo, S. K., 2004: Developing effective climate information for managing rainfed crop production in some selected farming centres in Ghana. *Proceedings of the School of Engineering Research Retreat held at HO*, (Unpublished).
- OMAFRA (2002) Corn. *Weed Control Agronomy Guide for Field Crops*. Publ. No. 811.
- Oteng'i, S. B. B., Stigter, C.J., Ng'ang'a, J. K. and Mungai, D. N., 2000: Wind protection in a hedged agroforestry system in semi-arid Kenya. *Agroforestry Systems*, 50, pp. 137 - 156.
- Prabhu L. P. and Shivaji, P., 2000: Meeting world maize needs: Technological opportunities and priorities for the public sector. *CIMMYT World Maize Facts and Trends*.
- Queensland Government Department of Primary Industries and Fisheries, 2004: Maize production in Queensland, Australia (<http://www2.dpi.qld.gov.au/fieldcrops/8606.html>)
- Sankula, S. and Blumenthal, E., 2004: Impact on US agriculture of biotechnology-derived crops planted in 2003. An update of 11 case studies. *National Centre for Food and Agricultural Policy*, [www.ncfap.org](http://www.ncfap.org) assessed on 05 – 02 – 2006.
- Stigter, C. J., Kinama, J., Zhang Yingcui, Oluwasemire, K. O., Zheng Dawei, Al-amin, N. K. N. and Abdalla, A. T., 2005a: Agrometeorological services and information for decision-making: some examples from Africa and China. *Journal of Agricultural Meteorology* (Japan), 60, pp. 327 - 330.
- Stigter, C. J., Oteng'i, S. B. B., Oluwasemire, K. O., Al-amin, N. K. N., Kinama, J. K. and Onyewotu, L. O. Z., 2005b: Recent answers to farmland degradation

- illustrated by case studies from African farming systems. *Annals of the Arid Zone*, in print.
- Unganai, L., 2002: Application of long-range rainfall forecasts in agricultural management: A review of Africa's experiences. *Proceedings of the International Forum on Climate Prediction, Agriculture and Development*, IRI 26 – 28 April.
- Wesley, B. B., Edmeades, G. O. and Baker, T. C., 2001: Molecular and physiological approaches to maize improvement for drought tolerance. *Journal of Experimental Botany*, 53, pp. 13 – 25.