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GROWTH AND PRODUCTION OF MAIZE: TRADITIONAL LOW-INPUT CULTIVATION

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Content

Summary

Maize (*Zea mays L.*) is the most important cereal crop in the world after wheat and rice. While in western countries maize production is highly mechanized, in many other - mainly developing countries – the crop is still grown by smallholders and medium-scale farmers, using traditional and low-input cultivation techniques. Yields under those circumstances are much lower.

The centre of origin for maize is in Mesoamerica, but the crop has now spread over more than 100 countries. No crop has received more intense genetic and cytogenetic attention than maize, and this explains the large variations in yields, from more than 12 tons/ha in commercial farming to less than 1 ton/ha in traditional low-input family farms in developing countries.

There are many maize cultivars, each of them with a specific growth cycle, and with a wide range of tolerance to environmental conditions. It is essentially a crop of warm countries, but most of the crop is grown in the frost free and warmer parts of temperate regions and in the humid (sub)tropics with a well-defined dry season. Under traditional farming, maize is often cultivated in association with other (food) crops, and is usually not fertilized. Traditional cultivars are susceptible to pests and diseases.

Maize is an important staple food in developing countries, in particular in Latin America and Africa, and a basic ingredient for local drinks and food products. It is also an outstanding feed for livestock, high in energy, low in fiber and easily digestible. As a source of starch, it is a major ingredient in industrialized food products.

1. Introduction

Maize (*Zea mays L.*) is the most important cereal crop in the world after wheat and rice. It is grown in more diverse regions than any other crop; vast genetic differences occur among the kinds of maize grown in these disparate areas. It is cultivated from northern Europe and Russia to South Africa, eastward through Asia, the Himalayas, China, Southeast Asia and the Pacific Islands, westward from Puerto Montt in Chile to New Brunswick in Canada. The name "maize" is derived from the Spanish connotation *maiz* for the plant. In the USA it has for a long time been named *Indian corn*, or simply corn. In South Africa it is known as *millies*, from the Portuguese word *milho*.

Maize has multiple uses. In most developing countries maize is grown as a food crop (grain maize); in other countries (USA, Brazil) it is an important animal feed or is a basic compound for ethanol production. In this paper the focus is on grain maize and its use as a staple food in many tropical areas, Latin America, Africa and Asia in particular.

The global world production of maize exceeds 780 million tons per year (Table 1), compared with almost 500 million tons of wheat and just less than 400 million tons of rice. The USA is by far the biggest producer (over 330 million tons in 2007; 42% of the world production), occupying double the area of any other crop planted in the country. It should however be noted that a major part of this is used for fodder and production. In the world ranking the USA is followed by China (152 million tons), Brazil (52 million tons), Mexico (23 million tons) and Argentina (21 million tons). The corresponding area planted has over the past 40 years increased by more than 40%. Both the global production and the area harvested show a steady increase since the 1960s.

Table 1. Maize grain production (in ,000 MT) in the major maize production regions and countries in the world (Source: www.fao.org)

Maize production in the USA, and in other developed countries in Europe, South America and Australia, is highly mechanized and based on commercial production methods using selected hybrids and agrochemicals. Production and management practices in these areas have been described in full detail in the companion paper on *Growth and Production of Maize: Mechanized Cultivation*.

These highly-mechanized production conditions are, however, in clear contrast with those in many developing countries, where maize is most often grown by medium- and small-scale farmers. Cultivation practices in these areas are generally less sophisticated; seed and plant quality is much lower; pests and diseases are much less under control; and cultivation techniques are by far less advanced or are even very traditional. In this paper the focus is mainly on these traditional and low-input forms of maize cultivation, with most examples drawn from Africa and South America.

2. Origin and Distribution

There is some controversy on the origin of maize, though it is generally accepted that its centre of origin is located in Mesoamerica, primarily Mexico and the Caribbean. Maize as we know it today has never been found growing in a wild state. Its domestication, probably from a wild *teosinte* form (*Euchlaena mexicana*), is believed to have started some 6,000 to 7,500 years ago in the Mexican highlands. Archeological evidence from Mangelsdorf, Reeves, MacNeish and others (reported by

Purseglove, 1975) and supported by radiocarbon dating, have indicated the existence of wild maize cobs in Mexico 5200-3400 BC, followed by a gradual extinction of wild maize in favor of modern varieties through a more intensive cultivation.

Introgression of *Tripsacum* into maize also occurred in South America, where *teosinte* is absent. The question of the separate domestication of maize in South America, in particular in Peru, still remains hypothetical.

Maize was the staple food of most pre-Columbian, Mesoamerican, South American and Caribbean cultures, whose life revolved around the *milpa* (cornfield). The crop is still associated with the Mesoamerican peoples' identity. Later it spread to North and South America and was brought by Columbus to Spain, from where it was further distributed throughout the world.

Maize has been introduced in Africa, and later in other tropical countries, mainly by Portuguese and Arab explorers in West and East Africa, from where it spread inland through the slave-trade routes, and later to Asia. Maize was a major cash crop on the West African Coast at the height of the slave trade in the seventeenth and eighteenth centuries, being used to provision slave ships and the forts where the slaves were assembled prior to shipment overseas. The crop was reported in China in 1573, but had probably been taken there at an earlier date by the Portuguese. It is likely that the Spaniards took it to Manila from Acapulco in the sixteenth century.

Because of its wide climatic adaptability maize cultivation expanded rapidly and the grain became soon a part of the local diet as a diversification of traditional root crops (cassava, yams, sweet potatoes) and various small grains. Maize is now cultivated in more than hundred countries.

Table 2 depicts production figures for a number of countries where maize is mainly cultivated by medium- and small-scale farmers. National production figures here are much lower than in the countries listed in Table 1, where cultivation is mainly by modern and highly-mechanized methods; in Nigeria, South Africa, China, India and Indonesia the production is mixed. Moreover, annual fluctuations in smallholder's yields are noteworthy, obviously due to adverse weather conditions and the occurrence of devastating pests and diseases, which are more difficult to control.

While in the 1960s the national production exceeded hardly 1 million MT in most African, South American or Asian countries (Table 2) total maize production has increased everywhere over the past 45-50 years. In some cases this was achieved with spectacular results, but generally speaking the gradual increase was only about 2% per year. The main reasons for this development were the worldwide promotion for the crop (Green Revolution), improved biotechnological research and the release of high-yielding varieties, and improved hybrid seeds in many developing countries.

Table 2. Maize grain production (in ,000 MT) in major maize growing African, Latin American and Asian countries with a dominance of medium- and small-scale farmers.
Evolution over the past 40 years. (Source: www.fao.org)

Africa - The large and sudden rise in maize cultivation in some African countries – both in terms of yield and in area planted - since the 1980s followed the introduction of different new hybrids from the USA and South America, all of them classified as *White Southern Dents.* The local yellow maize in Africa is derived from early introductions of Caribbean flints and from later ones through CIMMYT in Mexico. In Kenya and Tanzania, where there is a bi-modal rainfall pattern, the predominant maize types adapted to a shorter growing season. In West and Central Africa where this bi-modal rainfall pattern does not exist the cultivars with a longer growth cycle adapted best (Ristanovic, 2001).

The expansion of maize on the African continent has several reasons. First, its taste has been easily accepted by the local population and, therefore, it could rapidly replace traditional starchy food like sorghum and millets. It also became important when foodstuffs had to be transported to feed labor and populations which were not self-sufficient. Additional reasons for this rapid adoption and expansion include (Purseglove, 1975; Pingali and Heisey, 1999):

- It gives one of the highest yields per person/hour of labor spent on it;
- It provides nutrients in a compact form; it is easily transportable;
- The husks give protection against birds and rain;
- It is easy to harvest and does not shatter;
- It stores well if properly dried;
- It can be harvested over a long period, first as immature cobs, but can be left standing in the field at maturity before harvesting;
- Cultivars with different maturing periods are available;
- In terms of taste, many people prefer maize to their local cereals.

About two thirds of all African maize is produced in eastern and southern Africa. South Africa is the largest producer with about 35% of the total regional production. Nigeria is the second most important producer followed by Ethiopia, Tanzania and Kenya. Malawi has made an enormous progress due to the start of an important seed distribution program. The tremendous drop in production since 2000 in Zimbabwe is due to the political unrest in the country.

In sub-Saharan Africa maize production extends over approximately 20 million ha, and the total annual production is about 25 million tons (6% of total world production). In North Africa and the Middle East the only maize producing countries of importance are Egypt and Turkey; it accounts for approximately 15% of all African maize production.

West and Central Africa account for hardly 5.2 million tons. While relatively less important than in eastern and southern Africa, maize still provides a major source of calories, especially in parts of Nigeria, Ghana, Benin and Ivory Coast, and is a major component in the local diet. In these countries maize is almost exclusively grown on small family farms.

Asia - In south-eastern Asia, maize has never been as dominant as in Africa and South America, mainly because rice was plentifully available as a staple food. Only where the region was too dry for rice production, has maize taken its place in the local food economy.

Yield increases as part of the Green Revolution have nevertheless been most spectacular in Asia, especially between 1965 and 1985, because this resulted directly from the introduction of high-yielding cultivars and a more efficient use of inputs. By the late 1980s, however, crop yields had reached a point of diminishing returns to further intensification, mainly due to a combination of factors such as : degradation of land due to intensive cultivation, declining infrastructure and research investments; and increasing opportunity costs of labor. Additional factors that were responsible for local fluctuations were: (a) market and road infrastructure, and (b) subsidy policies. Yields are nowadays maintained at reasonable levels by the substitution of better knowledge and management skills for higher levels of input use, in particular related to appropriate timing and methods of fertilizer application (Singh and Morris, 1997).

Latin America – Except in Brazil and Argentina where part of the crop is cultivated in big estates, most maize in Latin America is grown by small farmers for local consumption. Local corn is grown from sea level to the Altiplano (over 2,000 m) in Guatemala, 2,700m in Mexico and even to 3,800 m elevation near Lake Titicaca in Bolivia and Peru. It is found from desert oases to zones with more than 5,000 mm rainfall along the western coast of Columbia, and up to about 42° S in Chile. At higher latitudes the frost free growing season is too short and the crop does not mature, making it only useful for fodder.

Maize yields under traditional farming in Latin America remain relatively low and suffer from the too limited availability of adapted seed varieties and shortage of labor ((Sain and Lopez-Perreira, 1999).

3. Botany

Maize is a 2-3m high grass with a solid single stem (stalk), 3-4 cm in diameter, with clearly defined nodes and internodes. The number of internodes ranges from 15 to 20. These are short and fairly thick at the base, but become longer and thinner near the terminal male inflorescence. The leaves arise from the nodes, alternately on opposite sides on the stalk.

Emergence after planting is quite fast and range from 4 days in warm soil to 20 days in cool soil. In moist warm soil the radicle emerges 2-3 days after planting, and the plumule breaks through the seed-coat 1-2 days later. The radicle grows out to produce the first seminal root, after which three or four adventitious roots grow out sideways from the embryo; they supply most of the soil-derived nutrition during the first few weeks. The permanent or coronal roots arise from the crown just below the soil surface once the seedling is growing well. Later on, more adventitious roots develop from above-ground nodes and grow into the soil, their function being to anchor the plant and support its upright position.

Maize is a monoecious grass with male and female flowers borne in separate inflorescences on the same plant. Although it is self-fertile, the plant's monoecious character and protandry ensure a cross-pollination of 90-95%. The tassel male inflorescence is a terminal panicle, up to 40 cm long, which stretches out from the enclosing leaves at the top of the stalk. The male or staminate flowers are present within spikelets on the branches. The stamens elongate at anthesis and the pollen is released by the anthers.

The female inflorescence, called the ear, develops on a short side-branch, which emerges from the axil of one or more of the middle leaves. An ear is a modified spike of which the central axis or cob bears paired spikelets, with one fertile flower each, in longitudinal rows. Hence, each ear will always have an even number of rows of kernels. The styles, called silks, are long and unbranched with short outgrowths called trichomes, which emerge from the husks at the top of the ear. After pollen has fallen on a receptive silk, the grain germinates, and grows a pollen tube down the inside of the silk, through which pass two sperm nuclei. When they reach the ovule, one nucleus fertilizes the haploid egg to form a diploid embryo, while the second fuses with the diploid central cell to form the triploid endosperm. The ovary wall and the ovule coat fuse to form the pericarp (hull, seed-coat).

The maize kernel consists of the embryo (10-13% of the grain), endosperm and pericarp and may differ in color, structure and chemical composition. The endosperm, in absence of the testa, is united with the pericarp. The most common kernel colors are yellow and white, though in some landraces they may also turn to red, purple or brown. The different kernel colors on the same ear are due to the out-crossing nature of the crop. The kernel structure depends on the type and nature of the endosperm. Commercial maize is classified into flint, dent, flour, sweet and pop types, depending largely on the degree of hardness of the endosperm (see below, Taxonomy and Classification).

Maize pollen are anemophilous, i.e. dispersed by wind. In calm weather and because of its large settling velocity most pollen falls within a few meters of the tassel; with high wind however, pollen can be carried distances of up to 500 meter. Pollen is shed over a number of days. It is very sensitive to high temperature and low air moisture. Under favorable conditions it is viable during 24 hours, whereas the silks are receptive for a much longer time, i.e. 7 to 12 days. This means that there is usually a good overlap in the timing of pollen shedding and silking, which ensures good seed setting. However, hot and dry weather usually delays silking and hastens pollen shedding, which may result in poor or no seed setting.

4. Taxonomy and Classification

4.1. Taxonomy

Zea mays L. is an annual monocotyledonous diploid (2n = 20) belonging to the Poaceae family and the Maydeae tribe of which eight different genera have been recognized. Three of these are found in the Americas and the remaining five are Asiatic in distribution. The three American genera, *Zea, Euchlaena* and *Tripsacum* are much more closely related to each other than to any of the Asiatic genera.

Maize's closest relative is teosinte (*Euchlaena mexicana*), an annual grass which grows as a weed in Mexico and Guatemala, where it is used as fodder. It crosses readily with maize, and the hybrids are fertile with normal meiosis**.** *Teosinte* resembles maize in habit, but produces a number of basal tillers.

Maize differs from other crop species in a number of aspects that affect the way genetic improvement activities are organized and carried out and, therefore, no other crop has received more intensive genetic and cytogenetic attention as maize. There are several reasons for this (Morris *et al.*, 2003):

- It is an open-pollinating species, unlike wheat and rice which are self-pollinating. A viable seed from the latter almost always comes from the same plant. By contrast, in the case of maize landraces and open pollinated varieties genetic material is exchanged between neighboring plants which are genetically distinct, and all new plants will differ from the preceding generation and from each other;

- Because male and female flowers are on the same plant but in different locations, cross pollination is relatively easy. Plants can easily be self-pollinated in controlled pollination, and this has led to the formation of inbred lines which, when crossed together, give rise to a significant degree of heterosis. This characteristic, in combination with its pronounced hybrid vigor, makes that no other grain crop can be manipulated as rapidly as maize. Hence, the improvement programs for the development of hybrids are both scientifically attractive and provide good perspectives from an economic point of view.

- Because the genetic composition of maize plants grown from farm-saved open-pollinated seed can change considerably from generation to generation, farmers who focus on high yields should purchase fresh seeds for each cropping cycle. This can present a bottleneck, particularly in developing countries where subsistence farming is still common and where there is no organized seed market.

The reasons above explain why cytogenetic progress in maize has been very successful in creating many maize varieties, but without direct impact on low-input agriculture. The CIMMYT-managed international testing network tries to overcome this handicap by providing national breeding programs with ready access to improved germplasm and information that they would be able to generate on their own adapted varieties that meet farmers' requirements..

4.2. Classification

Maize cultivars can be divided into groups according to the structure of the grain, which is usually dependent upon one or a few different genes. This classification, described below, is useful agriculturally, but has little meaning botanically, although the groups are sometimes given the status of botanical varieties. On a worldwide level the following groups can be differentiated (Purseglove, 1975):

- Pod corn (*tunicata* Sturt). This is the most primitive form of maize, which is comparable to wild maize (now extinct) and the earliest domesticated forms of the crop. It is not grown commercially, but is preserved in some localities by the Indians in South America who believe it to have magical properties.

- Popcorn (*everata* Sturt). It has also primitive characteristics, with small grains containing a high proportion of hard corneous endosperm and soft starch in the centre. On heating the steam generated inside the grain causes it to pop and explode. It is grown in small quantities in the United States and Mexico, and is the basis of popcorn confections.

- Flint maize (*indurata* Sturt). The multicolored grains, consisting of hard endosperm and soft starch in the centre, are smaller than those in dent maize, larger than popcorn, and have rounded ends. It is more resistant to insect attacks. It is the predominant type of maize grown in Southern Europe, South America, Asia and parts of tropical Africa.

- Dent maize (*indentata* Sturt). This is the principal maize type of the Corn Belt of the United States and Northern and Coastal Mexico. US dent maize is a hybrid, late-maturing dent grown originally by the Indians in the South, and an early-maturing flint corn from the North. Yellow dent is primarily used for livestock feed, white dent is primarily for meal and cereals for human consumption. Other dent lines have been bred for special purposes, e.g. high lysine maize for use in human food, pig or chicken feed, high oil maize for production of vegetable oil for human consumption.

- Soft or floury maize (*amylacea* Sturt). The endosperm consists of soft starch and the grain usually has no dent. This type, frequently found in Aztec and Inca graves, is widely grown in the drier parts of the United States, western South America and South Africa. The large-seeded corns of Peru are used in the preparation of *chicha*. In South Africa they are known as *bread mealies*.

- Sweet corn (*saccharata* Sturt). This is a genetic variation that accumulates more sugar and less starch in the ear, and is used in the preparation of *chicha*, Mexican and South American beer. The grains contain a sweetish endosperm and are translucent when immature. It is mainly grown in the United States, where it is picked immature for boiling as *corn on the cob*, is used for canning and freezing, and has become a highly popular vegetable.

- Waxy maize (*ceritina* Kulesh). In this type the starch is entirely composed of amylopectin, whereas in non-waxy cultivars it is a mixture of amylose and amylopectin. It is now mainly found in eastern Asia. In recent years it has found industrial uses in the United States as a substitute for tapioca.

4.3. Types of Maize in Traditional Low-Input Cultivation in Africa

Farmers in Africa plant many different types of maize. Most often the crop is cultivated in small- and medium-scale family farms; a few large-scale commercial farms are mainly concentrated in eastern and southern Africa, but are an exception in the rest of the continent. Smallholders continue to plant mainly unimproved traditional varieties, while large-scale commercial farmers grow hybrids and other improved maize varieties. Ristanovic (2001) makes a clear distinction between the varieties and production methods used in east-south Africa and west-central Africa.

In eastern and southern Africa, hybrids accounted for 25% of the total maize planted area in the 1980s, but now this figure has more than doubled. This spectacular increase is due to the recent massive introduction of hybrids in countries like Kenya, South Africa and Zimbabwe. Well-functioning maize-seed sectors have been established in these countries. Maize-seed enterprises in most other countries in the region are undeveloped. The acceptance of hybrid maize by small-scale farmers is, however, still very low. In some regions, improved maize material has not been adopted because it did not meet specific requirements of farmers. For example, in Malawi, the market expressed a clear preference for flint maize, but breeders neglected these types because they had little access to improved flint maize as source material in their breeding work. The breeding program eventually recognized this problem and now produces improved flint materials as well as dents.

In west and central Africa most maize is produced in family farms and only a very low percentage of the maize area is planted with improved genotypes. Farmers rely on their traditional varieties, or use grains from the former yield. Hybrids account for hardly 1% of the region's maize area, and about 10 % is planted with improved open-pollinated varieties.

In Benin, Ivory Coast and Burkina Faso most farmers still continue to plant traditional varieties, in part because improved materials are not available, but mainly because traditional varieties suffer less damage during storage and are better suited for local dishes. In other countries where improved seed material is available farmers gradually shift to new hybrids. This is, for example, the case in Nigeria, where a *National Accelerated Food Production Project* is active, or in Congo-Kinshasa, where *The Plan National Maïs* is releasing locally adapted new varieties.

5. Ecology and Growing Conditions

5.1. Climate

5.1.1. Temperature

Maize is basically a warm-weather crop, though modern cultivars are now developed that are also adapted to cooler climates. It requires a frost-free growing period. Growth and vegetative development of the plant are optimal at temperatures between 22° to 30° C. The crop cannot be grown if the mean minimum temperature in the growing season drops below 10° C, or if day temperature rises above 45 degrees for extended periods. Temperatures above 35° C seriously reduce yield; above 40° C the pollen is damaged and grain setting is reduced (Table 3).

The optimum temperature for germination is 18-21° C; above 21 °C the process slows down. Below 13° C germination is greatly reduced, and below 10° C it fails. Cold wet weather after planting favors the development of pathogens. Breeders are now mainly paying attention to cultivars which give a strong germination at low temperatures to produce earlier maturity. There is considerable genetic variation for tolerance to low temperatures available from highland landraces from Mexico and Peru.

5.1.2. Moisture and Rainfall

Maize requires a regular moisture supply and suffers from intermediate dry periods. Hence, a rain fed crop needs 450 to 600mm in temperate areas, and 600 to 900mm in the tropics The rainfall should be well-distributed over the growing period, with periods of clear warm weather between the rain storms. When the annual rainfall should drop below 350-400mm, additional moisture is needed to avoid yield decrease. The crop supports minor intermediate dry periods, though good moisture availability at the time of flowering is critical.

A supply of 100-125mm of water in the 15 days either side of flowering is considered ideal. Deficient moisture in combination with high temperatures at this time in the growth cycle may result in pollen being shed before silks emerge, or in death of the tassel and drying out of the silks. Kernel abortion after pollination is the main cause of yield reduction in drought-stressed maize.

Optimal and marginal rainfall requirements for maize in the Sahel are listed in Table 3. As a C4 plant maize is a water efficient crop, though still its water requirement is high, mainly because it produces an enormous amount of organic material. Water consumptive use varies between 2 and 3 mm/day for young plants, and up to 6 mm/day at or close to anthesis depending on atmospheric demand.

If the rainfall is not sufficient (not enough rain, too long intermittent dry spells) the plant has to rely on soil moisture storage. Roots of landrace varieties commonly explore the moisture in the root zone up to a depth of 100-150cm. That is the reason why maize grows best in deep sandy loams and loams with high water holding capacity (15 to 20%; 75-100 mm of water available to the plant over the upper 50 cm of the soil). Favorable water conditions for maize exist when soil moisture is in surplus at the roots, and rainfall is at least 500 mm and favorably distributed during the growing season. In drought conditions, photosynthesis slows down or even stops, resulting in decreased growth, slow or interrupted silk emergence, low kernel numbers, and decreased filling of the grain, all leading to substantial yield reduction.

Table 3. Impact of major climatic conditions on yield level in traditional maize cultivation in sub-Saharan West Africa (adapted from Verheye, 1990)

5.1.3. Other Climatic Hazards

Other climatic conditions which affect maize growth are (Brochet *et al*., 1975): wind, hail, sunshine and photoperiod, air humidity and extreme temperatures. Strong winds result in lodging. Hail can damage the leaf canopy and the cobs. Too high or too low air humidity at maturation and harvesting affects the quality of the ears and the storage of the grains.

Each cultivar is adapted to the specific circumstances under which it is grown. Day length affects photoperiod response, and maize flowers more rapidly in short days. However, modern hybrids from the US are now almost insensitive to day length. Relatively high temperatures are required from seeding to flowering while grain filling can take place in somewhat cooler conditions.

5.2. Soil

Maize grows on a wide variety of soils, but performs best on medium-textured, well-drained, well-aerated, deep, and fine-structured soils containing adequate organic matter and nutrients. Other soils which are either too wet or too dry, are waterlogged or are depleted in nutrients will only produce good maize crops with adequate management and good cultural practices. The crop is fairly sensitive to salts (Table 4).

Maize can be grown successfully on soils with a pH from 5.0 to 8.0, though the optimum is at 6.0-7.2. High yields of maize make a heavy drain on soil nutrients, nitrogen in particular. Under natural conditions this nutrient stock is rapidly exhausted and that is the reason why, if no additional fertilizers are supplied, yields in a slash-and-burn system are rapidly reduced to subsistence levels. Early-maturing cultivars have a better chance of setting seed before exhausting the moisture and available nutrients on the poorer soils than large full-season cultivars, especially under conditions of progressive drought. Full-season cultivars have generally deeper roots and can better exploit the moisture from the lower soil layers.

Higher yields are obtained from higher planting rates and heavy fertilization when soil moisture is adequate. Because of the risk for a rapid growth and consequent risk of lodging shorter hybrids are preferred under those conditions.

Since the crop leaves much of the ground uncovered in its early growth stages, soil erosion and water losses can be severe and attention should be paid to adequate conservation measures. Stem flow is an important factor for the initiation of micro-gullies at the base of the crop when planted on a slope.

Table 4. Impact of major soil and landform conditions on yield level in traditional maize cultivation in sub-Saharan West Africa (adapted from Verheye, 1990)

5.3. Natural Land Suitability

Maize yields obtained under traditional low-input management are more affected by natural soil and climatic conditions. While in high-technological (commercial) agriculture many production constraints can be overcome by adapted cultural practices, - e.g. water logging through soil drainage, water shortage by irrigation, nutrient deficiency by fertilizer application, etc. – this is not the case in traditional, low-input (subsistence) agriculture, either because the technical facilities are not available for remediating the land limitations, or because there is no financial or commercial backing of the operations.

In order to overcome this problem and still be able to evaluate the production output of the land, FAO has developed a land suitability system, whereby the different crop requirements listed in a suitability ranking are matched with natural land conditions (*see also: The FAO Guidelines for Land Evaluation).*

Tables 3 and 4 summarize the critical crop requirements for local maize varieties grown in the Sahel area south of the Sahara, and of their impact on the approximate yields obtained without direct amendments. The exercise starts by defining the growing period characteristics of the crop (in terms of start and length in days) and the maximal (optimal) yield that can be obtained under the most optimal climatic conditions, assuming that soil properties are no limitation. This figure is normally obtained from a reference research station for maize in the area, for example an ICRISAT station. Assume that this figure for the given agro-ecological zone is 4 tons/ha.

The second step is to collect the climatic information in terms of the criteria listed in the left column of Table 3 and to match this information with the classes in the right columns. Assume for example that the figures all match with the data in the second column (100-80% expected yield) of Table 3, except for the rainfall in the growing period which is 600 mm (column 80-50%, average 65%). This means that on the basis of the climatic conditions of the area the maximum obtainable yield is 2.6 tons/ha (4 tons x 65%) . This is the maximum yield that can be expected from this variety if all soil conditions are optimal.

The third step is to match the local soil properties with the data in Table 4. This matching will indicate the most important limitation, for example a soil depth of 60cm and a sum of bases being 6.2 me/100g soil. These figures correspond to a 65% of expected yield, referring back to the 2.6 tons/ha defined earlier. The anticipated yield for the given soil and climatic conditions is thus around 1.70 tons/ha (65% of 2.6 tons/ha).

This exercise provides a rough estimation of the approximate yields that can be expected in the area. The method can further be refined by replacing the average figure (65% as an average between 50% and 80%) by more precise estimations if the land component is nearer by the 50% or the 80% limit in the table. It should nevertheless be understood that, all figures being mean data, the annual fluctuations might seriously affect the results of a single year.

On the other hand, as the system is transparent, one might clearly identify the factors which are most limiting the production and, thus, they clearly focus on the type of land improvements that are needed to enhance yield. If the soil limitations would not have been the soil depth but only the sum of bases, this would mean that by improving the nutrient status (in combination with the cation exchange capacity status) the potential yield could have been improved to a level well above 1.70 tons/ha, but not higher than 4 tons/ha.

6. Land Husbandry

6.1. Cropping Systems

There are three main groups of producers, depending on the scale of the farm and the farming practices : (1) large-scale commercial farmers, cultivating several hundreds of hectare, often in a monocrop system; maize is their only product; (2) medium-scale farmers, growing maize next to other crops on 5 to 20 ha on average, and (3) small-scale farmers operating on fields of 1 to 3 ha, or even less, relying on family labor and practicing mainly a subsistence agriculture.

Large-scale commercial farmers – These are mainly concentrated in industrialized countries, and their practices have been discussed in more detail in: *Growth and Production of Maize: Mechanized Cultivation.* In Africa they occupy only 5% of the total area planted to maize, mainly in South Africa, Zimbabwe, Kenya and Zambia; they are virtually absent in Central and West Africa. In South America they operate only in Argentina and Brazil; in Asia they hardly occur.

The land is held under registered title. Farm operations are fully mechanized, and they rely on outside manpower. The crop is usually sold entirely to an agro-industrial company as a cash crop, though part of the harvest may be used to feed regional workers, e.g. on the tobacco and tea estates of Malawi.

Medium-scale farmers – They cultivate between 5 and 20 hectare, about half of which is planted to maize. They are spread all over Africa, though mostly in East and South Africa, and are considered among the wealthier farmers in the community. Most of them rely on family labor with some support of temporary external labor. The crop produced is partly for family consumption, partly sold in local markets. Cultivation is by draught animals, usually oxen or donkeys (Photo 1).

Photo 1. Weeding maize by ox-drawn implements in southern Africa
(Courtesy G.M. Ravagnan)

Medium-scale farmers practice mono-cropping on the land that is reserved for the cash crop, but always keep a portion of their farmland for intercropping with other food crops. In addition, maize is grown in rotation with other (commercial) crops, such as beans, groundnuts or soybeans, or with cotton, tobacco, clover and grass. Rotations have the advantage to balance the nutrient uptake from the soil and to meet different needs of different plants, to assist in the control of erosion and weeds, and to manage better the distribution of labor.

Small-scale farmers – Smallholders constitute by far the most important group in terms of numbers of producers, but because they cultivate only small fields the total area planted to maize does not exceed 40% of the total cropping area. Smallholders rely almost exclusively on family labor on plots of 1-3 ha held under traditional tenure arrangements. Most family farms practice intercropping and/or a rotation system with maize alternated with other food crops like beans, pumpkin, cowpea, pigeon pea, groundnut, sweet potato and cassava.

In west and central Africa the traditional agriculture is still to a large extent based on shifting cultivation and slash-and-burn methods, whereby the land is cultivated for 3 or 4 years after the forest is burnt, and then is left again into fallow. The length of the fallow depends on the natural soil fertility and on the pressure on the land. Intercropping (Photo 2) is common, whereby maize is one of the many other food crops for direct consumption by the family.

In Asia, where the pressure on land is more acute than in other parts of the world, maize is almost always associated with an intercrop. In irrigated areas, maize or sorghum are part of the rotation in rice cultivation where there is not enough water available to irrigate the second rice crop **(*see also: Management of Agricultural Land: Climatic and Water Aspects*).**

Photo 2. Maize intercropping with groundnuts in Indonesia.

6.2. Land Preparation

Newly-planted maize requires a weed-free soil that is warm, moist, well supplied with air and moisture, and has a fine tilth for optimal contact between seed and soil. Land preparation therefore aims at a loose, deep soil with a fine tilth to allow even seeding and uniform emergence.

The method and timing of land preparation depends upon the environment, more particularly on the type of soil and its moisture storage, and upon the resources of the farmer. Early plowing or cultivation (e.g. immediately after the first rains), followed by drying of the topsoil, may be necessary in heavy clays. In well-drained soils the land can be plowed immediately before planting in the furrows. In less well-drained soils the maize is planted on ridges.

Land preparation begins ideally just before the wet season to take advantage of the rains, but is rarely completed on time for various reasons, especially for small- and medium-scale farmers where work is done by hand or by animal traction, and the soil needs to be soft. Conventionally, early plowing before the onset of the rains is followed by one or two harrowings.

When land preparation is done manually by hoe the time may be too short between the end of the rains (or the withdrawal of the floods in alluvial valleys) and the rapid hardening of the topsoil. Hence, land preparation is not finished in due time and planting has to be delayed. Where animal traction is used, the animals are often too weak at the end of the dry season (due to the shortage of feed) and they need first a time of recovery before they can operate the ox-drawn plows. Usually, a single plowing is done, but occasionally it is supplemented by a harrowing before planting.

6.3. Planting Methods

Time of sowing - The time of sowing is mainly determined by the rainfall regime, the cultivar (early or late maturing varieties) and related length of growing season, and the fact that a dry period is needed for ripening. This means that maize should be planted as early in the season as possible, i.e. as soon as soil and climatic conditions are favorable. In temperate countries, the ideal planting time is shortly after frost risk is over (April-May in the northern hemisphere); in the equatorial zone this is at the beginning of the rains. A delay of planting of two to three weeks may easily reduce yield by as much as 15-25%.

Though this holds some risks, small-scale farmers in Africa and Asia start seeding shortly after the first rains. Depending on the irregularity of the rainfall pattern in this period, three or more plantings may be required to be sure of a reasonable crop. With sufficient soil moisture at the beginning of the growing season, uniformity of seedling emergence depends on seed quality (viability, purity), seed treatment against soil-borne pathogens, proper seeding methods (depth and spacing) and correct seed quantity.

Seed quality and quantity – Under traditional agriculture seeds are from ears selected from the former harvest. Many small-scale farmers still choose to plant unimproved local materials because improved varieties are not available, or their grain quality is unacceptable to them. On the other hand, in areas where fertilizer and other inputs are readily available, the interest in early-maturing varieties has been strong since these materials give farmers greater flexibility to stagger maize planting. Kenya, Zambia and Zimbabwe, and more recently Malawi have been particularly successful in delivering improved maize varieties to a large percentage of their small-scale farmers.

Planting methods - Planting may be done mechanically or by hand. Traditionally, planting is done in rows 75cm to 1m apart; in each row 2-3 seeds are planted every 30 cm. Another way of planting is to accumulate 3-4 seeds, at a distance 60-80 cm apart in all directions. Seeds are deposited 7-10 cm deep. The amount of seed for 1 hectare is 15-20 kg.

Planting methods used by medium-scale farmers vary depending on: area to be planted, soil moisture status at the time of planting, and availability of labor. In dry areas, the seed is broadcast directly onto the soil and then plowed in, a method especially suitable for planting rapidly a large area. Dibbling seed behind the plow is another method to plant quickly while soil moisture conditions are favorable. Seeds are dibbled in every other furrow and covered by return pass of the plow. Hoe-planting behind the plow is favored in some places to ensure uniform stands, although this method requires considerable labor. In parts of southern Africa, drilling with an ox-drawn planter has become increasingly popular in recent years. As improved varieties have gradually become available, medium-scale farmers have begun to demand germplasm with specific characteristics, especially drought-tolerance, high-yield potential and responsiveness to fertilizer. Interest in early-maturing varieties is strong because the grain is ready for consumption earlier in the season (Ristanovic, 2001).

The usual planting depth is 5-12cm depending on the soil type. On wet soil, and where predators like birds are present, 5cm may be sufficient. On dry soils planting should be deeper to get down to the moisture: about 7-8cm on clays, 10cm on silts and 12-13cm on sands. Replanting gaps is advisable with hand cultivation.

Plant spacing - The spacing depends upon local climatic and soil conditions, and upon the cultivar. Planting is done on hills, on the flat or on ridges. In the earlier days it was usual to plant three kernels per hill on a 100 cm check-spacing, giving a final population of 25,000 plants per hectare. Nowadays with modern hybrids, the usual spacing is about 75-100 cm between rows and the density is about 50,000 plants per hectare. In tropical Africa, a spacing of 90 cm between the rows is usually recommended (with space available for an intercrop), with 2-3 seeds at intervals of 90 cm or 30 cm between plants. The higher the distance between the seeds the smaller the competition for moisture and nutrients, but the higher the need for weeding. An average seed rate of 9-16 kg/ha is common. The mortality from lack of germination, insects and cultivation damage is usually 10-15%, increasing to 15-20% at a closer spacing.

The optimal plant density should, in fact, always be adjusted to local conditions and varieties grown. Generally, maize in Africa is grown in low densities (15,000 to 35,000 plants/ha). There are two major reasons for this: risk of drought and intercropping of maize with other crops. Overall plant population at global level varies from 25,000-50,000 plants/ha for grain production under rain fed conditions, to 40,000-60,000 plants when irrigated, and 100,000 plants/ha for fodder production, or for grain production in short-season temperate areas with modern hybrids. Under highly mechanized cultivation (as in the USA and Canada for example) the density varies between 60,000 and 80,000 plants/ha (*see also: Growth and Production of Maize: Mechanized Cultivation).*

6.4. Maintenance and Management

Hilling - Plants are earthed up when they are 45-50 cm high; this promotes development of side roots and makes the plant more stable.

Weed control – Maize does not compete well with weeds for space, water and fertilizer. Yield losses of 40-60% due to weeds are therefore not uncommon. Weed competition is particularly problematic in arid and semi-arid zones, since moisture lost to weeds is directly translated into yield reduction of the crop.

Striga spp. is an indigenous parasitic weed that attacks most traditional crops of the African savanna, including maize, sorghum, pearl millet, groundnut and cowpea; it infects almost 21 million ha of land in Africa (Manyong *et al*., 2003). Weeding is particularly necessary during the critical 10-30 day period after crop emergence. It is achieved by hand (smallholders' practices) or by using 1-2 kg/ha pre-emergent atrazine or simazine (medium- and large-scale farmers).

On smallholdings weeds can hardly be controlled by hand-hoeing alone and, therefore, remain a serious problem. Moreover, as the season progresses, farmers must often compromise between planting more land and weeding maize that has already emerged. The use of herbicides is rare.

Medium-scale farmers control weeds either by hand-hoeing or, less commonly, by ox-drawn cultivators (Photo 1). Planting in rows facilitates mechanical weeding. It is generally done several weeks after emergence while the plants are still small. Frequently, a late ridging to avoid lodging equally controls weeds. Herbicides are not commonly used by medium-scale farmers in Africa. Large-scale farmers control weeds by mechanical cultivation and with herbicides, applied by tractor-mounted sprayers or by air.

Irrigation - Irrigation is only used on large estates situated in low rainfall areas. It is often limited to a supplementary water supply during intermediate dry spells and at critical periods in the growth stage, i.e. at the time of tasseling. Medium- and small-scale farmers have generally no additional water at their disposal. In case they have a small water source available they will use the extra water to irrigate either their garden or the cash crops.

Fertilization and nutrient supply – The nutrient requirements for maize have been discussed at full in the companion paper on *Growth and Production of Maize: Mechanized Cultivation***.** The figures advanced for the high production levels in the Corn Belt in the USA are equally valid in other parts of the world, but have to be adapted to the much lower yield levels obtained under traditional low-input cultivation. In this respect it is recalled that the nutrients removed by a crop of 4,000 kg/grain per hectare are approximately 120kg N, 45kg P_2O_5 and 80kg K_2O.

Small- and medium-scale farmers in developing countries rarely use inorganic (mineral) fertilizers, because either they have no access to them (no marketing, no funds) or the climatic hazards remain too risky so as to overrule the possible profit of a fertilization. This situation is partly overcome by the application of animal manure, the incorporation of crop residues and the use of a rotation system. Crop residues from the previous crop, including stover when maize follows maize, can be incorporated into the soil or left on the surface as a mulch; the addition of nitrogenous manure will assist their decomposition.

In the African Sahel area there is a large number of roaming cattle belonging to the semi-nomadic Peul population which moves every year southwards to the arable zones where, by mutual agreement, their herds are allowed to graze the stubble of the cereal fields after harvest. These cattle bring in animal manure which, together with the incorporation of the crop residues, constitutes a reasonable nitrogen source to the soil. Besides this natural process which favors mainly small-scale farmers, there is a possibility – mainly for medium-scale farmers – to introduce a crop rotation system, using a legume crop.

It should be recalled that maize, and in particular hybrid maize, is very responsive for nitrogen and that as long as the N status of the soils under low-input cultivation is not consistently raised, there is little chance that the local farmers' communities will accept hybrid varieties of the crop.

The average application rate of nutrients (www.faostat) to cultivated land in sub-Saharan Africa is around 10 kg nutrients/ha; it is 100 kg for south and east Asia, and >200 kg/ha for the US and Europe.

6.5. Harvest and Storage

Maize is physiologically mature when, after a growing period of 90-120 days (early varieties) to 170-190 days (late varieties), a black separation layer forms at the pedicel and grain moisture content is about 35%. It is then usually left in the field for further drying before it can be harvested. Maize for silage is harvested while the plant is still green and the whole-plant dry matter content is around 35% and the grain is 95% filled. Sweet corn is harvested in the milk stage about three weeks after pollination, but before much starch has formed. Field maize is left in the field very late in the autumn, or as long as practicable in temperate climates, in order to thoroughly dry the grain.

The crop can be harvested by hand (Photo 3) or mechanically. In the first case the complete cobs are removed. Mechanized harvesting is possible by picker or combine. In the latter case, maize can be harvested at a moisture content of 25-28%, but it will not store well at this moisture level and should therefore first be dried afterwards.

Photo 3. Women harvesting maize by hand in southern Africa
(Courtesy G.M. Ravagnan)

Small-scale and medium-scale farmers in eastern and southern Africa start harvesting maize only when the plants have fully dried. Either the ears are picked or the entire plant is cut. Traditionally, small-scale farmers in Africa and Asia harvest maize when the husks start yellowing, an indication of physiological maturity. After husking, the ears are tied together and hung underneath a roof or other protective cover where they gradually dry.

Much of the harvest is stored on the farm. Most often, ears are kept in outdoor cribs in which insects are controlled by the smoke of a nearby fire. In some areas, raised clay or brick outdoor granaries (Photo 4) or underground storage pits are used. In dry areas, maize may be shelled and stored indoors in sacks, earthen jars, metal bins or other containers. Given the long dry season in these areas, the traditional storage methods provide good aeration and offer some protection from insects and rodents. The use of insecticides to control storage pests is increasing.

Storage of the maize is a major problem in rural Africa and in Latin America because it is affected by both rodents and insects. Before storage the ears should be well dried, and storage should take place in well aerated locations.

Photo 4. Outdoor storage of maize ears in southern Africa
(Courtesy G.M. Ravagnan).

6.6. Pests and Diseases

For data on the pest control and management in large-scale mechanized maize cultivation under mono-cropping, reference is made to the companion paper *Growth and Production of Maize: Mechanized Cultivation.* In the following chapter the focus will mainly be on low-input cultivation zones. Obviously, pest control management is quite different in areas where natural cultivars dominate over hybrids, as compared to the high-tech production zones.

Numerous diseases attack maize in low-input areas in Africa, Asia and Latin America. This refers in particular to the widespread incidence of ear rots, leaf blight, streak virus and stalk rot.

Ear rot, caused by *Fusarium* spp., *Stenocarpella* spp. and other fungi is probably the most serious disease in smallholder's cultivation; it reduces the yield and nutritional value of infected grains and causes the formation of mycotoxins. Besides, it affects the quality of seed that is saved to plant a new crop and causes stalk rot and lodging.

Common smut is a widespread fungus disease caused by *Ustilago maydis*. Galls of various sizes develop on all above-ground parts of the plants. The ears are most vulnerable to the infection. Rust is another disease caused by *Puccinia sorghi* at lower altitudes and *Puccinia polysora* at elevations up to 1,200m.

Downy mildew caused by *Sclerospora* spp. is of economic importance in the South Pacific, southern Asia, South Africa, southern Europe and the US. It is recognized by the occurrence of pale yellow streaks on the upper leaves which precede the development of downy mildew, necrosis and browning, and retarded development. Often, no grain is produced.

Leaf blight caused by *Exserohilum turcicum* and *Bipolaris maydis*, and ***maize streak***, caused by *Geminivirus I* (MSV), are widespread throughout Africa, where epidemics of maize streak occur periodically. The disease is most serious in crops that are planted late, sown during the small rainy season (in bi-modal rainfall zones), or grown during the cool season on residual moisture in swamp areas; it is transmitted by a leafhopper (*Cicadulina* spp.). Maize streak does not occur in Latin America; a similar but less serious disease there is called *rayado fino*, or fine stripe.

Research work on ***streak*** resistance has received high priority over time. A variety of chemical and cultural practices help to control maize diseases. The use of resistant germplasm is the most cost-effective method for disease control and is less harmful to the environment.

Insects affect maize yield at two levels : in the field and at the storage level. The most important field insects are (Ristanovic, 2001): cutworms, rootworms, stem borers and termites.

Cutworms (*Agrotis* spp.) often attack maize seedlings at or below soil level. They are controlled by row or spot treatment with chlorpyrifos or an appropriate pyrethroid. The larvae (white grubs) of the black maize beetle *Heteronychus* spp. and of other *Scarabaeidae* kill seedlings or retard their growth. Soil treatment at planting or seed treatment with an insecticide may be necessary.

Various ***stalk borers***, such as *Busseola fusca* (Noctuidae), *Sesamia calamistis* (Noctuidae) and *Eldana saccharina* (Pyralidae), damage young plants whereby the larvae tunnel into the stems near the growing point; they may also attack the developing ears. *Chilo partellus* is a major borer of lowland Africa. The cob borer *Heliothis*, another cosmopolitan pest, is usually controlled by early harvesting (stocking) and cultivation, crop rotation, early sowing and timely spraying or dusting of infected areas. These pests are controlled by application of pyrethroids.

Spodoptera spp. (Noctuidae) and *Marasmia trapezalis* (Pyralidae) are important ***leaf-eaters and army worms***. In case of severe attacks, the application of a pyrethroid is necessary. The earworm, *Helicoverpa armigera* (Noctuidae), is a common pest of maturing grain. Secondary ear rots (e.g. *Fusarium moniliforme*) may follow the infestation.

In Africa and Latin America, where maize is frequently stored before it is properly dried and without insecticide treatment, insect damage to stored grain can cause losses of 50% or more. Problems with storage pests develop as a result of high temperatures and intermediate humidity, which encourage insect populations to grow. The ***grain moth***, *Sitotroga cerealella*, the ***green weevil***, *Sitophyllus* spp., and the ***larger grain borer***, *Prostephanus truncatus* occur in many regions. A common control measure of storage pests consists in mixing grain with a small amount of an insecticide, e.g. malathion or pirimiphos-methyl at 1 or 2% active ingredient. In low-input agriculture these agrochemicals are, however, not always available.

Additional damage to maize is caused by local ***rodents*** such as rats, squirrels, wild pigs, game, and various large birds. In Zimbabwe and Botswana local administrations have sometimes to interfere in conflicts between ministries for the compensation to local farmers (supported by the Ministry of Agriculture) of damage to their fields and crops caused by herds of elephants breaking out of the game reserves (responsibility of the Ministry of Environment) and crossing the neighboring agricultural areas.

7. Yield and Yield Enhancement

Maize yields obtained under traditional management remain low, even if in the past the crop has been subject to intensive enhancement programs, i.e. the Green Revolution. Over the period 1965-2000 growth rates were poor in Africa and Latin America, and reasonably good in South-East Asia. Average maize yields in developing countries (excluding commercial producers China, Brazil, Argentina, Chile and South Africa which plant mainly hybrids) grew at less than 2% per year, with quite important annual fluctuations.

The predominantly rain fed maize production in sub-Saharan Africa and its subsistence orientation account for its low and fluctuating growth rates during the last 3 decades. The reasonable production increase in Asia was mainly achieved by a more efficient use of inputs, being itself the direct response to growing market demands (Singh and Morris, 1997).

Maize yields vary considerably from one area to another. First of all, a distinction has to be made between grain and fodder maize. While for grain maize the average yields in the American Corn Belt and other industrialized countries vary between 9 and 10 tons/ha, it is often below 1 ton/ha on the African and South American continents. The average yield potential under large-scale cultivation in the tropics with adequate water supply varies between 4 and 5 tons grain per hectare, depending on cultivars and environmental conditions. Maize harvested as green fodder for silage yields on average between 20 and 60 tons/ha wet weight, corresponding to an approximate 15-25 tons dry matter weight per hectare.

Table 5 displays the evolution of maize yield in Africa over the past half century. Maize under those circumstances is mainly grown for grain and as a food crop. Yields are lowest in West Africa, where they hardly attend 1 ton/ha. In Ivory Coast and Mali the crop is almost exclusively grown by smallholders, and yields have hardly increased in the past 50 years. Moreover, they vary randomly as maize is grown almost exclusively as a rain fed crop. The Ghana figures are somewhat better due to the relative success of a local seed distribution network.

Yields are somewhat higher in eastern Africa. The highest average yield (1.5 - 1.8 t/ha) is obtained in Ethiopia, Zambia, Tanzania and Kenya, obviously because the crop is mainly cultivated in mid-elevations where the milder temperatures allow for the highest adoption rate of hybrid seed.

The average yield is highest in southern Africa (Table 5). The figures for South Africa and formerly for Zambia are somewhat disturbed because of the presence of a few large-scale industrial farms which use modern production techniques and improved hybrids. The spectacular drop in yields in Zimbabwe over the past 10 years is mainly due to political unrest and the lack of farm maintenance.

Table 5. Average maize grain yields in a number of African countries compared to those of a few other world producers (Source: www.fao.org)

Many factors explain the low yields and geographical and temporal variability of yields in low-input maize cultivation in the tropics. First, because most maize is rain fed, yields depend largely on local weather conditions. This means also that farmers do not generally take the risk – even if they could pay for – to apply much fertilizers (one or two bags of 50 kg each per hectare) to the crop. Moreover, in the traditional food production system, maize is grown in low density and in mixed stands with one or more associated crops, including cassava, sorghum, pumpkin, squash, cowpea, groundnut, yam, sweet potato, and others, which all compete for water and nutrients in the soil (Photo 2). Mixed cropping lowers maize yields in themselves, but guarantees a minimum and diverse food supply for the family, even if any crop would fail. This is a basic principle of subsistence farming.

Still other factors come into play as well. Hence, land is still relatively abundant in west and central Africa compared to, for example, eastern Asia. Under these conditions farmers take advantage of this relatively easy access to land by applying a slash and burn system and, thus, using low levels of purchased inputs, especially fertilizer. Also, many African farmers continue to plant unimproved local varieties with very low genetic yield potential.

In the same sense can the geographical variability in yields be explained. Maize in Africa and Latin America is often grown in marginal environments characterized by unreliable rainfall or low soil fertility, while in east Asia both the climate and soil conditions are often more reliable, and maize is sometimes also irrigated and grown as a small cash crop. Maize growers in these countries suffer therefore less climatic risks, are more market oriented and are open to new technologies and inputs (use of hybrid seeds, fertilizers, and chemical pest control).

Future growth should almost always come from increased yield per unit of land. This is particularly the case for many countries in Africa and Latin America. This involves the introduction of modern cultivation techniques and better varieties through breeding and biotechnological innovations.

Of the three major cereals (wheat, rice and maize) the yield frontier for maize could be shifted most readily, in particular, through technology transfer from industrialized nations. This type of transfer is most likely to occur in China or other parts of Asia, where a rapidly expanding demand of feed maize will make the crop increasingly profitable in certain areas, and large private sector seed companies should be willing to make the necessary investments given the appropriate institutional environment. For regions that continue to rely heavily on maize for food, such as eastern and southern Africa and Mesoamerica, this type of transfer is far less likely, mainly because the technological progress was already achieved in the past (Morris, 2000).

Two areas in which considerable progress has been made in maize improvement include greater resistance to abiotic stresses through modified selection methods and greater resistance to biotic stresses through gene transfer. Apomixis, a process whereby plants reproduce asexually, is a technological option with a much longer horizon. This trait, when incorporated into maize, would eliminate the need to replace hybrid seed every year, while maintaining the yield advantage of hybrid maize (Morris, 2000).

While the growth in fertilizer and insecticide use can be managed through the adoption of efficiency-enhancing technologies, herbicide use is expected to increase dramatically across Asia for the foreseeable future. The growth in its use is closely linked to increasing wage rates and the substitution of manual weeding to chemical control.

A key role in yield enhancement in traditional maize production is reserved to the commercial seed industry. Since it is too costly and technically difficult for farmers to produce genetically pure maize seed, the fact that fresh seed must be acquired for each cropping cycle means that modern varieties can disseminate only with the support of a viable seed industry. This presents a bottleneck, particularly in developing countries because many subsistence-oriented farmers are not able to pay for hybrid seeds and, thus, have been neglected by the seed industry which tends to focus on more lucrative markets. Farmers who do not have reliable access to sufficient quantities of high quality seed have no chance to get out of this vicious circle.

The size of the commercial seed industry varies between regions and is a direct reflection of the financial strength of the region. Latin America presents by far the largest regional seed market, followed by East, South and SE Asia, with East and Southern Africa trailing far behind. In the absence of a commercial seed market government action is needed, as has already been the case with variable success in Nigeria, Malawi and Congo-Kinshasa (Smale and Phiri, 1998).

Zambia and Malawi have taken government action in order to supply modern hybrids to farmers. This has been the case in Zambia and Malawi, which have reached self-sufficiency for 73 and 96% respectively. As maize is considered a primary calorie source for the population, it has been the subject to various subsidy programs and, hence, has become a political crop. Unfortunately, maize remains a rain fed crop and despite this government involvement, the countries have still to import maize in low rainfall years (JAICAF, 2008).

8. Composition

Maize usually contains between 20 and 32% moisture at harvest, but these levels are too high for safe storage without drying. For storage on the cob the moisture content should be reduced to 20% or less, and for shelled maize it should hold less than 13% moisture. The composition of the grain on a dry-weight basis is about: 70-75% starch, 2% sugar, 9-10% protein, 5% fat, 5% pentosan, and 2% ash. The protein content is dominated by zein, and is deficient in tryptophan and lysine. More than 80% is in the embryo or germ. Yellow maize is fairly rich in vitamin A.

Maize, on a dry weight basis, has approximately the same number of calories as wheat or rice. It has less protein than wheat and is deficient in the amino acids tryptophan and lysine, but has a higher fat content. The grain is rich in thiamine, but low in niacin. The low content of niacin and tryptophan can lead to pellagra, a deficiency disease. Maize is unsuitable for bread making as it is deficient in gluten.

Pellagra is a deficiency symptom, due to a lack of niacin and of the above-mentioned two key amino-acids, lysine and tryptophan. Native Americans learned to remediate this malnutrition problem, first by soaking maize in alkali water and thus liberating the niacin, and then by balancing their maize consumption with beans and other protein sources such as amaranth, meat and fish. Pellagra still occurred up to the 1920s, but once alkali processing and dietary variety was understood and applied, pellagra disappeared, except locally in southern Africa.

For human nutrition, the important constituents of the grain are carbohydrate (starch and sugars), protein, fat or oil (in the embryo) and minerals. The protein quantity in a normal maize kernel is relatively low (8 -15%), but these proteins have a relatively high percentage of methionine and cysteine (sulfur-containing amino acids). Maize breeders have now managed to breed maize varieties containing 26.6% protein in the kernel, compared with 10.9% in the original varieties.

Commercial maize carries on average 4-5% oil in the embryo of the grain. Several genetic stocks in Europe and USA are approaching 22% oil. Maize oil is a highly poly-unsaturated oil and is therefore in high demand in the food industry (cooking, salad dressing) and for paints and varnishes. Carotenes are present in large quantities. Vitamins like riboflavin and pyridoxine are present in small quantities in the kernels.

9. Use and Trade

Maize is used for three main purposes: (1) as a staple human food, particularly in the tropics; (2) as feed for livestock, particularly in temperate industrialized countries, providing over 2/3 of the total trade in feed grains, and (3) as raw material for many industrial products. The major objective of traditional maize production is for local consumption.

Maize is prepared and consumed in a multitude of ways. It is usually ground and pounded and the meal may be boiled, baked or fried. The whole grain may be boiled or roasted and it may be fermented. Maize meal is cooked with water to provide a thick mush or dough, which is the commonest method of eating it in Africa. It may be cooked to a thinner consistency to provide gruel, porridge or soup. In North and Latin America tortillas are made by baking thin flat cakes until they are crisp. Tamales are produced by steaming the dough. Cornbread is made by mixing the meal with wheat flour. Immature cobs, preferably sweet corn, are boiled and eaten as corn on the cob, or the grain may be removed and eaten as a vegetable, or it may be canned. More mature cobs are roasted.

Local consumer preferences play a role in the selection of maize varieties as a staple food in Africa (Ristanovic, 2001). In eastern and southern Africa there is a strong preference for flint maize, which is ground into meal. Refined meal is usually produced at home, although partially processed meal may be taken to a village mill for final grinding. In some areas, maize intended for household consumption is taken directly to the village mill to be ground into whole, unrefined meal. Consumer demand for more refined types of meal in both rural and urban areas has been steadily increasing, probably because refined meal cooks faster.

In west and central Africa, preferences refer to different grain textures. In areas where grain is wet milled (i.e. milled after being soaked in water for several days), grain texture is less important and consumers generally prefer flint maize types because they store better. In areas where grain is dry milled, however, consumers prefer dent and floury maize types because they are easier to process by traditional milling methods.

Maize grain is an outstanding feed for livestock, high in energy, low in fiber and easily digestible. In industrialized countries and in homesteads it is used to feed pigs, cattle and poultry. Almost one third of the maize production in the USA is used for ethanol production. Maize has many other industrial uses. Future efforts in maize improvement are therefore mainly focusing on the quality requirements of industrial users such as food manufacturers or brewers. These aspects are discussed at large in *Growth and Production of Maize: Mechanical Cultivation*.

Most maize is used in the countries in which it is grown, and only about 10% enters to world trade of which the United States supplies 60% (Table 6). The total export of the USA has dropped from 63 million tons in 1980 to 48 million tons in 2000 and 57 million tons in 2007. Still, this is nearly four times more than the second large exporter, Argentina (15 million tons), and five times more than Brazil (10.9 million tons). China is both an importer and an exporter.

On the import side, Japan (16 million tons) is by far the largest importer, followed by the Republic of Korea (almost 9 million tons), Mexico (8 tons) and Egypt (4.5 tons).

Table 6. Trade figures in terms of maize imports and exports (in Million tons)
(Source: www.faostat.com)

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Glossary

Amylose: Any of a group of complex carbohydrates, as cellulose or starch, which are converted by hydrolysis into two or more sugars.
Amylopectin: A substance that is nearly insoluble and that is obtained from the outer part of starch granules.
Anemophilous: Dispersed by wind.
Anthesis: The time the flower is expanded, or the process of dehiscence (spontaneous opening when ripe) of the anthers.
Axil: Upper angle between the leaf and stem.
Bract: A reduced leaf subtending a flower or flower stalk.
Caryopsis: Small one-celled dry indehiscent fruit with thin membranous pericarp adhering closely to the seed, as found in grasses.
Cation exchange capacity : An expression of the amount of nutrients that can be held by the soil (mainly the clay and humus fraction) and later be made available for uptake by the roots.
Ear: Female inflorescence.
Glumes: The lower two sterile bracts at the base of grass spikelets.
Heterozygous: Having unlike alleles (= alternative genes located on corresponding loci) at corresponding loci of homologous chromosomes; an organism can be heterozygous for one or several genes.
Inflorescence: The arrangement and mode of development of the flowers on the floral axis.
Meiosis: Nuclear divisions in which the diploid chromosome number is reduced to half that of the parent cell to give the haploid number as in gametes (= sexual protoplasmatic body, egg or sperm, which unites with another for reproduction).
Monoecious: When the male and female flowers are separate, but borne on the same plant.
Pedicel: Stalk of each individual flower of an inflorescence.
Pericarp: The wall of the ripened ovary or fruit wall of which the layers may be fused into one, or be more or less divisable into exocarp, mesocarp and endocarp.
Plumule: The primary bud of an embryo or germinating seed.
Protandry: Situation whereby the stamens shedding pollen before the stigma is receptive.
Radicle: The first root of an embryo or germinating seed.
Silk: Female flowers.

Spike: A simple indeterminate inflorescence with sessile (= without a stalk) flowers along a single axis.
Spikelet: A small spike composed of one or more flowers within a common pair of glumes (= the lower two sterile bracts at the base of grass spikelets), as in grasses.
Tassel : An inflorescence of male flowers.
Testa: The outer coat of a seed developed from the integument.

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