ASSESSING THE IMPACT OF CLIMATE ON CROP WATER USE AND CROP WATER PRODUCTIVITY: THE CROPWAT ANALYSIS OF THREE DISTRICTS IN CAMEROON

Ernest L Molua and Cornelius M Lambi[1]

[1] Department of Economics, University of Buea, PO Box 63, Buea, Cameroon.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

The reports in this special series are the result of a multi-country research activities conducted under the GEF funded project: *Climate Change Impacts on and Adaptation of Agro-ecological Systems in Africa*. The main goal of the project was to develop multipliable analytical methods and procedures to assess quantitatively how climate affects current agricultural systems in Africa, predict how these systems may be affected in the future by climate change under various global warming scenarios, and suggest what role adaptation could play. The project has been implemented in 11 countries: Burkina Faso, Cameroon, Ghana, Niger and Senegal in west Africa; Egypt in north Africa; Ethiopia and Kenya in east Africa and South Africa, Zambia, and Zimbabwe in southern Africa. The study countries covered all key agro-climatic zones and farming systems in Africa. This is the first analysis of climate impacts and adaptation in the Africa continent of such scale and the first in the world to combine cross-country, spatially referenced survey and climatic data for conducting this type of analysis.

The analyses reported in this series focus mainly on quantitative assessment of the economic impacts of climate change on agriculture and the farming communities in Africa, based on both the cross-sectional (Ricardian) method and crop response simulation modeling. The cross sectional analysis also allowed for assessing the possible role of adaptation. Moreover, the project employed river-basin hydrology modeling to generate additional climate attributes for the impact assessment and climate scenario analyses such as surface runoff and streamflow for all districts in the study countries.

The Centre for Environmental Economics and policy in Africa (CEEPA) of the University of Pretoria coordinated all project activities in close collaboration with many agencies in the involved countries, the Agriculture and Rural Development (ARD) Department of the World Bank, the World Bank Institute (WBI), the Food and Agriculture Organization (FAO), Yale University, the University of Colorado, and the International Water Management Institute (IWMI). The project received supplemental funding from TFESSD, Finnish TF, NOAA-OPG, and CEEPA. We are grateful for the invaluable contributions of all these institutions and all individuals involved in this project. All opinions presented in this report series and any errors in it are those of the authors and do not represent the opinion of any of the above listed agencies.

Rashid Hassan, Project Leader
CEEPA, University of Pretoria

Ariel Dinar, Project Manager
ARD, World Bank

EXECUTIVE SUMMARY

Located on the Gulf of Guinea, Cameroon stretches from the second to the thirteenth parallel in the northern latitudes and experiences the quasi totality of intertropical climates. On the whole, temperatures and temperature ranges increase from south to north and from the coast to the hinterland. Rainfall, on the other hand, decreases from the coast towards the north and the interior of the country. Humidity is usually lower in the north than the south because of the different air masses that blow across the country. Cameroon is a microcosm of Africa. Because of its central position on the continent, its great length from north to south, its varied relief, the influence of mountains and proximity to the ocean, it offers a diversity of climate, soils and natural vegetation that make it important for this kind of study.

Since the impact of climate variation on crop yield has recently gained prominence, given the significant trend towards global warming and impending climate change, this study compares the differences between regions and between crops and attempts to assess the way these relate to climate variables – rainfall, temperature, humidity, sunshine and the air masses – on the premise that weather variability and uneven distribution of rainfall strongly influence crop yield. Cameroon's range of intertropical climates offers immense opportunity for agronomic studies that examine climate effects on crops, using weather station and satellite data. Given that crop water requirements and water productivity in rainfed and irrigated agriculture are essential indicators for assessing the effect of climate on crop production, the goal of this study is thus threefold: to evaluate water use efficiency and crop water productivity under prevailing rainfall patterns and traditional farm practices; to assess the impact of rainfall variability and climatic change on yield and production; and to define options for farm improvements and appropriate strategies related to crop choice, planting time, soil cultivation and crop cultivating practices, in order to optimize yields and reduce the risk of crop failure.

Agriculture is the main economic activity in the country, with over 80% of the population involved in it, and agricultural products contribute significantly to household and national incomes. Because physical conditions in Cameroon vary, cropping systems and types of crop cultivated vary throughout the country. Three agro-ecologies were thus sampled for comparative analysis: Ambam in the humid moist forest zone, Bamenda in the high savanna zone and Garoua in the Sahel savanna zone. These study zones offer diverse temperature, rainfall, sunshine and wind speed data that make them suitable for examining the influence of these variables on cropping patterns and crop specific requirements, and are important because they contribute a significant share of 25% to Cameroon's agricultural GDP.

In the course of the modeling process, we describe in detail the agro-meteorology of the study zones, the agronomic requirements of the selected crops studied, the analytical framework and the nature of the data used. Crop simulation methods are then used to ascertain crop water requirements and the influence of climatic variables on plant growth and development. The simulation procedures incorporate micro-crop models that incorporate crop physiologic and phenological development processes accounting for photosynthetic assimilation, partitioning and respiration, and root growth and the water balance processes that simulate the way water from rain or irrigation infiltrates the soil, is taken up by the roots for transpiration and percolates deeper layers. Principally, the study employs the guidelines and methodologies from the FAO Land and Water Development Division on crop water management at the farm level. This hinges essentially on the methodologies for the calculation of crop water requirements and crop water productivity in irrigated and rainfed agriculture. Owing to the difficulty in obtaining accurate field measurements, crop water requirements were derived by estimating crop evapotranspiration according to standardized crop and climatic conditions.

The field observations revealed diverse farming patterns. In terms of rotation, the fallow system can be distinguished from perennial cropping, shifting cultivation and permanent farming. In terms of provision of water, both rainfed and irrigated farms are identified. The degree of commercialization varies: there are subsistence, partly commercialized, semi-commercialized and highly commercialized farms. Total nomadism and semi or partial nomadism are common in savanna zones. Terracing predominates in some parts of the country, especially highland areas. Both monoculture or plantation farming (growing one type of crop at a time on a piece of farmland) and mixed or mélange farming (growing more than one type of crop on a piece of farmland at the same time) are found.

The differing climate regimes across the ecological zones in the country lead to varying consequences in productivity and efficiency. From the crop water simulation, three major crops were identified for analysis: maize, groundnuts and soybean The reference evapotranspiration (ETo) figures for maize differed across the selected farming districts: 413mm, 570.1mm and 890.1mm for Ambam, Bamenda and Garoua, respectively. The average crop coefficient (Kc) for maize was 0.67 and the yield reduction factor (ky) is 1.25. The crop evapotranspiration (ETc) for maize was 276.9mm, 381.9mm and 596.4mm for Ambam, Bamenda and Garoua respectively. The soil water loss was thus highest for Garoua. Reference evapotranspiration (ETo) figures for groundnut were 427.1mm, 588.7mm and 919.8mm for Ambam, Bamenda and Garoua respectively. The reference evapotranspiration (ETo) for soybean was 413.3mm, 570.1mm and 890.1mm for Ambam, Bamenda and Garoua respectively. The average crop coefficient (Kc) for soybean was 0.68, and the yield reduction factor (ky) was 0.85. The crop evapotranspiration (ETc) for soybean was 281.03mm, 387.7mm and 605.3mm in Ambam, Bamenda and Garoua respectively.

The findings of this study have important ramifications for farmers, extension services and future studies. Although farmers may be adapting to the climatic variation, the government needs to help the adaptation process by making available the necessary resources and providing irrigation infrastructure, especially in the drier northern parts of the country, to counter the debilitating effect of low soil moisture, peaking daily temperatures and runaway evapotranspiration. To ease water constraints and enhance productivity, there is need to improve crop patterns and cultivate crops with lower water requirements, and improve irrigation by changing the traditional system to more efficient systems such as drip irrigation and pipe irrigation. Various aspects of water resource management should be considered, such as supply, demand and construction management. Crop water demand must be met as this strongly determines crop emergence, development and survival in the tropical regions.

1. Introduction

The impact of climate variation on crop yield has recently gained prominence, given the significant trend towards global warming and impending climate change. This study compares the differences between regions and between crops and attempts to assess the way these relate to climate variables, on the premise that weather variability and uneven distribution of rainfall strongly influence crop yield.

Cameroon, situated north-east of the Gulf of Guinea, has a wide range of intertropical climates, influenced by mountains and the proximity of the ocean, and thus offers immense opportunity for agronomic studies that examine climate effects on crops, using weather station and satellite data. Climate regimes differ across its ecological zones, so productivity is variable. Given that crop water requirements[2] and water productivity[3] in rainfed and irrigated agriculture are essential indicators for assessing the effect of climate on crop production, the goal of this study is thus threefold. It aims

- to evaluate water use efficiency and crop water productivity under prevailing rain patterns and traditional farm practices;
- to assess the impact of rainfall variability and climatic change on yield and production; and
- to define options for farm improvements and appropriate strategies related to crop choice, planting time, soil cultivation and crop cultural practices (weeding, density and fertility) to optimize yields and reduce the risk of crop failure.

These specific objectives could help define national and provincial policies, plans and strategies to meet food requirements under conditions of drought and limited water supply in Cameroon's rainfed and limited irrigated agriculture. The study provides important advice for farmers for optimizing crop production and income under conditions of reduced water supply and for optimizing the timing and rate of irrigation. The rationale for a study of this magnitude is to enable farm managers to achieve high levels of water use efficiency, irrigation efficiency and crop productivity and thus maximize return on investments in rainfed and irrigated conditions under adequate or deficit water supply.

2. Climate as a factor in crop production

2.1 Temperature

Most plant processes related to growth and yield are highly temperature dependent. Crop species may be classified as either warm or cool season types. The optimum growth

[2] Crop water requirement is the amount of water required to compensate for the evapotranspiration loss from a cropped field (Smith 2002a).

[3] Water productivity is an efficiency term quantified as a ratio of a product output (goods and services) over water input. The output could be biological goods or products such as crop (grain, fodder) or livestock (meat, eggs, fish) and can be expressed in terms of yield, nutritional value or economic return. The output could also be environment services or functions. Water productivity can be quantified at different scales, and for a mixture of goods and services (Smith 2002b).

temperature frequently corresponds to the optimum temperature for photosynthesis. Temperature increases can have both positive and negative effects on crop yields. Higher temperature also affects the rate of plant development (vegetative growth) and hence speeds annual crops through the developmental process. Temperature increases, however, have also been found to reduce the yields and quality of many crops, particularly cereal and feed grains. For example, higher temperatures shorten the life cycle of grain crops, resulting in a shorter grain filling period, so the plants produce smaller and lighter grains, culminating in lower crop yields and perhaps poorer grain quality, i.e. lower protein levels (Wolfe 1995; Adams et al. 1998). This is because temperature increases are associated with higher respiration rates, shorter periods of seed formation and consequently lower biomass production. Figure 1 shows that in eastern England a 3^{o}C rise in mean annual temperature is estimated to reduce the winter-wheat yield by about 10%, although the direct effect of a doubling of ambient atmospheric carbon dioxide might more than compensate for this (Squire & Unsworth 1988). A significant increase in growing season temperatures will therefore require shifts to new varieties that are more heat tolerant, do not mature too quickly, and have a higher temperature optimum for photosynthesis.

For countries in higher latitudes, global warming will extend the length of the growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. In the warmer lower latitude regions, increased temperatures may accelerate the rate at which plants release carbon dioxide in the process of respiration, resulting in less than optimal conditions for net growth. When temperatures exceed the optimum for biological processes, crops often respond negatively with a steep drop in net growth and yield. The accompanying accelerated physiological development may result in hastened maturation and reduced yield. In addition, Rosenzweig et al. (1993) find evidence for important threshold effects. Their findings indicate positive crop yield responses to temperature increases of 2^{o}C but yield reductions are observed at a 4^{o}C increase. They also assert that crop impacts in lower latitudes tend to be more negative than crop impacts in higher latitudes, particularly with respect to wheat and maize yields. Rice yields are less variable than wheat and maize yield impacts. Wolfe (1995) concludes that, for farmers in the temperate regions, climate change and global warming will be beneficial and the resultant longer growing season will provide opportunities to grow a wider range of crops.

2.2 Precipitation

Agronomists and soil scientists are interested in precipitation and rainfall in particular as a source of soil moisture to crops. Water supply is usually the most critical factor determining yield. The effects of water shortages on production may vary according to the particular crop, the soil characteristics, the root system, and the severity and timing of shortages during the growth cycle (Ahn 1993). Reliability of rainfall, particularly at critical phases of plant development, accounts for much of the variation in agriculture's potential. Interannual or interseasonal rainfall variability is a major challenge to rain-dependent agricultural producers. In tropical agriculture, the high dependence on rainfall, coupled with low input use and degraded soils increases farmers' vulnerability to vagaries of weather.

Climate change will also modify evaporation, runoff and soil moisture storage (Feddema & Freire 2001; Nicholson 2001).[4] The occurrence of moisture stress during flowering, pollination and grain filling is harmful to crops, particularly to maize, soybean and wheat. The demand for water for irrigation is projected to rise in a warmer climate, leading to increased competition between agricultural and non-agricultural uses for water, falling water tables, and peak irrigation demands. Increases in precipitation may benefit semi-arid and other water shortage areas (e.g. Sahelian semi-arid regions such as northern Cameroon) by increasing soil moisture, but could aggravate problems in regions with excess water (e.g. in humid tropical regions such as southern Cameroon), while reduction in precipitation could have the opposite effect. Feddema and Freire (2001) further affirm that global warming will affect regional water sources and have a significant impact on river flow regimes. They further observe that reduced water holding capacity may result in increased water runoff during the wet season. Water lost to runoff may increase deficits during rainy seasons, thus causing crops to suffer higher water stress during the dry season. Intensified evaporation may further increase the hazard of salt accumulation in the soil. This may disrupt growing conditions and result in crop failures, with serious implications for food security. Under such conditions, agricultural productivity could be severely limited. Investment in dams, reservoirs, wells and pumps may be needed to develop irrigation networks in new locations.

Figure 2 shows that other factors such as humidity and wind speed combine to influence crop water needs. Crop water needs are higher when it is dry than when it is humid, and crops grown in windy climates use more water than those in calm climates (Brouwer & Heibloem 1986). In most parts of sub-Saharan Africa, agricultural production is currently constrained by reduced soil moisture, e.g. in the West African Sahel and parts of southern Africa. Because water availability limits plant growth, further drying would reduce plant productivity (Schlesinger 1990; Glantz 1996). The mean soil moisture (relative to soil water holding capacity) of the continent in the 1980s was about 9% lower than the average at the beginning of the century. Soil moisture in northern and southern Africa has decreased by about 12% since the 1960s, indicating that climate change may have reduced the availability of soil moisture in Africa (Cao et al. 2001). Soil warming may further cause declines in net primary productivity (NPP) as warming encourages microbial activity and can thus cause declines in the carbon stocks in soils (Oechel et al. 1993; Schimel et al. 1994).

3. Methodology

In contrast to the yield response function that employs regression methods to correlate yield to agro-meteorological variables, crop simulation models are more versatile as they attempt to describe the crop's behavior (physiology and development) as a function of environmental conditions. The simulation procedures employed in the current study incorporate micro-crop models that incorporate crop physiologic and phenological development processes accounting for photosynthetic assimilation, partitioning and respiration, and root growth and the water balance processes that simulate the way water from rain or irrigation infiltrates the soil, is taken up by the roots for transpiration and percolates deeper layers. For this research, in the course of

[4] Plants use water according to the withdrawal of the soil moisture by the roots and evaporation of that water from pores in the leaves. The water lost through the plant tissue is known as transpiration, and the water lost directly from the soil surface is evaporation. The combined total loss of water from the soil and the plant to the atmosphere is known as evapotranspiration. Potential evapotranspiration is the amount of water a plant could be using according to its growth stage.

the modeling processes we describe in detail the principal agro-meteorology of the study zones, the agronomic requirements of the selected crops studied, the analytical framework and the nature of the data used. Crop simulation methods are then used to ascertain crop water requirements and the influence of climatic variables on plant growth and development.

4. Background to the districts selected for analysis

Three of Cameroon's eight agro-ecological zones were selected for comparative analysis: Ambam in the humid moist forest zone, Bamenda in the high savanna zone and Garoua in the Sahel savanna zone. These study zones offer diverse temperature, rainfall, sunshine and wind speed data that make them suitable for examining the influence of these variables on cropping patterns and crop specific requirements, and are important because they contribute a significant share of 25% to Cameroon's agricultural GDP. Table 1 summarizes the ecological characteristics of these three zones. The study examined the farming systems, cropping patterns and output levels of the three zones, and the effect of real-time weather conditions on crop production.

Ambam

Ambam, in the Valle du Ntem Division of South Province, is situated at longitude 11.27^{o}E and latitude 2.34^{o}N in the dense humid forest zones of Cameroon. While Ambam is the nerve centre of the subdivision, beekeeping activities form the principal engagements of inhabitants of the surrounding villages.

Bamenda

Bamenda, in the Mezam Division, is the chief town of Northwest Province and the economic hub of the region and its markets are the major conduit of agricultural products to the rest of the country. The surrounding districts and villages are the breadbasket for Cameroon's growing population, and its inhabitants the leading agricultural producers in the country. The high altitude farming zones around Bamenda have highly productive soils.

Garoua

Garoua is the main town in the Benoue Division of North Province, located between Ngaoundere in the south and Maroua in the north, forming the main network route of administration in that part of the country. As a pacesetter in the region, notably economic and agriculture, it is buttressed by proximity to the main river, the Benue, that serves as catchment to the Mayo Kebi and Logone rivers. It has the necessary blend of sea breeze and mountainous climate suitable for the growing of crops specific to the northern provinces.

4.1 Agro-ecology of the selected districts

Cameroon is a microcosm of Africa. Because of its central position on the continent, its great length from north to south, its varied relief, the influence of mountains and proximity to the ocean, it offers a diversity of climate, soils and natural vegetation. Annual rainfall decreases from the coast northwards. Vegetation is closely related to rainfall, relief and the nature of the soil, which determines drainage. The coastal lowlands, with abundant rainfall that drains away very slowly, are covered with dense forest, unlike the areas with low average rainfall that are well drained and so lack sufficient moisture to support large trees.

Agro-ecology of Ambam

Ambam is in the equatorial forest region of Cameroon. It is close to the Atlantic forest, which has tall trees struggling for sunlight filtering through the thick canopy. The vegetation is dark damp and gloomy, with scanty undergrowth. The combined actions of farmers and their grazing animals, in particular the ruthless clearing to create new lands for cultivation when old ones have been exhausted, have caused part of the forest flora to become extinct. Trees of economic value in this region include obeche, ebony, mahogany, iroko, raffia and wild oil palm. Plantation trees include rubber, cocoa, oil palm and robusta coffee. Subsistence food crops of the region are cassava, cocoyams, plantains, some maize and yams.

Agro-ecology of Bamenda

Often referred to as the grassfield region, Bamenda has diverse agro-ecology: wooded grasslands and the dry central Sudanese forests. Here, vegetation is essentially herbaceous, with a preponderance of the Andropogon genus (*Cymbopogon giganteus*, *Diheteropogon hagarupii*, etc.),which can attain a height of several meters. The mountainous regions near Bamenda have a sub-alpine zone, with high attitude species such as *Andropogon lima*, *Senecio clarenceanus* and *Pentaschistis Manii*. The foothills have vegetation which begins at 800–1200m above sea level, and is often damaged and in some places has even completely disappeared as a result of intensive land reclamation for farming or grazing purposes.

Agro-ecology of Garoua

Garoua is in the tropical grassland zone, characterized by dry or Sudan savanna and the Sahel type, especially during the very dry seasons of the year. In this drier northern zone, the grass is shorter and the trees more scattered, generally small, and twisted from the effects of fire. Outcrops of hard rocks are common. Most valleys are covered with either trees or seasonal shrubs and ferns. As rainfall diminishes towards the north, the grass becomes patchy and semi-desert conditions prevail. During the rainy season the savanna region of Garoua is covered with exuberant herbaceous vegetation, extremely dense and robust. Food crops here are mostly cereals, and the inhabitants of the north keep cattle, goats and sheep.

4.2. Agriculture in the selected districts

Agriculture is the main economic activity in Cameroon. Over 80% of the population is involved in it, and agricultural products contribute significantly to household and national incomes. Because of the variety of physical conditions in Cameroon, cropping systems and crops vary considerably.

Agriculture in Ambam

Agriculture here is typical of the equatorial forest zone, with hoes and cutlasses as principal tools. Patches of woodland are cleared, sown and crops are harvested year by year until decreasing yields show that the land is losing its fertility. The high atmospheric humidity at all seasons, as well as the rich deep alluvial soil located at an altitude of 400–800m high, are ideal conditions for a range of tubers including cocoyams and cassava. Maize and groundnuts are also cultivated in small quantities for household use. The soils are also suitable for plantains. It is difficult, however, to make a distinction between cash and subsistence crops in this district, as farmers typically use their crops for exchange.

Agriculture in Bamenda

Agriculture is the main occupation of about 70% of the people of this district and most of the farming population are women. Farming here is mainly for subsistence purpose and only excesses are marketed in the towns for household income. However, despite its relative importance, agriculture here remains predominantly traditional and primitive, with little or no mechanization. Land is fragmented, there is not much use of fertilizers and high yielding seeds, and the farming population is ageing and illiterate.

Agriculture in Garoua

Garoua has only one annual agricultural season, which begins with the rains and ends at harvest. Millet and maize are the main crops and are cultivated almost everywhere in North Province. Swamp rice is also grown on both sides of the coastal plain of the Logone river. Agriculture is practiced by small-scale farmers, individual households for subsistence and peasants on smallholdings. The deep and well drained light and soft sandy soils of this district contain just enough moisture and so are suitable for growing many different crops, including cash crops. Worth mentioning is the growing of cotton supervised by the Cameroon Cotton Corporation (SODECOTON) as a cash crop for export. Groundnut is also cultivated as a cash crop, although the greater quantity is sold within the country.

5. Agro-meteorology

Located on the Gulf of Guinea, Cameroon stretches from the second to the thirteenth parallel in the northern latitudes and experiences the quasi totality of intertropical climates. However, despite its intertropical location the country does not have a uniform climate. The rainfall, temperature, humidity, sunshine and air masses vary from region to region. The expected zonal arrangement of the intertropical climatic domains from south to north is interrupted by local factors such as proximity to the sea and altitude. Cameroon is hot, like most intertropical countries, with average annual temperatures varying from 20°C to 28°C. The southern part of the country has an equatorial climate. On the whole, temperatures and temperature ranges increase from south to north and from the coast to the hinterland. However, altitude lowers the temperatures of certain areas. Rainfall, on the other hand, decreases from the coast towards the north and the interior of the country, with highland areas receiving more rain than lowland ones. The variation is from 4016mm annually in the south to as low as 400mm in the north. The humidity is usually lower in the north than the south because of the different air masses that blow across the country.

Climate in Ambam

Ambam falls in the equatorial climate domain in the south of Cameroon which covers all the areas extending from 2° to 6° N. The basic trait of this region is the heavy rainfall, ranging from 1500 to 4000mm. The average annual temperature is close to 25°C with small ranges of 1–3°C and constant humidity of more than 80% especially during the rainy season that brings cloudiness and constant humidity of over 85%. Like other areas in Cameroon's humid tropical forest zone, Ambam has a long rainy season of close to nine months and short dry season. The relative humidity is higher than that of Garoua in the north. In July, the monsoon winds invade the south of Cameroon bringing the rainy season. The air masses at this time are deflected in a southwesterly direction and are warm and humid from their movement over the Atlantic. The dry season, around the months of December and January, is dominated by the strong north-east trade wind, the cold and dry harmattan, and the wet season, the months of June and July, by the warm and wet weak monsoon winds.

Climate in Bamenda

Bamenda, in the western highlands, is about 1600m above sea level and 250km from the sea. It has an average annual rainfall of 2500mm. It exhibits the climatic characteristics of the tropical grassland regions. Most of its rain falls between April and October. The mean monthly rainfall varies from month to month, with peaks usually recorded between the months of April and September. Temperature decreases as both latitude and altitude increase, and it is also influenced by the degree of cloudiness. The average annual temperature is about 19.4^oC. Minimum and maximum temperatures for January are 16^oC and 30^oC, April 19^oC and 28^oC, July 21^oC and 33^oC and October 19^oC and 25^oC.

During July and August Bamenda becomes very cloudy and experiences torrential rainfall as a result of the strong southwesterly monsoon winds that blow from southern to northern Cameroon. The same scenario is observed during September and October. During December and January, the degree of cloudiness is considerably reduced, water droplets in the atmosphere are reduced and the region experiences a dry season. This is as a result of the strong dry northeasterly trade winds blowing from the north of the country to the south.

Humidity varies from season to season in this part of the country, being highest during the high rainfall season from July to September. During the dry season, December to January, relative humidity drops, small streams dry up, and the volume of water in big streams and rivers is reduced in some parts. The rate of evaporation drops significantly. The grass is scorched by the blazing sun and the ground becomes almost bare. The countryside is dull and brown, except for some green vegetation in the valleys and along water courses. The amount of sunshine around the Bamenda farming districts also varies from season to season. The highest amount of sunshine is usually recorded during the dry season between December and January. With the coming of the wet season, the amount of sunshine amount decreases considerably as rainfall and cloudiness increase.

Climate in Garoua

Garoua's climate is Sudano-Sahelian, with a four-month rainy season and an eight-month dry season. Further north, the duration of the dry season increases and the rainy season lasts barely three months, with a very high rate of evaporation. During the dry season, from December to March, temperatures are cool at night and very hot during the day. The humidity is 10% in the north at this time, and the harmattan haze reduces visibility to almost zero. Some small streams dry up, many big rivers shrink, and vegetation turns brown. The climate of Garoua is influenced by the harmattan or northeasterly trade wind, which is hot and dry from its long journey over the Sahara. This wind is very stable, and blows across the region from October to June. In January, the St Helence is stronger than the monsoon, so that the intertropical front is pushed southwards to around latitude 5^oN. At this time, the whole of North Cameroon, including Garoua, is invaded by the harmattan, which brings the dry season. The monsoon wind at this time is very weak.

July to August is the main rainy period with rainfall generally low. At the start of the season the rains are torrential and usually accompanied by tornadoes, which are common to the north of the Benoue basin and over the plains of Mayo-Danay, Diamare, and the Mandara mountains. As shown in Figure 3, temperatures over the year are very high, with an overall average of 28^{o}C. The average for April is 40^{o}C, with a maximum of 40–42^{o}C, and January has the lowest average – 26^{o}C. Average annual rainfall ranges from 900 to 1000mm. December, January and February experience no rainfall (0mm) while August is highest with 209mm, as shown in Figure 4. Because the humidity is so low, sunshine is plentiful.

6. Cropping practices

In Cameroon farming systems may be classified according to diverse crop cultivation methods. In terms of rotation, the fallow system can be distinguished from perennial cropping, shifting cultivation and permanent farming. In terms of provision of water, both rainfed and irrigated farms are identified. The degree of commercialization varies: there are subsistence, partly commercialized, semi-commercialized and highly commercialized farms. Total nomadism and semi or partial nomadism are common in savanna zones. Terracing predominates in some parts of the country, especially highland areas. Both monoculture or plantation farming (growing one type of crop at a time on a piece of farmland) and mixed or mélange farming (growing more than one type of crop on a piece of farmland at the same time) are found.

Cropping practices in Ambam

Cropping systems in this part of the country are similar to those of most humid regions. Shifting field cultivation is very popular. Here fields rather than crops are rotated, by preliminary clearing by 'slash and burn' and by short periods of cropping alternating with long fallow periods. Only human labor is used, as there are usually no draught animals. Farmers clear a patch of woodland or forest, till, sow and harvest their crops year by year until decreasing yields show that the land is losing its fertility, and then without difficulties they move into another area and clear new farms. After the piece of land has been chosen, usually in the dry season, it is then cleared using rudimentary tools such as cutlasses and hoes and with the aid of axes sizeable trees are felled. When the vegetation has dried up it is burned to clear and prepare the land for tilling. In some very fertile areas, farmers do not even till the soil. After the grass has been cleared and allowed to decay, food crops are planted directly into the soil. After some months the weeds are removed manually while the crops are allowed to grow.

Typical crops grown here are tubers such as cassava, yams, cocoyams, plantains, banana, maize and groundnuts. Cereals grow quite well here but because of insufficient sunlight and too much humidity do not ripen fast. Permanent cropping is also practiced with tree crops such as oil palms and valuable fruit trees (mango, pear, plum and guava). Yields are yearly for cocoa and coffee immediately the plants start producing. These perennials are intercropped with food crops. In sum, shifting field cultivation is widely practiced alongside mixed cropping. It is against this background that agriculturalist have become increasingly concerned about the risks of soil exhaustion and decline in fertility. Of course with the present low population density, the system still remains the best as it overcomes severe resource constraints.

Cropping practices in Bamenda

This region is conducive to the cultivation of all types of crops because of its mountains, which affect the prevailing climatic conditions. Different climate conditions exist at different altitudes. Lowland areas such as the Mbaw plain, Ndop plain and the Bafut Lowland are favorable for tree crops, especially oil palm and tea. The increasing length of the dry season in this region despite the abundant amount of rainfall favors the cultivation of cereals, especially maize. At very high altitudes, especially around Santa, temperatures are quite low making it suitable for the cultivation of temperate crops such as potatoes, carrots, green beans, tomatoes, cabbage and other vegetables. Other crops include upland rice.

Shifting cultivation is the dominant system in the region, being an adaptation to the climatic conditions. The heavy rainfall experienced here contributes to a high degree of soil nutrient leaching. The soil therefore quickly loses its fertility within a short period of cultivation. The piece of land is then left fallow, in order to maintain soil fertility without necessarily making use of fertilizers.

The planting season which starts from the month of March with the coming of the first rain is usually short. Sowing is done by use of simple agricultural tools. Land clearing and debris burning takes place in February. The harvest period varies from crop to crop, with food crops that mature quickly usually being harvested three months after sowing. Yields vary from one farming season to another, and the output for a particular period or year will be the function of favorable climatic factors such as rainfall, sunshine and temperature. It is therefore possible that agricultural yield denoted A_y is a function of climatic variables among others, i.e. $A_y = f$ (rainfall, sunshine, humidity, wind, soil fertility, topography). A priori, it is expected that when climatic conditions are favorable, the harvest is abundant and so are the yields.

Cropping practices in Garoua

The soils of Garoua, being in the Sudano-Sahelian zone, are less fertile than those of the other two districts, so here tubers do not thrive and give way to cereals. Food crops such as maize, millet, sorghum and groundnut are widely cultivated in a single farming season. The farming system here is shifting cultivation on a relatively small scale with little or no technology, with farmers using mostly hand tools. Manure is not much used. Bush fallowing is common: a piece of land is farmed and then abandoned when yields starts decreasing, so that vegetation can grow on it and yields will be better the next farming season. Most of the food crops are meant for subsistence, though a portion is traded. However, most farmers own separate farms for subsistence and cash crops. Where yields are to be marketed, monoculture is common, especially for groundnuts. There is some combined livestock and crop farming in this region.

Most of the farmers grow cotton, using some form of specialized farming system different from food crops. Land is intensively cultivated around the southeastern part of Garoua where advantage is taken of the Benue river and its tributaries for irrigation. Cotton cultivation in the north depends on the brief rainfall and irrigation. The seeds are generally sown in well-tilled and well-drained clay or sandy and moisture retaining soil at the beginning of the rains in June. They may also be sown on plots where millet and groundnuts have been grown during the previous years. During the dry period, water may be obtained from the Benue river and tributaries through various forms of irrigation, distributed and controlled on the farms in canals. Alternatively, water is drawn directly by hand from wells in buckets and poured into canals dug in the ground and later rises to the surfaces of the beds through capillary action, to be used by the crops. Cotton is planted in June and picked at the end of November or beginning of

December. When the cotton plant matures it bears yellow flowers that develop into bolls which contain cotton. The bolls require a sunny period to ripen, when they burst open and the cotton is exposed, ready for harvest. Cotton is generally picked by hand during the harvest season, during which more labor is employed. Individual peasant planters' yields are usually small, yet they all add up to a reasonable amount for export, somewhere between 10,000 to 20,000 tons per year. The same irrigated system of farming is applied to cotton farming along the Logone plain and valleys. The yields are not large, as just a few farmers are involved and they use a relatively low level of technology. Further north toward the Mandara mountains, farming is principally on terraces.

7. Soil types

Cameroon has tropical soils consisting of a series of horizontal layers called horizons, which collectively make up the soil profile.[5] This profile shows a vertical section with a succession of horizons and the underlying parent materials. The well developed, undisturbed soils have distinctive soil horizons distinguished from one another by sharp boundaries. Three basic horizons may be distinguished. The uppermost layer, often referred to as surface soil, harbors the greatest biological activity and has the most plentiful organic matter. Since falling rain reaches here first, soluble materials and tiny particles such as clay are leached by percolating water. Immediately below the surface soils is the subsoil, containing deposited materials from the surface soil, thus referred to as the zone of accumulation. Both the surface and subsoil constitute the true soil or solum. Here, soil forming processes are active, and living roots and other plant and animal life are largely confined to these two layers.

The varying soil types in Cameroon are the result of their varying formation processes. Such factors as parent materials, climate, plants and animals, and topography are major determinants to be considered. The nature of the soil is ultimately linked to the original composition of the parent materials, which determines the rate of weathering and thus the rate of soil formation. The mineral composition of the parent rock affects the fertility and texture of the soil.

Climate also affects soils, and the variety of climatic regions in Cameroon is therefore also responsible for the variety of soils. Climate determines the rate at which weathering, leaching and decomposition of organic matter takes place, as well as whether chemical or mechanical weathering will predominate. Types of vegetation cover and animal life are a function of the climatic condition that affects soil types. Plants and animals essentially provide organic matter to the soil. Soils in some parts of the country are composed almost entirely of organic matter, while others such as those in northern Cameroon may contain only a small portion.

Cameroon has a variety of rock types, according to the relief of the regions, thus the geology as well as the climate influences the soils. Much of the western highland, Adamawa and Mandara, is composed of volcanic rocks on cliff edges. The southern plateau has metamorphic rocks, while those in the lowland areas are generally sedimentary. Soils in Cameroon can be classified

[5] Soil (the loose materials which forms the upper layer of earth's mantle) is a combination of minerals and organic matter, air and water. It is that portion of the earth's surface that supports the growing of plants. About half of the total volume of good quality surface soil is a mixture of disintegrated and decomposed rock (minerals matter) and the remains of animals and plant life (organic matter). The remaining half consists of pore spaces, where air and water percolates (Neba 1987).

into two groups: zonal soils, which are soils of the equatorial forest and the tropical regions, and azonal soils, which are alluvial and volcanic soils.

Dominant soil types in Ambam

Soils found around Ambam are azonal. These soils are too young to show features. They have not been sufficiently subjected to soil formation processes to have developed mature characteristics. Being immature soils they do not have distinct horizons. They have evolved very little, being formed of materials that have been deposited by wind. Ambam's soils are black or brown vertisols. They formed over flat areas (topomorphic vertisols) or over basic rocks (lithomorphic vertisols). The soil mix here also reveals ferralitic soils. These soil combinations are extremely fertile and tubers (cassava, cocoyam, yams and sweet potatoes) thrive in them.

Dominant soil types in Bamenda

The distribution and characteristics of the principal soil types in Bamenda are linked to the region's geographical features and geological constitution. The soil spectrum in the Bamenda farming district consists principally of ferrasols that cut across a broad variety of soil types such as lateritic, tropical ferruginous, pockets of volcanic soils rich in organic matter, the ferrallitic soil, alluvial soils and hydromorphic soils. The process by which these soils were formed involved individualization of iron sesquioxides and aluminium hydroxides. Volcanic alluvial soils have been formed over material that has been deposited recently by volcanoes or by the wind. They are generally black, and rich in organic matter, with deep soil horizons with little leaching. Other soils here have developed over recent basalts. They are very fertile but subject to erosion. The lateritic soils in the region can be divided into (i) orthitic soils (red, porous, soft and permeable), (ii) alliatic soil (with a very fine granular structure nearly always with an indurated horizon), and (iii) humus-bearing lateritic soils found at high elevations (formed by the accumulation of organic matter).

Dominant soil types in Garoua

The soils found around Garoua are often classified as zonal soils. These are mature soils that show features related to the region's climate. In Garoua potential evapotranspiration is greater than rainfall for a considerable time of the year. In other words, there is a net annual rainfall deficit. Consequently, the period of rock decomposition is reduced and the soil is not as thick and deep it is elsewhere in Cameroon. Northern Cameroon has a variety of soils. In the transitional zone occupied by the Guinea savanna we find that they are essentially clayed, resulting from the decomposition of crystalline rocks such as granite and gneiss. Generally they are deep, often about ten meters. However, the silica content of these soils is usually washed out (leached) by percolating water. These soils usually do not support farming for long because they quickly get exhausted and therefore need very careful farming methods with a lot of manure application. The quick exhaustion of this soil is the result of hot and humid conditions facilitating quick decomposition of humus. This is what makes farming practices difficult, rather than the poor nature of the soil. This is generally solved by shifting field cultivation, where farmers move from an area that has been exhausted to another uncultivated area.

Hydromorphic soils are also found in Garoua around the Benue valley. These are generally unsuitable for agriculture, but can sometimes be used as paddy fields for rice. They are the result of the action of groundwater on the source rock.

Northern Cameroon with its dry conditions has mostly brown sandy clay ferruginous soil. During the rainy season soluble compounds are leached by percolating water, especially silica, which is quickly leached in the presence of abundant moisture and high temperatures. However, during the dry season this same water is brought to the surface again by capillary action before being evaporated in the atmosphere by hot dry air. As evaporation takes place, the already dissolved components are again deposited near the surface, but this time in a precipitated form. These precipitated compounds continue to accumulate so that with time, small and strong concentrations of iron and aluminium oxide are formed. Sometimes they appear quite near the surface of the ground and sometimes at a greater depth. Under certain conditions, an enormous quantity hardens to form a very hard rocky substance which is referred to as 'hardpan' or *cuirasse*. This rock-like substance is very high in iron, bauxite and manganese.

In sum, laterite soils are typical of Garoua's Sudanian climate. They are brown or brownish red in color. Their organic matter content is comparatively low and cannot therefore support thick vegetation or forest. Areas with such soils are important for cereal cultivation, especially millet and groundnuts. Besides these soils, alluvial soils (fluvisols) are found in some isolated zones, especially at the bottom of the Benoue and Logone valleys.

8. Crop selection and agronomic development

Maize

Maize is one of the most important cereals for both human and animal consumption and is cultivated throughout Cameroon. It is grown in climates ranging from temperate to tropical, during a frost-free period when mean daily temperatures are above 10–12^{o}C. For optimal growth, an average temperature of 22–25^{o}C is suitable. Maize makes efficient use of water in terms of total dry matter production, and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800mm of water depending on climate.

Different varieties of maize are adapted to a range of climates and growing seasons. In recent years, new varieties have been developed which have further enlarged the geographic area of the crop. These include varieties that require less sunshine than usual, which are grown in areas formerly considered unsuitable. Growing seasons are mainly within the range 90–200 days. There is a general increase in growing season of about 20 days for each 100m increase in altitude above 1500 m, or for each 0.5^{o}C drop in mean temperature below 20^{o}C. Most maize is grown in areas with temperatures of 21–30^{o}C at the tasseling period. The optimum temperature at germination is considered to be 18–21^{o}C. Maize has a C-4 photosynthetic pathway; photosynthetic rates peak at 30–40^{o}C, and rates of leaf emergence at about 30^{o}C. However, production can be expected to be greatest when nights are cool and there is marked diurnal range of temperature.

Rainfall requirements vary with the variety, and range from 200 to 900mm in the growing season. Maize is an important component of cropping systems in the tropics where rainfall is in the range 750–1750mm per year. In drier regions such as northern Cameroon the growing season may be too short and the incidence of dry spells within the season too frequent, so here maize is increasingly being replaced by sorghum and millet. The maize seed is large, and relatively large amounts water are required at imbition (the process of seeds absorbing water).

Maximum moisture demand is from the tasseling to the hard dough stages, after which water needs decline. Maize is relatively sensitive to periods of low rainfall and water stress. It is empirically recognized that maize is particularly sensitive to water deficit at flowering. Water stress reduces leaf area, and lowers the leaf photosynthetic rate during the stress period, though this may recover afterwards. It delays silking and reduces grain numbers.[6]

Maize grows well on a wide variety of soils, but best on intermediate textures (sandy loams to clay loams) with a good structure and aeration. Poor soil structure, inadequate aeration, and soil compaction restrict root development and lower yields. Maize is a heavy nutrient feeder with a high nitrogen requirement, demanding phosphorus and sensitive to a low phosphate supply, particularly at the early stages of growth (Ahn 1993).

Table 2 shows the visible changes during the phenophases (shooting, flowering, graining, ripening, etc.) of the selected crops. The intervals between the phases are not equally sensitive to water and temperature. These differences in sensitivity motivate an examination of the relationship between the length of these phases and the meteorological variables and perhaps the developing rate, given the influence of these variables. In Cameroon, the sowing date of maize may be from mid-March to mid-April, because adequate soil moisture is required for emergence. Maize growing to harvesting averages 135 days. The initial period (Stage I) of shooting and root establishment following sowing is 25 days. During this period the roots penetrate to a depth of about 0.3m. Stage II, the consolidation and vegetative development of the plant, requires 40 days. The mid-development flowering period (Stage III) requires another 40 days. The time between flowering and silk production is very short, roughly 3–10 days. The late stage (Stage IV) for maturing and ripening is about 25 days, when the plant achieves a root depth of about 1m.

In Table 2, the crop coefficient (Kc) indicates the relationship between the maize crop transpiration and soil evaporation, taking into account the crop characteristics and the specific stage of development. The values of 0.3, 1.2 and 0.5 for stages I, III and IV respectively indicate increasing water requirements for the crops, with a peak demand at stage III. This correlates with the yield response factor (Ky)[7] which indicates values of 0.4, 0.4, 1.3, and 0.5 for Stages 1–IV respectively, showing that water stress peaks at Stage III during flowering and silking.

Groundnut

Groundnuts can be grown at a wide range of latitudes. During the growing season, usually three and a half to five months, rainfall of at least 500mm is needed. Adequate moisture is particularly important between flower initiation and flowering, but dry conditions are needed for ripening and harvesting. Under heavy continuous rainfall, vegetative growth increases, resulting in low yields and longer growing periods. Groundnuts are best suited to light textured soils, particularly loose, friable sandy loams that are well supplied with calcium and not low in organic matter. The soils must be well aerated and well drained, and should not harden when dry or form crusts, as this hinders the penetration into the ground of the pegs on which the nuts

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[6] Maize yields in the tropics are generally lower than those in temperate regions. This appears to be related in part to above-optimum temperatures and to sensitivity to stress when water is limited.

[7] Ky is a factor the describes the reduction of relative yield according to the reduction in crop evapotranspiration caused by soil water shortage. Ky values are crop specific and vary over the growing season according to growth stage.

form. Harvesting is easiest in loose friable soils but becomes more difficult in heavy soils that adhere to the nuts and form hard clods when dry.

Table 2 shows that the intervals between the development phases of groundnut are not equally sensitive to the water and temperature. Groundnut growth to harvest development averages 140 days. The initial period (Stage I) for shooting and root establishment following sowing is 25 days. During this period, the roots penetrate to a depth of about 0.2m. Stage II, the consolidation and vegetative phase, requires 35 days. The mid-development flowering period (Stage III) requires 45 days. The late stage (Stage IV) for maturing and ripening is about 35 days, when the plant achieves a root depth of about 0.5m. The crop coefficient (Kc) indicates values of 0.40, 1.15 and 0.6 for stages I, III and IV respectively, indicate increasing water requirements for the crop, with a peak demand at stage III. This correlates with the yield response factor (Ky) which indicates values of 0.4, 0.6, 0.8, and 0.4 for Stages 1–IV respectively, showing that water stress peaks at the mid-development stage.

In general, groundnut production has not fared well in Cameroon. Figure 6 shows the levels of national production of maize and groundnut. The yield of maize picked up in the mid-1970s following token measures put in place at the advent of government's green revolution campaign. However in the early 1990s when Cameroon's economic crises were biting hard the agriculture and farming sector were not spared. Increases in the price of basic farming inputs, and a slump in market demand following the economy-wide reforms that led to job losses, reduced public and private sector salaries and the devaluation of the CFA franc, impeded the response of the agricultural sector. In general, however, maize production has fared better than groundnut. These crops are both staples in Cameroonian diets.

Soybean (Based largely on extracts from Herbek & Bitzer 1988)

'The soybean is a versatile crop that can be used for many purposes. Today it is grown almost exclusively as a cash crop for its oil-bearing seed or bean which is then processed and refined into many oil and meal products. However, soybeans can also be grown for hay, silage, residue utilization, green manure crop and specialty markets.' Soybean is a crop in which 'no one set of planting practices is best suited for all situations. Each location, year and set of growing conditions will alter planting recommendations. Planting date, planting depth, inoculation, seeding rate and row width must all be adjusted for specific conditions and taken into consideration for other production practices. Planting on time is necessary to obtain enough plant growth and development for good yields. If planting is delayed beyond the optimum date, yields are reduced. Likewise, planting too early can reduce yields.'

'Like other crops, soybeans are more likely to reach their yield potential on soils with no rooting restrictions, high fertility and adequate moisture. Thus, in general, first class soybean soils are deep or moderately deep, well to moderately well-drained, medium-textured, fertile soils that occur on level or gently sloping land where flooding, run-off and erosion are minimal. Although soils having these characteristics have the greatest potential for maximum yields, profitable yields can be obtained on soils with less than optimum conditions. However, as the characteristics of soils selected for soybean production become less desirable, decreases in yield should be expected.'

'Many tillage systems, involving different tillage and planting equipment, can be used to prepare soil for planting soybeans. Methods ranging from complete tillage (conventional) to reduced tillage and no-tillage can be successfully used, but different methods are best for different situations.' 'Planting depth can greatly influence soybeans' ability to emerge and establish a uniform stand. Ideal planting depth depends on soil texture and moisture.' Farmers 'plant the seed deep enough to be in moist soil but no deeper than necessary. Planting soybeans too deep is a frequent cause of poor stands. The ideal planting depth for best emergence is 1 to 1.5 inches under most conditions.' Farmers 'avoid planting deeper than 2 inches if possible because at deeper levels emergence is delayed, seedling vigor is reduced, and it is harder for a soybean seedling to break through a crust that may have formed. Varieties also differ in their ability to emerge from greater depths. As a result, although all soybeans emerge slowly when planted deep, the ability to emerge successfully differs among varieties. Soil type will also influence soybeans' ability to emerge from deep plantings. Heavy rains can cause hard crusts to form on fine-textured heavy soils. When this happens, it is harder for deep planted soybeans to break the crust. In such cases, the seedlings may completely deplete the food stored in their cotyledons before they emerge and eventually die. The most severe damage resulting from a soil crust is the breaking of the hypocotyl arch during emergence, resulting in a reduced stand. When crusts develop, rotary hoeing may help emergence.'

'The soybean plant is a legume and capable of supplying nitrogen for its growth through the symbiotic nitrogen fixation process with certain bacteria (*rhizobia*) in the soil. These bacteria form nodules on soybean roots and extract nitrogen from the air for the plant to use. If soybean plants are well-nodulated with effective nitrogen-fixing bacteria, this condition will supply the soybean's nitrogen requirement and no additional nitrogen as a fertilizer will be needed. Thus, it is very important that the soybean plant have effective nodulation for good nitrogen fixation. The safest way to ensure good nodulation is to inoculate the soybean seed with the proper bacteria. Only *Brady rhizobium japonicum* has been shown to effectively nodulate and fix nitrogen with soybeans.'

As shown in Table 2, the intervals between the development phases are not equally sensitive to water and temperature. Soybean overall development averages 135 days. The initial period (Stage I) of shooting and root establishment following sowing is 20 days. Stage II, the consolidation and vegetative development of the plant, requires 30 days. The mid-development period (Stage III) that embodies flowering requires another 60 days. The late stage (Stage IV) for maturing and ripening is about 25 days, when the plant achieves a root depth of about 0.4m. The crop coefficient (Kc) indicates values of 0.4, 1.15 and 0.5 for stages I, III and IV respectively, indicating increasing water requirements for the crop, with a peak demand at Stage III. This correlates with the yield response factor (Ky) which indicates values of 0.4, 0.8, 1.0, and 0.4 for Stages 1–IV respectively, showing that water stress peaks at vegetative growth.

9. Analytical framework for crop water use and productivity

In recent years the need for assessing land capability and planning production has grown to occupy priority position in agricultural policy making. Decision making in agriculture at every level must begin with the estimation of production circumstances. This includes the assessment of predictable hazards (droughts, floods etc.) in order to be able to prepare for them. This study uses the FAO Land and Water Development Division's guidelines and methodologies on crop water management at the farm level. This hinges principally on the methodologies for the calculation of crop water requirements and crop water productivity in irrigated and rainfed agriculture (see FAO 1975, 1992, 1993, 1998).

9.1 Estimating crop evapotranspiration: The dual step-single crop coefficient

'Owing to the difficulty in obtaining accurate field measurements, the estimation of crop water requirements were derived from estimating crop evapotranspiration[8] according to standardized crop and climatic conditions. A range of empirical methods have been developed to estimate potential crop evapotranspiration (ETc) from readily available climatic parameters. The water requirements of a given crop are then derived through a crop coefficient that integrated the combined effects of crop transpiration and soil evaporation into a single crop coefficient, based on the following relationship:

$$ET_{crop} = K_c x ET_0 \qquad (1)$$

where;

ETo is reference crop evapotranspiration,[9]

Kc is crop coefficient,

ETcrop is the crop evapotranspiration, computed from optimal conditions (ETc). ETc is defined as the evapotranspiration from a disease-free, well fertilized crop, grown in large fields, under optimum soil water conditions, and achieving full production under the given ecological environment' (Kassam & Smith 2001).

ETcrop is thus estimated through Kc and ETo over the growing season. 'Crop transpiration is determined by the typical crop physiological and morphological characteristics and increases over the growing season with the growth of the canopy surface. Soil evaporation decreases proportionally over the growing season as the ground surface is increasingly shaded by the crop canopy. The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient (Kc) incorporating crop characteristics and average effects of evaporation from the soil' (Kassam & Smith 2001). The calculation procedure for ETc consists of:

'1. identifying the crop growth stages, determining their lengths, and selecting the corresponding Kc coefficients;

2. adjusting the selected Kc coefficients for frequency of wetting or climatic conditions during the stage;

3. constructing the crop coefficient curve (allowing one to determine Kc values for any period during the growing period); and

4. calculating ETc as the product of ETo and Kc' (Kassam & Smith 2001).

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[8] 'Evapotranspiration (ET) essentially comprises the simultaneous movement of water from the soil and vegetation surfaces into atmosphere through evaporation (E) and transpiration (T)' (Kassam & Smith 2001).

[9] 'Reference crop evapotranspiration (ETo) is the evapotranspiration from a reference crop with the specific characteristics of grass, fully covering the soil and not short of water, and represents the evaporative demand of the atmosphere at a specific location and the time of the year independent of crop type, crop development and management practices, and soil factors. The only factors affecting ETo are climatic parameters, consequently ETo is a climatic parameter and can be computed from weather data' (Smith 2002b; Kassam & Smith 2001).

Advances in crop water management research and more accurate procedures in determining crop water use motivated Jensen et al. (1990) to compare a range of 20 different ETo. Estimation methods demonstrated clearly the superior performance of the procedures introduced by Monteith (1965) in the Penman equation.[10] 'The FAO expert consultation in 1990 reached unanimous agreement in recommending the Penman-Monteith approach as the best performing method to estimate evapotranspiration of a reference crop ETo and adopted the estimates for bulk surface and aerodynamic resistance as elaborated by Allen et al. (FAO 1998) as standard values for the reference crop' (see Smith et al. 1991). 'Many studies on various crops have shown, however, that the crop resistance factor, which represents the stomatal behavior of the crop,[11] is affected by climatic conditions. Solar radiation, air temperature, vapor pressure deficit, day length and wind have all been found to affect the crop resistance in different degrees and directions' (Smith 2002a). 'The adoption of the Penman-Monteith method would in theory allow the possibility of calculating ETc directly from climatic data and by integrating the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. However, as there is still considerable lack of information for different crops, the dual step procedure is maintained using the crop coefficient Kc to derive crop evapotranspiration from the evapotranspiration of a reference crop.'[12] 'Difference in leaf anatomy, stomata characteristics, aerodynamic properties and even albedo causes the crop transpiration to differ from the reference crop evapotranspiration under the same climatic conditions' (Kassam & Smith 2001).

9.2 Crop yield response to water

'The uptake of soil water by crop to meet evaporative demand results in reduced water content in the soil and crop. When full crop water requirements is not met, water deficit in the plant can

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[10] 'By introducing the aerodynamic and canopy resistance in the Penman-Monteith combination method, a better simulation of wind and turbulence effects and of the stomatal behavior of the crop canopy is achieved (Monteith 1965). The earlier difficulties in the use of the method related to the estimation of the canopy resistance values was largely overcome by progress in research and reliable estimates of the two parameters for a range of crops including the reference crops, grass and alfalfa' (Kassam & Smith 2001).

[11] 'Most agricultural plants have a stomate aperture mechanism. A plant may have open stomates during a condition of ample water, and the stomates (or holes in leaves) allow carbon dioxide in and water and oxygen out (gas exchange through that pore). Most agricultural plants, if they come under stress, have a pore system that becomes very restricted if not completely closed. This serves as a water control mechanism. Not all plants on the earth have this capacity to close their stomates under stress. About one-third of the natural growing plants do not demonstrate this capacity under imposed stress. The plant would just wilt if it could not have all the water available to it that it needed rather than be able to close the stomates and remain unwilted. Agricultural plants do have a stomate-closing mechanism, so that water stress results in closed stomates and in restriction in the uptake of carbon dioxide, which results in diminished growth or dry matter increase for the plant. Therefore, we can evaluate the potential yield by knowing how much stress that plant has been under. That is, what percentage of the time were the stomates closed? And from that we can know the reduction in yield, or at least have some idea concerning it' (Weather Risk Management Association www.wrma.org/wrma/library/file775.pdf Accessed 14 August 2006).

[12] 'The Penman-Monteith method is used for the estimation of the evapotranspiration of a hypothetical reference crop with fixed crop parameters, i.e. ETo. Experimentally determined ratios of ETc/ETo, called crop coefficients (Kc) are used to relate ETc to ETo.' 'Due to variations in the crop characteristics throughout its growing season, Kc for a given crop changes from sowing till harvest. A review of crop coefficients given in FAO (1975) resulted in an update of Kc values to be applied to the FAO Penman-Monteith method and procedures to arrive at better estimates under various climatic conditions and crop height and expanding the range of crops and crop types' (FAO 1998).

develop to a point when stomatal closure would occur to reduce further water loss and water stress, if soil and plant water content is not restored by either rain water or irrigation. The closure of the stomata results in a parallel reduction in the uptake of CO_2, photosynthesis and biomass production. Plant water deficits can therefore develop into reduced crop growth, and crop development and yields may be affected depending on the extent of the water deficit and the impact on vital phenological and growth processes (Kassam & Smith 2001).'[13]

The FAO (1979) revealed the plausibility of 'linear crop-water production functions to predict the reduction of crop yield when crop stress is caused by a shortage of soil water according to the following relationship:

$$(1-\frac{Y_a}{Y_m}) = K_y(1-\frac{ET_{c-adj}}{ET_c}) \qquad (2)$$

Where;

Ky is the yield response factor,[14]

ETc-adj is adjusted evapotranspiration (actual evapotranspiration, ETa),

ETc is crop evapotranspiration for standard conditions (no water stress) (maximum evapotranspiration, ETm),

Ya is actual crop yield,

Ym is maximum expected or agronomically attainable crop yield under no biotic or abiotic stress.'[15]

9.3 CROPWAT computer estimation

CROPWAT 4 Windows version 4.3 is a program that uses the FAO Penman-Monteith method for calculating reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations. The program uses the same Penman-Monteith methodology as used in CROPWAT versions 5.7 and 7.0 and uses the same data such as the CLIMWAT climate and rainfall data files.

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[13] 'The manner in which crop water deficit affects growth, development and yield varies with crop and crop type, and crop growth stage' (Kassam & Smith 2001).

[14] Ky is a factor that describes the reduction of relative yield according to the reduction in Etc caused by soil water shortage. Ky values are crop specific and vary over the growing season according to growth stage.

[15] 'For a given crop Ym is derived from net crop biomass, taking into account the effect of radiation and temperature on crop photosynthesis, and of temperature on crop respiration. A knowledge of length of growth cycle and leaf area index at maximum cover is required' (Kassam & Smith 2001). To compute Ym, we could use either the method based on Kassam (1977) which is applicable to many crops.

CROPWAT calculates crop water requirements and irrigation water requirements[16] from climatic and crop data. The program algorithm allows for the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping patterns (see Fig. 7 below). The program is essentially meant as a practical tool to help carry out standard calculations for design and management of irrigation schemes, and for improving irrigation practices and the planning of irrigation schedules under varying water supply conditions. The CROPWAT model is very sensitive to climatic and crop growth data. To run CROPWAT model we need to calibrate and validate the obtained results with local lysimeter measurements. Due to lack of these data it was not possible to do calibration and validation for the study area. Reference manual that contains generally calibrated values for the model for different crops in Cameroon was used to validate the results. Despite these limitations, given the robustness of the model, it is confidently relied upon for the estimation and analysis of crop water requirements in selected districts in Cameroon. Water balance procedures also allow an assessment of effective rainfall (part of the rainfall that contributes to crop water requirements) and an evaluation of rainfed production through calculated yield decreases through water balance procedures.

9.4 Required CROPWAT data

Climatic and crop data for the CROPWAT model was obtained from multiple sources for the essential factors of mean maximum and mean minimum temperature (^oC); relative humidity (%/month), wind speed (km/day) and daily sunshine (hrs). Other data such as latitude, longitude, and altitude were incorporated into the model (CROPWAT needed data are in the Appendix, Tables A1–3). Crop data variables such as cropping pattern, planted area and crop calendar were obtained from household field survey and from the Provincial Offices of the Ministry of Agriculture.

Figure 7 shows the flowchart of the CROPWAT model. It highlights the groups of data required: crop, meteorology and soil data. The meteorology data include: (1) maximum and minimum temperature; (2) wind speed; (3) sunshine hours; (4) relativity humidity; and (5) rainfall. The Penman-Monteith explicit equation is used to calculate the potential evapotranspiration (ETo). Effective rainfall was calculated using the following equation:

$$PE = P_{tot} * \frac{125 - 0.2P_{tot}}{125} \text{ (for } P_{tot} < 250\text{mm)} \quad (3a)$$

and

$$PE = 125 + 0.1 * P_{tot} \text{ (for } P_{tot} > 250\text{mm)} \quad (3b)$$

Where: PE is effective rainfall (mm) and P_{tot} is total rainfall (mm). After the basic input data was entered into the model, the CROPWAT model calculates crop data in each district, such as

[16] 'The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation also includes additional water for leaching of salts and to compensate for non-uniformity of water application.'

(1) crop coefficient, (2) crop leaf index, (3) crop evapotranspiration, (4) percolation, (5) effective rainfall, and (6) crop water requirements. The model is extended to simulate the on-farm crop water balance, including: (1) irrigation times, date and depth, (2) soil moisture depletion, (3) amount of percolation, (4) actual crop evapotranspiration, and (5) crop yield.[17] The on-farm water balance is based on the theory of Equation 2, and estimated as:

$$SMD_t = SMD_{t-1} + ET_c - PE - IR + RO + DP \quad (4)$$

Where; SMD_t, SMD_{t-1} is soil moisture (mm) depletion at t and t-1 periods; ETc is actual crop evapotranspiration (mm); PE is effective rainfall (mm); IR is irrigation depth (mm); RO is runoff (mm); and DP is deep percolation (mm). The crop yield reduction in each stage is evaluated based on the degree of soil moisture depletion to supply the crop evapotranspiration requirements (Equation 3, Ky factor).

After finishing the simulation of irrigation schedule for each crop, the CROPWAT model would furthermore estimate the monthly agricultural water requirements of irrigation scheme (see Harnos 1994), based on different cropping patterns.

$$Q_{gross} = \frac{1}{e_p * t} \text{x} \left[0.116 \text{x} A_{scheme} \text{x} \sum_{i=1}^{n} \left(ET_{crop} - P_{eff} \right) \text{x} \frac{A_{crop}}{A_{scheme}} \right] \quad (5)$$

Where Q_{gross} is monthly agricultural water requirement of irrigation scheme (l/s); e_p is irrigation efficiency (≤1, dimensionless); t is time operational factor (≤1, dimensionless); *i* is crop index within cropping pattern; A_{crop} is crop planted area (ha); A_{scheme} is total area of irrigation scheme (ha); ET_{crop} is crop evapotranspiration (mm/day); and P_{eff}: effective rainfall (mm/day).

10. Empirical findings on crop water use and water productivity

Crop water use for maize

We examined the crop water use for maize and attendant irrigation needs, and the findings are presented in Table 3. The climate data were entered into the CROPWAT model, and the reference evapotranspiration (ETo) figures obtained differ across the selected farming districts, being 413mm, 570.1mm and 890.1mm in Ambam, Bamenda and Garoua respectively. The average crop coefficient (Kc) for maize is 0.67 and the yield reduction factor (ky) is 1.25. The evapotranspiration of the maize crop (ETc) is 276.9mm for Ambam, 381.9mm for Bamenda and 596.4mm for Garoua. The soil water loss is thus highest for Garoua.

[17] More importantly, the model can potentially estimate the irrigation schedule for each crop with five different options: (1) each irrigation defined by irrigation manager, (2) irrigation at below or above critical soil depletion, (3) irrigation at fixed interval per stage, (4) deficit irrigation, and (5) no irrigation.

The estimated maximum yield for maize for small farms in Cameroon is 2000kg. However, the average actual yields in the study zones are 600kg, 500kg and 700kg for Ambam, Bamenda and Garoua respectively. The combination of this information into Equation 2 to obtain the moisture stress factor (Ks) allows for the generation of the actual crop evapotranspiration of 38.76mm, 57.29mm and 77.53mm for Ambam, Bamenda and Garoua respectively.

Other interesting information obtained is the crop water requirements (CWR), the field water supply (FWS) and irrigation water requirements (IWR). The CWR, FWS and IWR for Garoua are particularly high, indicating an increased demand for soil moisture and a need for irrigation scheduling for optimum water supply.

Crop water use for groundnut

Table 4 presents the reference evapotranspiration (ETo) figures obtained for groundnut, across the selected districts: 427.1mm, 588.7mm and 919.8mm for Ambam, Bamenda and Garoua respectively. The average crop coefficient (Kc) for groundnut for the different growth stages is 0.72 and the yield reduction factor (ky) is 0.7. The evapotranspiration for groundnut (ETc) is 307.7mm for Ambam, 429.9mm for Bamenda and 662.3mm for Garoua. The uptake of soil water by groundnut to meet evaporative demand is highest in Garoua. This implies that there is a high potential for crop water deficits in Garoua, which could cause reduced crop growth, thus affecting crop development and yields. The estimated maximum yield for groundnut for small farms in Cameroon is 4000kg. However, the average actual yields in the study zones are 1300kg, 1500kg and 900kg for Ambam, Bamenda and Garoua respectively. Given these yield figures, the actual crop evapotranspiration is 89.2mm, 77.4mm and 218.6mm for Ambam, Bamenda and Garoua respectively. The CWR, FWS and IWR are highest in Garoua, confirming the particularly high demand for soil moisture and need for irrigation scheduling for optimum water supply.

Crop water use for soybean

The reference evapotranspiration (ETo) for soybean is 413.3mm, 570.1mm and 890.1mm for Ambam, Bamenda and Garoua respectively. Table 5 shows that the average crop coefficient (Kc) for soybean is 0.68, and the yield reduction factor (ky) is 0.85. The evapotranspiration of the soybean crop (ETc) is 281.03mm in Ambam, 387.7mm in Bamenda and 605.3mm in Garoua. The estimated maximum yield for maize for small farms in Cameroon is 2500kg in Ambam, 2000kg in Bamenda and 1500kg in Garoua. However, the average actual yields in the farming zones are 1200kg, 1500kg and 800kg for Ambam, Bamenda and Garoua respectively. The computation of this information given the moisture stress factor (Ks) reveals that the actual crop evapotranspiration is 25.3mm, 15.5mm and 48.4mm for Ambam, Bamenda and Garoua respectively. The average field water supply (FWS) for soybean is 0.01 litres per second per ha during the growing season in Ambam, 0.02 l/s/ha in Bamenda and 0.43 l/s/ha in Garoua.

11. Impact of climate change on crop water use

For expediency, we selected the maize crop to study the impact of climate change. Outputs of three General Circulation Models (GCM) were used to evaluate the impact on maize. The Genesis (GEN), HadCM2 and CSM models were employed. The modified climate data were entered into the CROPWAT model, and the reference evapotranspiration (ETo) figures, evapotranspiration of the maize crop (ETc) and moisture stress factor (Ks) obtained differed across the selected farming districts for the different climate scenarios.

The findings presented in Table 6 generally reveal that changes in temperature and CO_2 concentration lead to increased water requirements and uptake by the maize plant. However, the effects vary considerably from region to region. In a projected scenario of reduced rainfall and higher temperatures, such as in the Garoua District, these findings have profound implications for agriculture and food security.

12. Policy and agronomic implications of crop water use

The findings of this study have some important ramifications for farmers, extension services and future studies. We established that in the humid forest zones of Cameroon, with more than adequate rainfall, moisture stress is less significant. However, in the drier Sudano-Sahelian zone moisture stress is significant, particularly at the onset of the farming season. Given the higher temperatures, the heat stress compounds water stress. Water stress is brought on by increased crop needs for water (or high atmospheric demands for water because of high temperatures). So temperature changes the demand for water, and crops in Garoua and across the northern region could be responding to water stress rather than high temperature stresses.

It is acknowledged that for proper crop growth soil humidity has to be above 90%, and atmospheric humidity 25–30%. However, in northern Cameroon, where atmospheric humidity is less than 20%, soil humidity may not be optimal for crop germination and growth. Assuming that there is sufficient moisture in the soil for plants to germinate and emerge and begin their early growth, temperature then stands out as the sole limiting factor. The temperature effect on emergence of maize, groundnut and soybean is dramatic. The primary soil temperature or the temperature at which maize and soybean will emerge most rapidly is near 26.7°C. If the temperature is 15°C or less, emergence will be very slow. If the soil temperature averages 10–13°C at the time of planting, it may take three weeks for maize to emerge. If the soil temperature averages 10°C, it may take ten days. If the temperature averages 21.1°C it may take five days, and the maize crop may emerge in three to four days with soil temperatures somewhere near 26.7°C. In the case of soybeans, the crop emerges with vigorous growth if temperatures are somewhat above the base temperature. Soil temperature is thus a very important factor in determining when the plant will emerge and when it will go through its growth stages. 'During early stages of development, soil temperature has dramatic effects. Some controlled soil temperature studies in the field were conducted in Illinois (Bellero et al. 1996) and greenhouse work has shown dramatic differences in plant development between heated air and under-the-bench radiant heating. Cold soil and warm air may result in abnormal coloration of young maize.'[18]

As revealed in Figure 1, if atmospheric temperatures are cooler than usual, the crop may develop at a slower rate than usual. As temperature increases, the growth rate increases somewhat, and then does fairly well. Thereafter, at a certain point, it levels off. The crop grows according to an S-shaped curve depending on atmospheric temperature, with the ideal temperature for crop growth, if everything else is satisfactory such as nutrition and water availability, being somewhere around 34°C. Common maize varieties will not grow below 10°C, grow fastest at 34°C, will not grow above 46°C, and die at 48°C, with growth rate

[18] Weather Risk Management Association www.wrma.org/wrma/library/file775.pdf Accessed 14 August 2006.

responding to atmospheric temperature in an S-shaped curve between 9.5°C and 34°C (Bonner & Galston 1952). Above 34°C, the growth rate begins to drop off again. If the temperature rises above 43.3°C, it drops off very rapidly. That would be true heat stress, a temperature of 43–46°C. Between 20° and 34°C, the crop can grow very well.

In the tropics, notwithstanding, precipitation and soil moisture play more significant roles in influencing crop growth and development. Soil water is an important phenomenon affecting yield. Soil water is the amount of water available to a crop from the soil. Not all water in the soil is crop-available water. Across Cameroon, there is variability in the amount of water typically available to the crop. Examples of measurements of crop available moisture for maize in the study area are shown in Tables A1–3. In mid dry season in the south, Ambam for instance typically has 0.2m of plant-available water in the top 1.0m of soil. This assumes that crops have a 1.0m rooting depth and the water in the top 1.0m of soil is the water available to the crop. Some years, of course, both maize and soybeans may root deeper than 1.0m and, on occasion, the roots may not reach the 1.0m depth. But basically that is the rooting depth. About 0.2m of plant-available water typically available to the crop provides about one-third of the total requirement for the growing season. Across the region there is some variability in plant-available water. The water-holding field capacity of the soil is about 0.25m. 'Water at the beginning of the farming year is somewhat of a crop insurance plan. The bank of water that is built up in the soils can carry a crop through a brief period of heat stress, or water stress, by providing moisture to the roots' (Weather Risk Management Association www.wrma.org/wrma/library/file775.pdf Accessed 14 August 2006).[19]

In sum, therefore, water stress affects crop growth and productivity in many ways. Most of the responses have negative effect on production but crops have different and often complex mechanisms to react to shortages of water. Several crops and genotypes have developed different degrees of drought tolerance, drought resistance or compensatory growth to deal with periods of stress. Highest crop productivity is achieved for high yielding varieties with optimal water supply and high soil fertility levels. However, the same varieties are often highly sensitive to water stress and will obtain low yields or fail under conditions of even milder water stress during sensitive growth periods. While these findings have important implications for Cameroon's current agrarian policy and for managers of Cameroon's agriculture sector, the findings inherently raise a number of policy questions, particularly relevant to the introduction of new techniques for soil and crop water conservation. These are: (i) what should be the role of technical assistance in creating local awareness of opportunities for improved soil and crop water management? (ii) If it is important for farmers to have better weather forecasts, in what ways should meteorological services be strengthened? (iii) If new types of equipment or materials are needed for specific intervention, where would they come from, and at what cost? (iv) Might farmers require special once-off incentives or subsidies to allow them to initiate new practices for soil and crop moisture management? How would these be financed? How would continued dependence on subsidies be removed? (v) What would be the optimum means of

[19] Roots withdraw the plant-available moisture, depending on where the roots are and the water demand into the atmosphere. If soil is completely loaded with water and the plant is healthy in mid dry season, the plant would be using 80% of the water that would evaporate from the pan. This is the potential amount a plant could use. When the soil is at less than field capacity, less water is available for plant use and may affect the crop's actual water usage. Assuming that the soil is at 50% of field capacity (50% available); the crop will use almost the full amount as if the soil were at field capacity under low or medium demand conditions. On a day with very high demand, such as a hot, windy day, the amount used will drop off by 5–10%. If the soil is only at 25% of field capacity on a high demand day, the amount of water used by the crop may be only half the potential. If the day is cloudy, humid, and calm, the plant may use around 95% of the water if the soil is filled with moisture.

providing land husbandry advice to farmers? (FAO 1995, section on defining the government's role and actions).

National policy can therefore have important positive effects on soil and crop water conservation. An appropriate policy environment and the provision of adequate support services will assist farmers to adopt appropriate soil and crop water conservation strategies. 'Incentives and support services must be stable and sustained. Arbitrary alterations by governments of policy or the support framework may inadvertently provoke altered farm level decisions, which in turn can encourage soil degrading practices that are antagonistic to optimal capture and use of rainfall' (FAO 1995, section on defining the government's role and actions). Based on the findings of the research, the following recommendations are thus made:

1. To ease water constraints and enhance productivity, there is need to consider improving crop patterns and cultivate crops with less water requirements.

2. There is need to improve the irrigation efficiency by changing traditional irrigation system to more efficient systems such as drip irrigation and pipe irrigation.

3. There is need to mount an effort to integrate small farms into big units to increase the irrigation efficiency.

4. Various aspects of water resource management should be considered, such as supply, demand and construction management.

13. Concluding comments

The relative practical importance of precipitation, temperature, wind and sunshine is documented in this report. This study re-echoes the relative importance of climate in Cameroon, whose agriculture depends entirely on rainfall and is at the mercy of unpredictable weather and climatic instability. In a scenario where agricultural producers do not have access to climate forecast information, variations in local climate and changes in long-term climate could bring unpleasant consequences to a sector that employs 70% of the labor force and contributes more than 30% to the national income. It is established that despite the abundance of rainfall in some parts of the country, soil conditions, wind and sunshine interact to deprive crops of effective precipitation. Although farmers may be adapting to the climatic variation, the government needs to help the adaptation process by making available the necessary resources and providing irrigation infrastructure, especially in the drier northern parts of the country, to counter the debilitating effect of low soil moisture, peaking daily temperatures and runaway evapotranspiration. Crop water demand must be met as this strongly determines crop emergence, development and survival in the tropical regions. However, more accurate knowledge about crop response to water is essential in a range of crops for applications for policies and investment strategies at national and provincial levels.

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Table 1: Geographic description of study zones

Farming district	Location			Ecology	Soil type
	Long.	Lat.	Alt.		
Ambam	11.27°E,	2.34°N	602m	Humid moist forest	Vertisols
Bamenda	10.15°E	5.97°N	1609m	High savanna	Ferralsols
Garoua	13.38°E	9.33°N	244m	Sahel savanna	Ferruginous, hydromorphic (fluvisols)

Table 2: Crop development requirements and indicators

		I	II	III	IV	Total
Maize	Stage lengths	25	40	40	30	135
	Kc	0.30	>>>	1.20	0.50	
	Ky	0.40	0.40	1.3	0.50	1.25
	Rooting depth (m)	0.30	>>>	1.00	1.00	
	Depletion levels (p)	0.50	>>>	0.50	0.80	
Groundnut	Stage lengths	25	35	45	35	140
	Kc	0.40	>>>	1.15	0.60	
	Ky	0.40	0.60	0.80	0.40	0.70
	Rooting depth (m)	0.30	>>>	0.80	0.80	
	Depletion levels (p)	0.45	>>>	0.45	0.50	
Soybean	Stage lengths	20	30	60	25	135
	Kc	0.40	>>>	1.15	0.50	
	Ky	0.40	0.80	1.0	0.40	0.85
	Rooting depth (m)	0.30	>>>	1.00	1.00	
	Depletion levels (p)	0.50	>>>	0.60	0.90	

Notes: Ky (yield reduction factor), Ks (stress factor). Estimates simulated from CropWat 4 Windows Ver 4.3.

Table 3: Crop water use for maize

Farming dstrict	ETo (mm)	Kc	ETc (mm)	Ky	Ya (t)	Ym (t)	Ks	CWR (mm)	ETa (mm)	FWS (l/s/ha)	IWR
Ambam	413.28	0.67	276.89	1.25	0.6	2	0.14	335.61	38.76	0.01	15.68
Bamenda	570.11	0.67	381.97	1.25	0.5	2	0.15	460.25	57.29	0.01	17.39
Garoua	890.12	0.67	596.38	1.25	0.7	2	0.13	723.79	77.53	0.37	432.95

Notes: ETo (reference crop evapotranspiration), ETc (evapotranspiration of the maize crop), Ky (yield reduction factor), Ya (actual yield of maize crop), Ym (maximum yield of maize crop), Ks (stress factor), CWR (crop water requirement), ETa (actual evapotranspiration), FWS (field water supply), IWR (irrigation water requirement).

Table 4: Crop water use for groundnut

Farming dstrict	ETo (mm)	Kc	ETcrop (mm)	Ky	Ya (t)	Ym (t)	Ks	CWR (mm)	ETa (mm)	FWS (l/s/ha)	IWR
Ambam	427.31	0.72	307.66	0.70	1.3	4	0.29	361.36	89.22	0.01	9.24
Bamenda	588.77	0.72	429.91	0.70	1.5	4	0.18	495.64	77.38	0.01	12.35
Garoua	919.89	0.72	662.32	0.70	0.9	4	0.33	778.77	218.56	0.38	464.25

Notes: See Table 3.

Table 5: Crop water use for soybean

Farming dstrict	ETo (mm)	Kc	ETcrop (mm)	Ky	Ya (t)	Ym (t)	Ks	CWR (mm)	ETa (mm)	FWS (l/s/ha)	IWR
Ambam	413.28	0.68	281.03	0.85	1.2	2.5	0.09	367.23	25.29	0.01	11.14
Bamenda	570.11	0.68	387.67	0.85	1.5	2.0	0.04	504.69	15.51	0.02	20.31
Garoua	890.12	0.68	605.28	0.85	0.8	1.5	0.08	792.05	48.42	0.43	501.05

Notes: See Table 3.

Table 6: Climate change and crop water use for maize

Farming district	Climate change scenario	ETo (mm)	Kc	ETc (mm)	Ky	Ya (t)	Ym (t)	Ks	CWR (mm)	ETa (mm)	FWS (l/s/ha)	IWR
Ambam	Original	413.28	0.67	276.89	1.25	0.6	2	0.14	335.61	38.76	0.01	15.68
	CSM	382.12	0.67	271.45	1.25	0.6	2	0.14	356.02	50.23	0.01	19.05
	GEN	410.05	0.67	265.33	1.25	0.6	2	0.14	330.54	32.68	0.02	30.33
	HadCM2N	408.73	0.67	275.01	1.25	0.6	2	0.14	325.18	35.96	0.01	25.97
	HadCM2S	406.42	0.67	268.02	1.25	0.6	2	0.14	340.65	30.07	0.03	41.56
Bamenda	Original	570.11	0.67	381.97	1.25	0.5	2	0.15	460.25	57.29	0.01	17.39
	CSM	523.22	0.67	323.87	1.25	0.5	2	0.15	453.54	40.04	0.01	23.62
	GEN	561.83	0.67	312.04	1.25	0.5	2	0.15	471.46	60.03	0.01	33.54
	HadCM2N	501.54	0.67	334.13	1.25	0.5	2	0.15	425.56	48.14	0.03	26.89
	HadCM2S	530.07	0.67	372.15	1.25	0.5	2	0.15	463.05	53.75	0.01	45.33
Garoua	Original	890.12	0.67	596.38	1.25	0.7	2	0.13	723.79	77.53	0.37	432.95
	CSM	808.31	0.67	548.92	1.25	0.7	2	0.13	755.21	79.98	0.23	301.43
	GEN	845.26	0.67	512.54	1.25	0.7	2	0.13	780.32	70.73	0.16	405.76
	HadCM2N	789.62	0.67	563.58	1.25	0.7	2	0.13	655.5	90.01	0.35	550.45
	HadCM2S	827.19	0.67	533.65	1.25	0.7	2	0.13	740.18	84.23	0.28	450.93

Notes: ETo (reference crop evapotranspiration), ETc (evapotranspiration of the maize crop), Ky (yield reduction factor), Ya (actual yield of maize crop), Ym (maximum yield of maize crop), Ks (stress factor), CWR (crop water requirement), ETa (actual evapotranspiration), FWS (field water supply), IWR (irrigation water requirement).

APPENDIX

Table A1: Crop water use for maize in Ambam

8/02/2006 CropWat 4 Windows Version 4.3

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Crop Water Requirements Report

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- Crop # 1 : MAIZE (Grain) in **Ambam**
- Block # : [All blocks]
- Planting date : 1/3
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 100%

Date	ETo (mm/period)	Planted Area (%)	Crop Kc	CWR (ETm) (mm/period)	Total Rain (mm/period)	Effect. Rain (mm/period)	Irr. Req. (mm/period)	FWS (l/s/ha)
1/3	32.74	100.00	0.30	9.82	47.48	35.09	0.00	0.00
11/3	32.63	100.00	0.30	9.79	48.34	35.82	0.00	0.00
21/3	32.42	100.00	0.33	10.82	48.44	36.07	0.00	0.00
31/3	32.11	100.00	0.54	17.21	47.95	35.92	0.00	0.00
10/4	31.73	100.00	0.76	24.14	47.00	35.45	0.00	0.00
20/4	31.28	100.00	0.99	30.85	45.78	34.76	0.00	0.00
30/4	30.81	100.00	1.18	36.27	44.45	33.94	2.34	0.03
10/5	30.32	100.00	1.20	36.39	43.15	33.07	3.31	0.04
20/5	29.84	100.00	1.20	35.81	42.04	32.25	3.56	0.04
30/5	29.39	100.00	1.20	35.26	41.23	31.55	3.72	0.04
9/6	28.97	100.00	1.16	33.76	40.81	31.01	2.75	0.03
19/6	28.62	100.00	0.96	27.34	40.84	30.70	0.00	0.00
29/6	28.33	100.00	0.72	20.45	41.37	30.63	0.00	0.00
9/7	14.08	100.00	0.55	7.70	21.04	15.37	0.00	0.00
Total	413.28			335.61	599.93	451.63	15.68	[0.01]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Table A2: Crop water use for maize in Bamenda

8/02/2006 CropWat 4 Windows Version 4.3

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Crop Water Requirements Report

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- Crop # 1 : MAIZE (Grain)
- Block # : [All blocks]
- Planting date : 1/3
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 100%

Date	ETo	Planted Area	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS
	(mm/period)	(%)		---------- (mm/period)		----------		(l/s/ha)
1/3	46.64	100.00	0.30	13.99	34.99	26.85	0.00	0.00
11/3	46.24	100.00	0.30	13.87	41.34	32.32	0.00	0.00
21/3	45.70	100.00	0.33	15.24	46.27	36.69	0.00	0.00
31/3	45.02	100.00	0.54	24.13	50.11	39.93	0.00	0.00
10/4	44.24	100.00	0.76	33.67	53.37	42.13	0.00	0.00
20/4	43.40	100.00	0.99	42.78	56.57	43.48	0.00	0.00
30/4	42.51	100.00	1.18	50.04	60.27	44.23	5.81	0.07
10/5	41.60	100.00	1.20	49.93	64.92	44.65	5.28	0.06
20/5	40.72	100.00	1.20	48.86	70.85	44.98	3.89	0.04
30/5	39.88	100.00	1.20	47.86	78.22	45.44	2.42	0.03
9/6	39.11	100.00	1.16	45.57	86.99	46.19	0.00	0.00
19/6	38.43	100.00	0.96	36.71	96.95	47.32	0.00	0.00
29/6	37.86	100.00	0.72	27.33	107.66	48.87	0.00	0.00
9/7	18.76	100.00	0.55	10.25	57.92	25.13	0.00	0.00
Total	570.11			460.25	906.42	568.19	17.39	[0.01]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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Table A3: Crop water use for maize in Garoua

8/02/2006 CropWat 4 Windows Version 4.3

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Crop Water Requirements Report

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- Crop # 1 : MAIZE (Grain)
- Block # : [All blocks]
- Planting date : 1/3
- Calculation time step = 10 Day(s)
- Irrigation Efficiency = 100%

Date	ETo	Planted Area	Crop Kc	CWR (ETm)	Total Rain	Effect. Rain	Irr. Req.	FWS
	(mm/period)	(%)		----------	(mm/period)	----------		(l/s/ha)
1/3	69.77	100.00	0.30	20.93	0.00	0.00	20.93	0.24
11/3	70.03	100.00	0.30	21.01	0.00	0.00	21.01	0.24
21/3	69.93	100.00	0.33	23.34	1.07	1.01	22.33	0.26
31/3	69.51	100.00	0.54	37.26	8.58	7.52	29.75	0.34
10/4	68.81	100.00	0.76	52.37	16.29	14.25	38.12	0.44
20/4	67.91	100.00	0.99	66.96	22.75	20.00	46.96	0.54
30/4	66.85	100.00	1.18	78.71	28.07	24.63	54.08	0.63
10/5	65.70	100.00	1.20	78.84	32.64	28.26	50.58	0.59
20/5	64.51	100.00	1.20	77.41	36.93	31.13	46.28	0.54
30/5	63.34	100.00	1.20	76.01	41.39	33.53	42.48	0.49
9/6	62.24	100.00	1.16	72.52	46.36	35.75	36.76	0.43
19/6	61.24	100.00	0.96	58.50	51.96	38.01	20.49	0.24
29/6	60.38	100.00	0.72	43.59	58.11	40.40	3.19	0.04
9/7	29.92	100.00	0.55	16.36	31.45	21.14	0.00	0.00
Total	890.12			723.79	375.5	295.62	432.95	[0.37]

* ETo data is distributed using polynomial curve fitting.
* Rainfall data is distributed using polynomial curve fitting.

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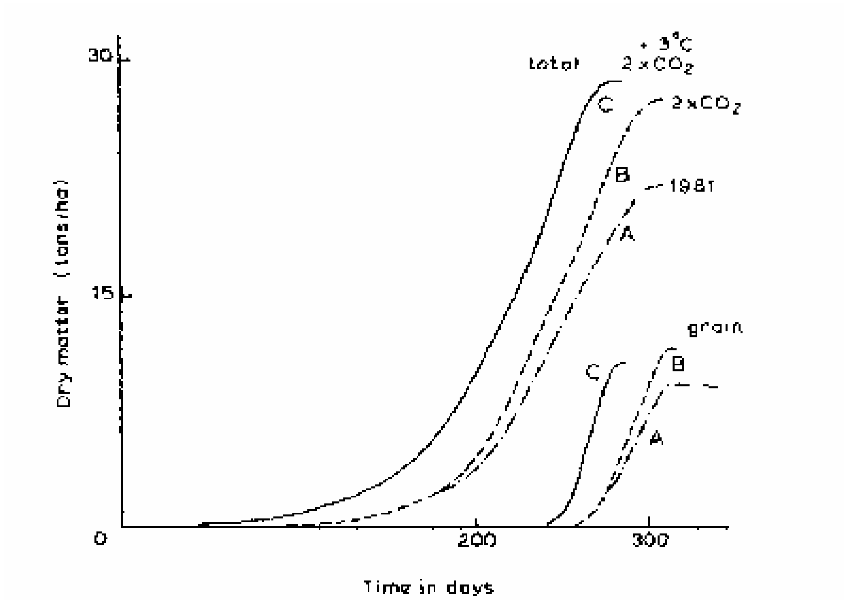
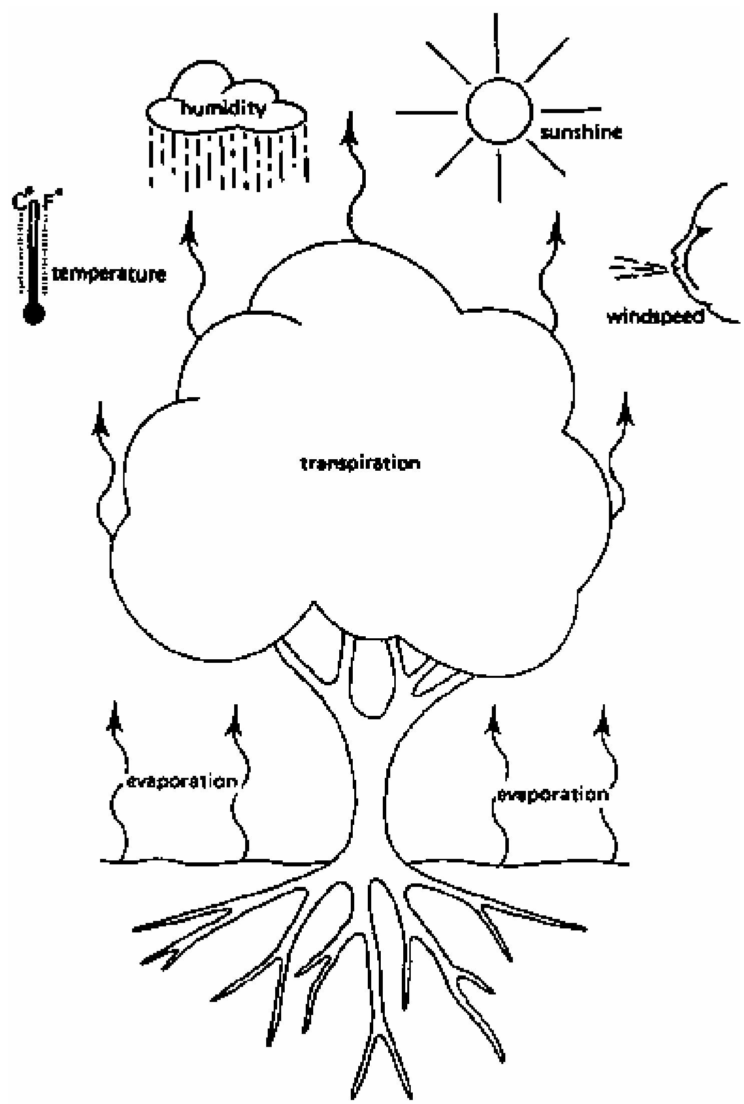


Source: Squire & Unsworth 1988
A = present climate conditions represented by 1981 data.
B = Simulation of the effect of doubling carbon dioxide concentration.
C = The effect of both a doubled carbon dioxide concentration and a rise in mean temperature.

Figure 1: Modeled response of total dry matter production and grain yield of wheat



Source: Brouwer & Heibloem (1986)

Figure 2: Major climatic factors influencing crop water needs

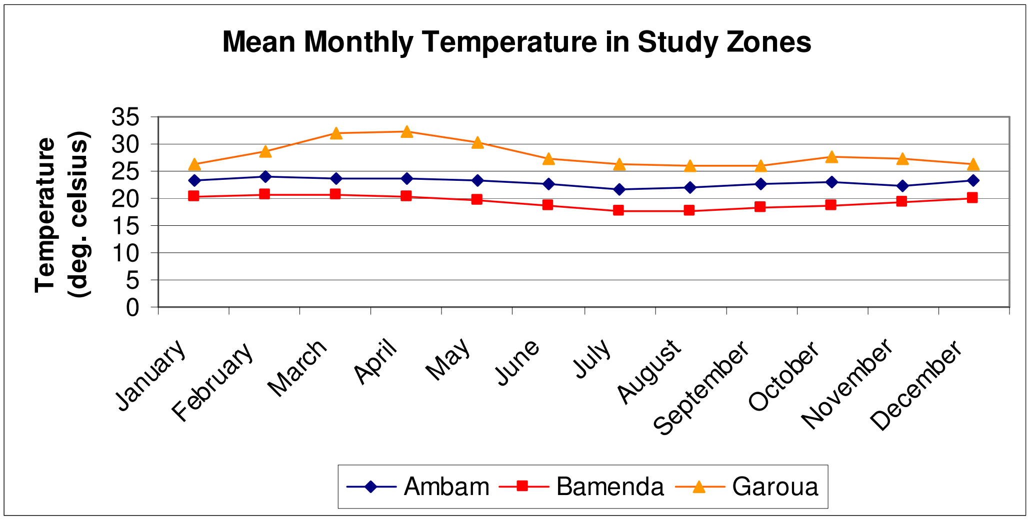


Figure 3: Mean monthly temperature distribution in the study zones

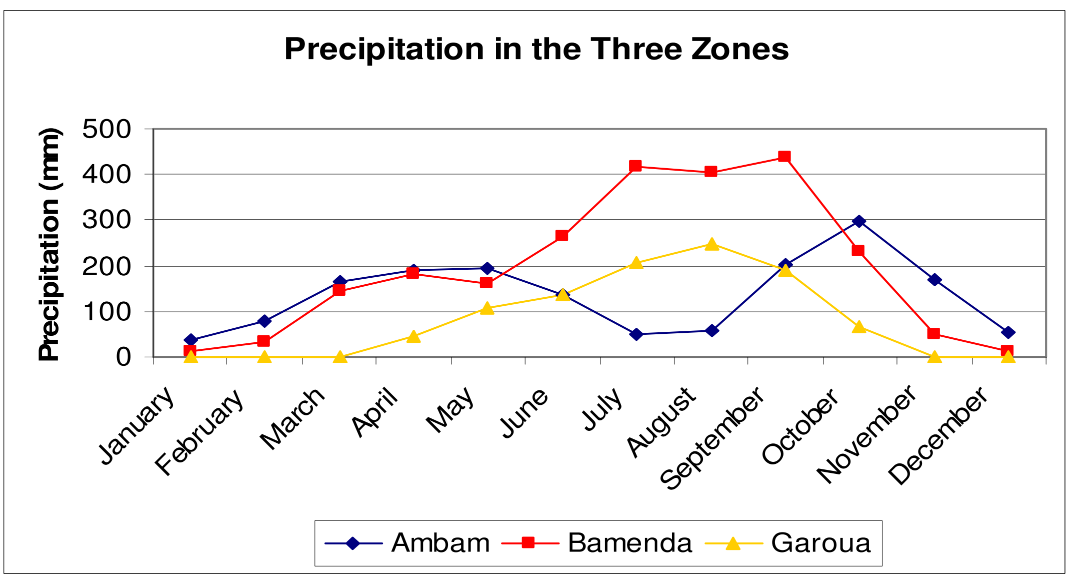


Figure 4: Mean monthly precipitation distribution in the study zones

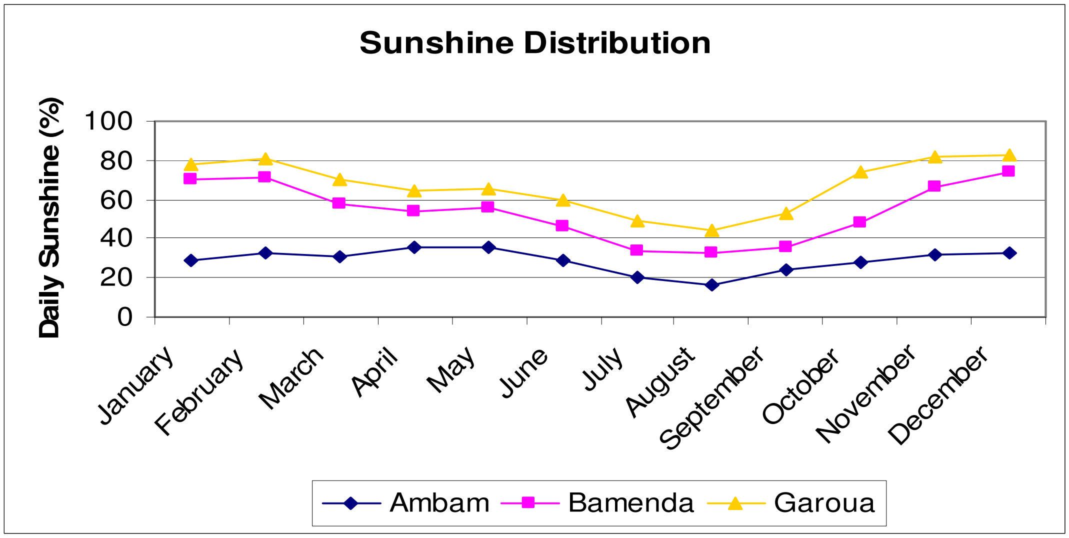
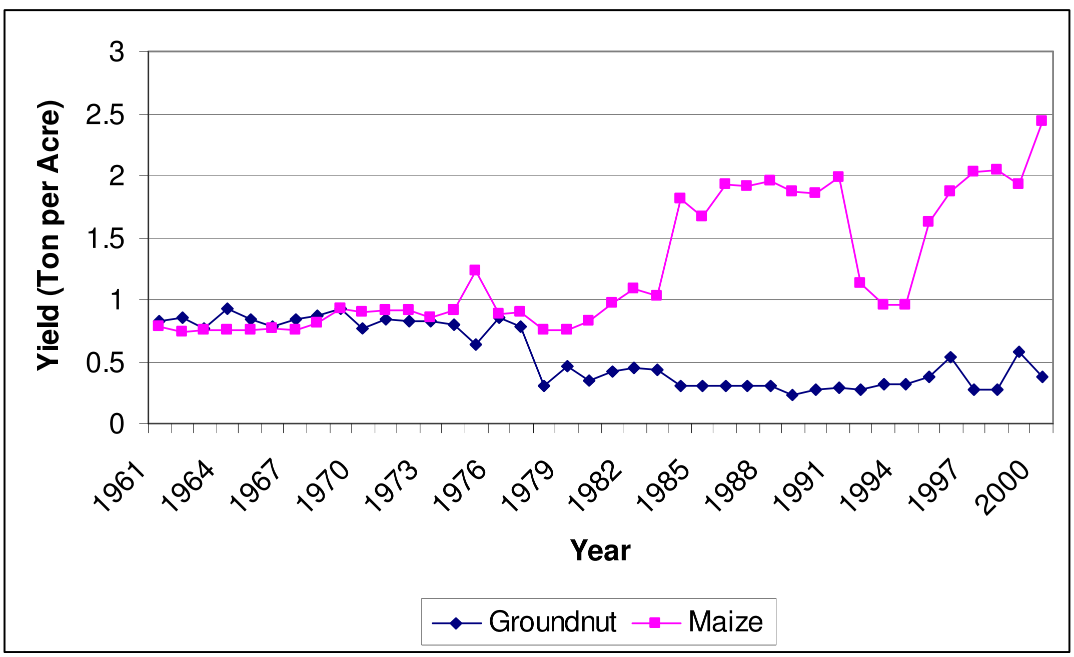


Figure 5: Comparative distribution of sunshine in the study areas



Source: FAO database

Figure 6: Maize and groundnut yields in Cameroon (tons per acre) (1961–2000)

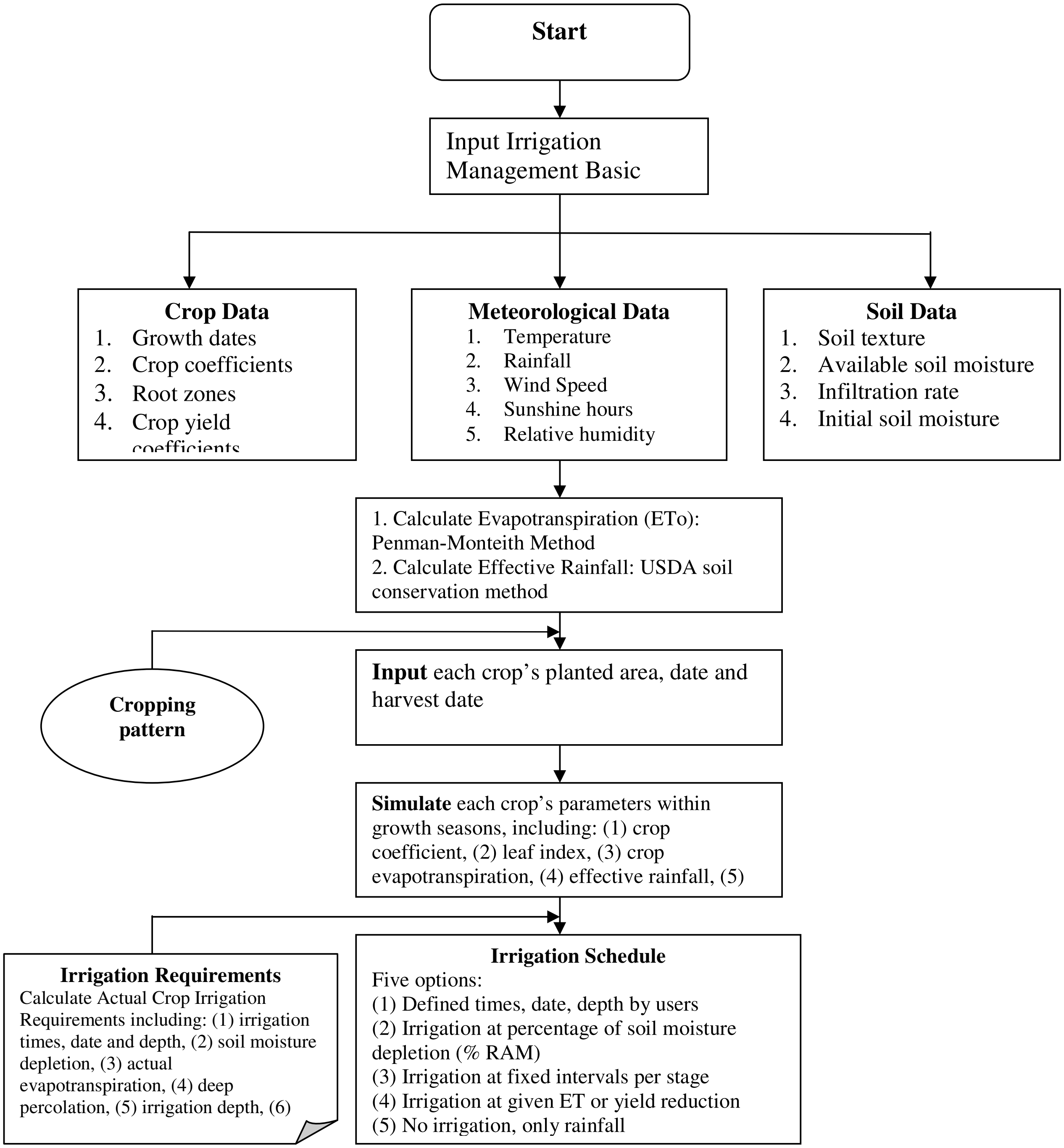


Figure 7: Flow chart of the CROPWAT crop water management model (FAO 1998)