Journal of Agriculture and Environmental Sciences
June 2014, Vol. 3, No. 2, pp. 197-218
ISSN: 2334-2404 (Print), 2334-2412 (Online)

Published by American Research Institute for Policy Development

Net Irrigation Requirements for Maize in Isra-Nioro, Province of Kaolack (Senegal)

Demba Diakhate[1]

Abstract

The aim of this work is to provide an easy methodology for the estimation of the Net Irrigation Water Requirements (Irnet) to be used in any developing country as first step in irrigation systems design. The present study uses state-of-the-art software to allow answering the question "Is the introduction of irrigation useful in the specific agro-climatic conditions in order to increase crop yield?". For better understanding, the present study applied the suggested methodology to one typical hot climate crop as maize - Zea mays, cultivated in the Nioro of Rip area, Kaolack region (Republic of Senegal). To estimate and examine all required data, different software were utilized. FAO software (CROPWAT 8.0 and New_LocClim) were adopted to compute Reference Evapotranspiration (ETo), Crop Water Requirements (CWR) and Net Irrigation Water Requirements (Irnet) of the two analysed crops. Excel (version 2007) was used to examine the rainfall data from a statistical point of view in order to have a frequency analysis for the considered events. Daily climatic data for a seven-year time period (January 2001 - December 2007) were analysed to calculate ETo. These data were obtained from the Agro-meteorological Station of ISRA-Nioro research (Kaolack region, Republic of Senegal). During the considered seven-year time period, in almost all cases, total rainfall is over **760.6 mm per year**. It means that effective rainfall (computed utilizing the USDA S.C. Method) is around **536.4 mm**. In rainy season, CWR for maize was 414.0 mm and 417.6 mm obtained respectively from New_LocClim method and Meteorological station method. And his Irnet was 9.9 mm and 5 mm obtained respectively from New_LocClim method and Meteorological station method. In rainy season condition maize, yield reduction has been equal to 0.0%. Knowing the CROPWAT approximation level, for practical purposes those values can be neglected and maize can be assumed to produce at their maximum. Given that in rainfed conditions no water stress is practically observed along the entire crop cycle, we can affirm that no irrigation system is needed to be designed in such a specific climate and soil conditions. In conclusion, the best choice for seeding in dry season in Nioro area is to seed in November. Indeed, seeding in November can be beneficial for maize. In this situation, plantation still produces its maximum and yield reduction equal 0.0%.

Keywords: Net Irrigation Water Requirement; Zea mays; Sorghum bicolor; Nioro of Rip; Cropwat 8.0; New_LocClim

[1] Agronomist engineer - PhD Candidate in Applied mechanization to the UEL –Brasil. Senegalese Institute of Agricultural Research (ISRA), Bambey in National Center of Agricultural Research (CNRA), Fone l: Sénégal +221 77 527 54 01 / Brasil. : + 55 43 98 24 24 01,
E-mail: agrogrdemba@yahoo.fr/ agrogrdemba@gmail.com, Senegal

Chapter I- Introduction

Senegal, like many African countries, based its development on Agriculture occupies about 70% of the population and contributes 10% GDP (ANSD, 2002). The agricultural sector contributes to improving the food security through the provision of food and raw materials for agro-industry. It also represents an important outlet for the industrial, semi-industrial and craft.

In fact, for two decades, the agricultural sector is experiencing difficulties illustrated by decrease its contribution to GDP, which increased from 18% in the period 1960/1986 to 10.6% between 1990/1995 (UEMOA, 2002), and an explosion population resulting in increasing pressure on natural resources. These difficulties make it difficult to meet a share of food requirements and other populations from export needs.

This situation is exacerbated by that of the new world economic order, regulated and dominated by competition, requires African states to respect international standards of quality of productions. It is within this framework that the state of Senegal through ISRA seeks ways to boost Senegalese agriculture by providing producers of high-yielding varieties.

To achieve these results ISRA account on these centers and research stations, particularly the station Nioro. But in this recent years have seen a decline in crop yields at the station linked mainly by declining soil fertility. This situation has led the authorities of ISRA to review their crop calendar. It is in this context that this study "Net irrigation requirement "for maize in ISRA-Nioro region Kaolack, Senegal" part.

The objective of a proper irrigation schedule is to supply the right amount of water before harmful stress occurs (optimum quantity and timing). It's very important to define a precise strategy when designing an irrigation system. Knowing the crop water requirements enables to determine the proper irrigation schedule at any given time; irrigation managers need to calculate the best time to irrigate, and how much water to use so that crops are produced economically, and water resources are managed in a sustainable manner. The calculation of seasonal and peak project supply required for a given cropping pattern and intensity includes the net irrigation requirements (Irnet) and other water needs including leaching of salts and efficiency of the distribution system.

Irrigation requirement is one of the principal parameters for the planning, design and operation of irrigation and water resources systems. Detailed knowledge of the Irnet and its temporal and spatial variability is essential for assessing the adequacy of water resources, for evaluating the need of storage reservoirs and for the determining the capacity of irrigation systems. It is a parameter of prime importance in formulating the policy for optimal allocation of water resources as well as in decision-making in the day-to-day operation and management of irrigation systems (FAO, 2002).

Simulation models, information systems and decision support systems can be relevant to support farmer's selection of water-use options, including crop patterns and irrigation systems, and to implement appropriate irrigation scheduling (Solinas, 2011). FAO software, such as *CROPWAT, ETo Calculator* or *AquaCrop*, are nowadays wildly used to calculate crop water requirements and irrigation requirements and to develop irrigation schedules for different management conditions (FAO, 1992).

The aim of this work is to provide an easy methodology for the estimation of the Net Irrigation Water Requirements (Irnet) to be used in any developing country as first step in irrigation systems design. The present study uses state-of-the-art software to allow answering the question "Is the introduction of irrigation useful in the specific agro-climatic conditions in order to increase crop yield. For better understanding, the present study applied the suggested methodology to one crop as maize, cultivated in the ISRA research station of Nioro (Kaolack region, Republic of Senegal).

Once Crop Water Requirements (CWR) during the analysed time period have been estimated, it was possible to assess if the design of an irrigation system for both crops was to be suggested to farmers or not.

The work consists in five chapters. This first Chapter provides a brief introduction about water related issues, such as the importance and uses of water - especially regarding the agricultural sector - and the problems related with irrigation and water scarcity. Chapter 2 focuses on the materials and methods used. It presents some general definitions, the software, the selected area and respective meteorological station, the most representative soil and, finally, th chosen maize crop. In Chapter 3 results are discussed and interpreted. In Chapter 4 key conclusions and recommendation are summarized.

Chapter II- Materials and Methods

2.1. Definitions

Evapotranspiration (ET, normally expressed in mm/day) is the combination of two separate processes: evaporation (water lost from the soil surface) and transpiration (water lost from the crop). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

When the crop is small, water is predominately lost by soil evaporation (at sowing, nearly 100% of ET comes from evaporation), but once the crop is well developed and completely covers the soil, transpiration becomes the main process (FAO, 1998).

Weather parameters, crop characteristics, management and environmental aspects are factors influencing evaporation and transpiration.

The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ETo). ETo (expressed in mm/day) is defined as "the evapotranspiration rate from a reference surface, not short of water; the reference surface is a hypothetical grass reference crop with specific characteristics"[2].

The principal weather parameters influencing evapotranspiration are radiation, air temperature, humidity and wind speed. A large number of empirical or semi-empirical equations have been developed for assessing reference crop evapotranspiration from meteorological data. Numerous researchers have analysed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the ETo (FAO, 1998). For daily, weekly, ten day or monthly calculations, the FAO Penman-Monteith equation requires:

[2] The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m-1 and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground (FAO, 1998).

- **Site location**: altitude above sea level, latitude and longitude;
- **Air temperature** (°C): maximum and minimum temperature or mean temperature;
- **Air humidity** (%): maximum and minimum or mean relative humidity;
- **Radiation** (MJ/m²/day or hours/day): net radiation or actual duration of bright sunshine;
- **Wind speed** (m/s): wind speed.

All meteorological data can be estimated using agro-meteorological stations; these stations are commonly located in cropped areas where instruments are exposed to atmospheric conditions, similar to those for the surrounding fields. In these stations, air temperature and humidity, wind speed and sunshine duration are typically measured at 2 m above an extensive surface of grass or short crop. Where needed and feasible, the cover of the station is irrigated (FAO, 1998).

Calculations of ETo are often computerized. Many software packages use the FAO Penman-Monteith equation to assess ETo: nowadays, FAO *EToCalculator* and *CROPWAT* are largely used.

The selection of the time step with which ETo is calculated depends on the purpose of the calculation, the accuracy required and the time step of the climatic data available. In this work, daily time step has been utilized.

Crop Water Requirements (CWR) are defined as *"the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment"* (FAO, 1984).

The water requirements of each crop are calculated taking into consideration the evapotranspiration rate; this depends mainly on climate, but also on growing season and crop development (FAO, 1977). Crop evapotranspiration under standard condition (ETc) is the sum of transpiration by the crop and evaporation from the soil surface. Prediction methods for CWR are used owing to the difficulty of obtaining accurate field measurements. The methods often need to be applied under climatic and agronomic conditions very different from those under which they were originally developed.

To estimate ETc a three-stage procedure is recommended (FAO, 1977):

- Effect of climate on crop water requirements is given by ETo;
- Effect of the crop characteristics on CWR is given by the crop coefficient (Kc) which represents the relationship between reference (ETo) and crop evapotranspiration under standard condition (ETc). Values of Kc vary with the crop; the main factors affecting its values are crop characteristics, crop planting or sowing date, rate of crop development and length of growing season;
- Effect of local conditions and agricultural practices on CWR includes the local effect of variations in climate over time, distance and altitude, size of fields, advection, soil water availability, salinity, irrigation and cultivation methods, for which local field data are required.

ETcadj represent the crop evapotranspiration under non-standard condition, and depends on weather parameters, crop characteristics, management and environmental factors. Also in this case, prediction methods have been developed for ETcadj quantification, which can be calculated multiplying ETc by Ks (water stress coefficient). Ks describes the effect of water stress on crop transpiration. According to FAO, p factor (critical depletion coefficient, due to water stress conditions) is the average fraction of Total Available Water (TAW; the amount of water that a crop can extract from its root zone, varying depending on soil moisture content) that can be depleted in order to have no crop water stress. By multiplying TAW by p factor, it is possible to obtain the readily available water (RAW; the fraction of TAW that a crop can extract from the root zone without suffering water stress). Ks is equal to 1 (ETc = ETcadj) when the soil water content is within the RAW, while Ks is lower than 1 (ETc > ETcadj) when the soil water content drops below the p fraction, reaching 0 when the soil water content is at Permanent Wilting Point.

The Net Irrigation Requirements of the crop (Irnet), defined as *"the amount of irrigation water that needs to be supplied to the crop to compensate all evapotranspiration losses"* (FAO, 2002), are calculated using the soil water balance, which includes crop evapotranspiration, effective rainfall, groundwater contribution, stored soil water at the beginning of each period and leaching requirements:

$$Irnet = ETc - (Pe + Ge + Wb) + LR$$

Where:

- **Irnet** = Net irrigation requirement (mm);
- **ETc** = Crop evapotranspiration (mm);
- **Pe** = Effective dependable rainfall (mm): not all dependable rainfall is effective and some may be lost through surface runoff, deep percolation or evaporation. Only a part of the rainfall can be effectively used by the crop, depending on its root zone depth and the soil storage capacity. Different methods exist to estimate the effective rainfall, one of the most commonly used is the USDA Soil Conservation Service Method;
- **Ge** = Groundwater contribution from water table (mm): the contribution of the groundwater table to the soil water balance varies with the depth of the water table below the root zone, the soil type and the water content in the root zone (FAO, 2002);
- **Wb** = Water stored in the soil at the beginning of each period (mm): some water could be left in the soil from the previous irrigation or rainfall event, which can be used for the next crop. This amount can be deducted when determining the seasonal irrigation requirements;
- **LR** = Leaching requirement (mm): an excess amount of water is applied during the irrigation, where necessary, for the purposes of leaching.

If irrigation is the only source of water supply for the plant, the gross irrigation requirements will always be greater than the ETc to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement can be considerably less than the CWR (FAO, 2002).

2.2. Software

2.2.1. CROPWAT 8.0[3]

CROPWAT 8.0 for Windows is a decision support tool developed by the Land and Water Development Division of FAO in 2006. It is used for the calculation of CWR and Irnet based on soil, climate and crop data.

---

[3] http://www.fao.org/nr/water/infores_databases_cropwat.html.

The computer program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns.

Calculation procedures - All calculation procedures used in CROPWAT 8.0 are based on two FAO publications of the Irrigation and Drainage Series, namely, No. 33 titled *"Yield response to water"* (1979) and No. 56 *"Crop Evapotranspiration - Guidelines for computing crop water requirements"* (1998). The development of irrigation schedules in CROPWAT 8.0 is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions.

Data input & output - In order to run properly, CROPWAT 8.0 needs some data inputs, namely: climatic and rainfall data, crop characteristics and soil features. As a starting point, and only to be used when local data are not available, CROPWAT 8.0 includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained from the climatic database, CLIMWAT, containing date from more than 5000 stations worldwide. After all inputs have been correctly introduced, the software gives some important outputs, such as reference evapotranspiration, effective rainfall, net and gross irrigation requirements[4].

After CRW has been calculated, CROPWAT 8.0 can simulate different types of irrigation scheduling, mainly depending on the user desired option: by changing the *Irrigation timing* (irrigate at critical depletion, irrigate at user defined intervals, irrigate at given yield reduction, etc..) and *Irrigation application* (fixed application depth, refill soil to field capacity, etc..) the user can find the more suitable irrigation scheduling for the specific situation.

2.2.2. New_LocClim

2.2.2.1. What is New LocClim?

[4] Apart from a completely redesigned user interface, CROPWAT 8.0 for Windows includes a host of updated and new features, including: monthly, decade and daily input of climatic data for calculation of ETo; decade and daily calculation of crop water requirements based on updated calculation algorithms including adjustment of crop-coefficient values; interactive user adjustable irrigation schedules; daily soil water balance output tables; easy saving and retrieval of sessions and of user-defined irrigation schedules; graphical presentations of input data, crop water requirements and irrigation schedules; easy import/export of data and graphics through clipboard or ASCII text files; extensive printing routines, supporting all windows-based printers; multilingual interface and help system: English, Spanish, French and Russian.

New LocClim is a tool for spatial interpolation of agroclimatic data. Since quite a variety of tools for spatial interpolation of any data already exist, one might question whether a new one is necessary. Each of the existing tools has its advantages and disadvantages. Some of them are quite advanced but very expensive, some are very general, some are not at all easy to use. It is especially designed for the interpolation of agroclimatic data, offering the possibility of producing climate maps from user provided station data. However, where such station data are unavailable, New_LocClim is also capable of producing climate maps of the average monthly climate conditions (8 variables) taken from the agroclimatic database of the Agromet Group of the Food and Agriculture Organisation of the United Nations. Finally, to learn about the properties of different interpolation methods with respect to different spatial fields, the nine methods provided by New_LocClim can be compared with respect to pre-given spatial fields. New_LocClim allows for an extensive investigation of interpolation errors and the influence of different settings on the results. This allows to optimise the interpolation with respect to the data analysed.

2.2.2.2. How to use New_LocClim?

New_LocClim is easy to use. It can be explored by trial and error. However, all of the workbench-menu items are described in the section Workbench Menu Items.

It runs in 3 modes: **the Automatic Mode, the Single Point Mode and the Workbench Mode**. The first automatically writes interpolated products into files using user chosen formats and methods.

The second provides more detailed information on annual cycles of climatological variables for single points. The latter mode offers to experiment with methods and settings, grid size and so on. This mode should be the first to be run by the user in order to get an impression of the data used. It furthermore allows to detect, alter or withdraw strange data and to do further cross checking. Both modes use statistical analysis of the interpolated spatial fields. From this statistical analysis, all information relating to the climate of a place in the world is known. This analysis can be done with the "single point mode. Climate information in this area can be represented by a drawing.

2.3. Meteorological Station

It was built in 1937 by Senegalese Institute for Agricultural Research denoted ISRA. It is an agricultural research station. It depends on the National Agricultural Research Center denoted CNRA located in the province of Diourbel.

The Geographical location of Nioro Research Station is 14° l0 and 14° 20 latitudes in the north and 15°05 and 15°20 longitudes in the West, under the Peanut basin of Senegal where the average rainfall is around 700 mm.

2.3.1. State of Nioro

The ISRA Research Station is located in Peanut Basin, where the peanut is a common practice. It is characterized by:

2.3.1.1. Climat

Two seasons alternate in this area of the Southern Peanut Basin denoted SBA during the year:

- A dry season that lasts an average of seven months (November to May);
- A rainy season shorter (June to 0ctober) with a maximum precipitation in August.

2.4. Representative Soil Characteristics

2.4.1. General Characteristics of Soils

The soils of the station are generally characterized by their position on slope and therefore their exposure to water erosion due to runoff water from rain.

They have a reddish colour and little or very little humus. The texture is mainly sandy and generally massive structure.

These soils are low in nitrogen, which ranged between 0.2 and 0.3‰ and lower phosphorus 30 ppm. They have a low cation exchange capacity at very low and slightly acid reaction (AGETIP, 1995).

2.4.1.1. Soil Classification

These soils are subdivided into four units (figure 3), depending on the average percentage elements purposes (Silt + Clay) of 40 cm surface, which are (AGETIP, 1995):

- Ferruginous tropical hydromorphic soils on fine-grained material moderately present (A + L)> 15% of depression areas " Soil Deck";
- Leached ferruginous tropical soils on fine-grained material weakly present (12% <A + L< 15%) lower slopes: "soil Deck – Dior";
- The integrals, ferruginous tropical soils, lateritic soils on material thin-grained weakly present (A + L <12%) of slopes related to the plates: "Soil Dior" reddened;
- The contribution of poorly evolved colluvial ferruginous material on gravelly or cuirass ferric spreading the glaze: Soil unable for cultivation.

2.5. Crop

Maize is the most important cash crops worldwide cultivated. They represent an important source of income both for substantial farming and big agricultural enterprises.

In Senegal, the maize was planted in all agro-ecological zones. They are well appreciated by the people and they fall into their habits cooking. This is the reason why the state of Senegal, with its food self-sufficiency program, encourages mass production (e.g GOANA)[5] and crop diversification. This state policy for the replenishment of seed capital has been entrusted to ISRA. It is in this context that the ISRA has initiated a five-year plan in light of pre seed production bases (see Table 1). ISRA has also accompanied the multiplier lower levels (Base, N1, N2, R1, and R2) for further traceability (ANSD, 2009).

2.5.1. Maize (Zea mays L.)[6]

Maize (*Zea mais* L.) originates in the Andean region of Central America. Present world production is about 822 million tons grain from about 162 million ha.

---

[5] large agricultural offensive for food and abundance
[6] http://www.fao.org/landwater/aglw/cropwater/maize.stm'.

Generally speaking, maize is grown in climates ranging from temperate to tropic. When mean daily temperatures, during the growing season, are greater than 20 °C, early grain varieties take 80 to 110 days and medium varieties 110 to 140 days to mature. In the present work, a medium grain variety with a 120 days cycle has been considered since, according to Nioro, the ISRA Selection (see extended varieties), i.e. the ones with a crop cycle between 90 and 120 days, is the most cultivated one. It is sown in early wintering more precisely in June. The crop is very sensitive to frost, particularly in the seedling stage, but it tolerates hot and dry atmospheric conditions so long as sufficient water is available to the plant and temperatures are below 45°C. In respect of day-length, maize is considered to be either a day-neutral or a short-day plant.

Plant population varies from 20.000 to 30.000 plants per ha for the large late varieties to 50.000 to 80.000 for small early varieties. Spacing between rows varies between 0.5 and 0.8 m. Sowing depth is 5 to 7 cm with one or more seeds per sowing point (figure 6).

The plant does well on most soils but less so on very heavy dense clay and very sandy soils.

The soil should preferably be well-aerated and well-drained as the crop is susceptible to water logging.

Maize is moderately sensitive to salinity. Yield decrease under increasing soil salinity is: 0% at ECe 10 mmhos/cm, 50% at 5.9 mmhos/cm, 75% at 3.8 mmhos/cm, 90% at 2.5 mmhos/cm and 100% at ECe 1.7 mmhos/cm.

The crop coefficient (Kc) is for the initial stage 0.30, mid-season stage 1.20 and at harvest 0.35 (Table 3). Yield response factor (Ky)[7] is for the initial stage 0.40, mid-season stage 1.30 and at harvest 0.50.

[7] Ky is a factor describing the reduction in relative yield according to the reduction in ETc caused by soil water shortage. Ky are crop specific and may vary over the growing season. In general, the decrease in yield due to water deficit during the vegetative and ripening period is relative small if compared with the one during flowering and yield formation periods (FAO, 1998).

Table 1: Maize Main Crop Coefficients Used for Water Management (CROPWAT 8.0)

	Initial	Development	Mid-season	Late	Total
Crop coefficient Kc	0.3	-------------	1.20	0.35	-------
Stage length [days]	20	35	40	25	120
Rooting deep [m]	0.3	---------------	------------	0.9	-------
Critical depletion (fraction)	0.55	---------------	0.55	0.8	-------
Yield response (fraction)	0.40	0.40	1.30	0.50	1.25
Crop height [m]	---------	----------------	2.00	---------	-------

Being an indigenous crop to tropical environments, maize requires hot-humid climates; as a result, together with both heat and nitrogen, the third fundamental production factor is water (Tassinari, 1976). For maximum production, a medium maturity grain crop requires between 500 and 800 mm of water depending on climate.

Maize appears relatively tolerant to water deficits during the vegetative and ripening periods.

Greatest decrease in grain yields is caused by water deficits during the flowering period (Table 1).

The effect of limited water on maize grain yield is considerable and careful control of frequency and depth of irrigation is required to optimize yields under conditions of water shortage.

When evaporative conditions correspond to ETc of 5 to 6 mm/day, soil water depletion up to about 55% of available soil water has a small effect on yield (p = 0.55). To enhance rapid and deep root growth a somewhat greater depletion during early growth periods can be advantageous.

Depletion of 80% or more may be allowed during the late season (Table 1).

Where rainfall is low and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficits during the flowering period, followed by yield formation period.

Under conditions of marginal rainfall and limited irrigation water supply, the number of possible irrigation applications may vary between 2 and 5.

Chapter III- Results and Discussion

3.1. Reference Evapotranspiration/ETo Estimation Using Available Climatic Data

The first objective of this work is to estimate ETo in Nioro (State of Nioro, Kaolack Region Senegal) from real data collected in Meteorological Station of Nioro and from New_LocClim. For the first method as Meteorological Station, daily climatic data for a Seven-year time period (January 2001 – December 2007) have been analysed[8]. All meteorological data have been obtained from the Agrometeorological Station of Nioro. In order to estimate the ETo values over the Seven-year time period, FAO Cropwat version 8.0 has been utilized.

First, climatic data - namely: maximum and minimum air temperature (°C), wind speed (m/s), mean relative humidity (%) and hours of sunshine (h/d) - have been written in Cropwat 8.0 particulary in the session Climate/ETo. After it has been possible to estimate the daily ETo over the entire time period (Figure1).

For the second method as New_LocClim, the same procedure as above was used to estimate ETo (Figure 1). New_LocClim data covers a period of 30 years seen from 1961 to 1990 (Solinas, 2011).

[8] Due to space constraints, it has not been possible to include all initial climatic data for the considered Seven-year time period.

Monthly ETo Penman-Monteith - D:\Documents and Settings\All Users\Application Data\CROPWAT\data\clim...

Country: Senegal Station: Nioro

Altitude: 20 m. Latitude: 13.73 °N Longitude: 15.78 °W

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	15.1	34.5	39	69	7.3	'7.3	3.74
February	17.2	36.3	34	86	8.4	20.3	4.61
March	18.9	39.5	41	86	7.6	20.5	5.09
April	20.6	39.9	49	95	8.3	22.4	5.65
May	22.0	39.9	54	104	8.3	22.2	5.76
June	24.2	36.2	66	130	7.1	20.1	5.23
July	23.3	33.2	80	104	6.5	'9.2	4.36
August	24.0	32.7	82	69	6.5	'9.4	4.22
September	23.6	32.6	82	52	6.3	'8.7	3.98
October	23.3	34.7	77	26	7.1	'8.8	3.96
November	18.4	35.3	61	26	7.2	'7.4	3.42
December	16.8	35.7	49	52	6.5	'5.7	3.38
Average	**20.6**	**35.9**	**60**	**75**	**7.3**	**19.3**	**4.45**

Monthly ETo Penman-Monteith - D:\Program Files\New_LocClim V1.10\Nioro .pen

Country: Senegal Station: Nioro

Altitude: 20 m. Latitude: 13.73 °N Longitude: 15.78 °W

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	15.1	33.5	48	69	7.5	17.6	3.64
February	16.5	35.5	50	86	8.6	20.6	4.51
March	19.2	37.7	53	86	7.9	21.0	4.95
April	21.7	38.7	53	95	8.6	22.8	5.58
May	23.0	38.5	59	104	8.5	22.4	5.64
June	24.1	36.5	71	130	7.2	20.2	5.15
July	23.6	32.7	84	104	6.8	19.7	4.35
August	23.1	32.0	93	69	6.9	20.0	4.14
September	23.1	32.5	93	52	6.5	19.0	3.96
October	22.6	34.0	90	26	7.2	18.9	3.98
November	18.1	34.7	80	26	7.3	17.6	3.55
December	14.6	32.9	59	52	6.8	16.1	3.22
Average	**20.4**	**34.9**	**69**	**75**	**7.5**	**19.7**	**4.39**

Figure 1 : Estimate the Daily ETo over the Entire Time Period from Meteorological Station (Up) and from New_LocClim (Down) in Nioro

3. 3. CWR and Irnet for Maize Simulated in Rainfall Season and dry Season in Nioro

3.3.1. Net Irrigation Water Requirements (Irnet)

This estimated of the net irrigation requirements of a crop (maize and sorghum) will be done with actual data from the station on the one hand and secondly by New_LocClim software data. In order to estimate the net irrigation requirements of a crop, all parameters for the field balance equation must be estimated.

Using computer techniques, all variables can be combined in a water balance model. In this work, CROPWAT 8.0 has been used in order to estimate CWR and Irnet of maize and sorghum.

In rainfall condition, Irrigation at 50% depletion of RAM was similated, which had no effect of yield reduction. The seeding date coincides with the onset of the rainy season where depletion is low. This means that irrigation water is applied whenever the entire RAM has been depleted such that the crop will never be exposed to water stress.

As in the case of rainy season the same considerations regarding timing, application and irrigated at 50% depletion of RAM will be reused for seeding in November. Choosing this option is necessary because the period between planting date and the end of the rainy season is short even one month apart.

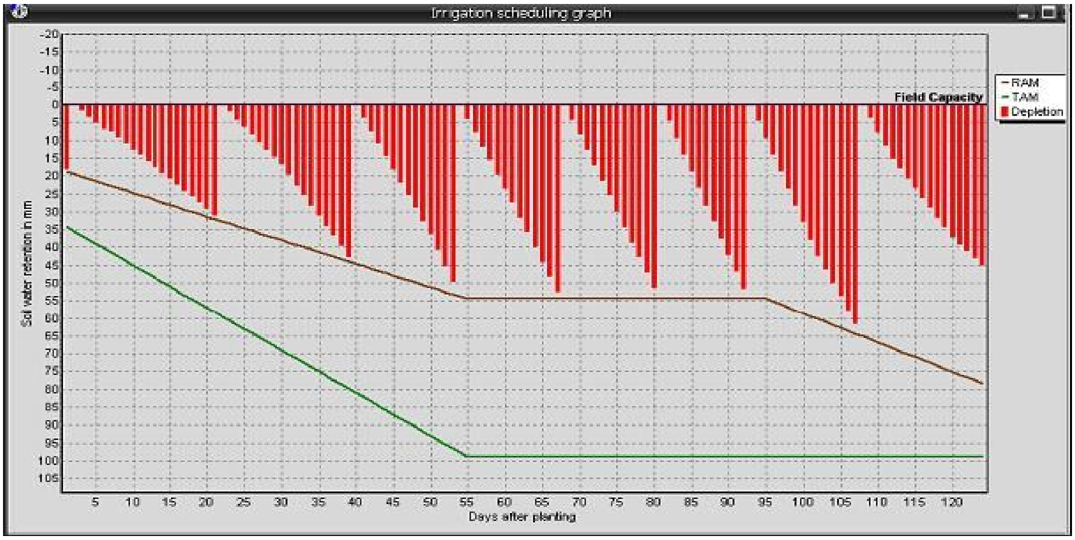
In full dry season as March, irrigated at 80% depletion of RAM will be used because the period between planting date and the end of the rainy season is long even five months apart and in this case irrigation will be needed.

Table 2: Estimation from Meteorological Station data of Nioro of CWR and Irnet for Maize in Different Season

Type of crop	Parameter	Rainy season
Maize	CWR (mm)	417,6
	Irnet (mm)	5,0

Table 3: Estimation from New_LocClim of CWR and Irnet for maize in different season

		Rainy season	Dry season	
Type of crop	Parameter		November	March
Maize	CWR (mm)	414	389,1	552,4
	Irnet (mm)	9,9	384,9	485,7



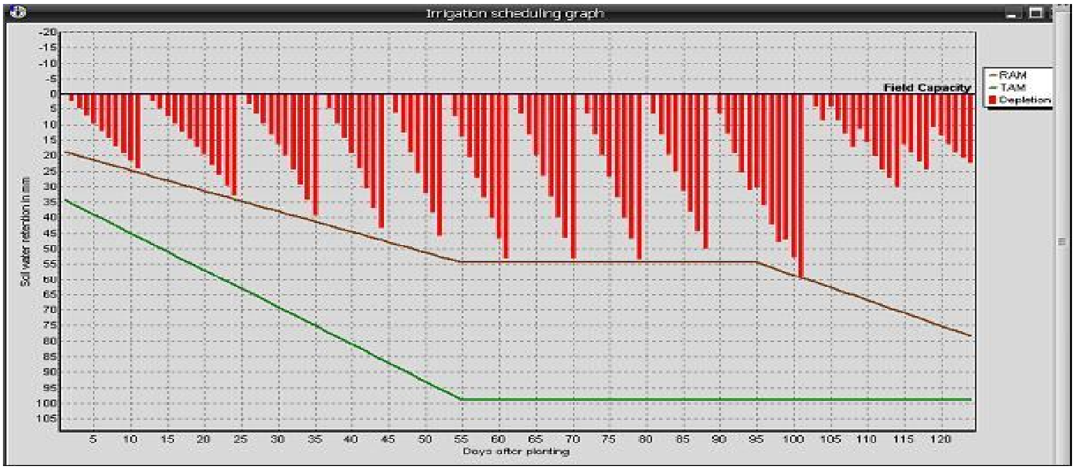


Figure 2: Maize Irrigation Scheduling Graph Obtained from the Simulated in November (Up) and March (Down)

In dry season as March, as shown in the graph (see figure 24), just during ten periods of the whole crop cycle (from 10 to 12, from 22 to 25, from 33 to 35, from 43 to 45, from 50 to 53, from 60 to 63, from 70 to 72, from 77 to 80, from 86 to 88 and 100 to 102 days after planting), due to a lower precipitations rate, the depletion bars went close to the readily available water line causing some limited water stress to the crop. In this situation, knowing the CROPWAT approximation level, yield reduction is 0,2% ; it means that this value could be affected the real yield, and the production of maize decrease. The observed water stress during the ten periods of the whole crop cycle was practically present and so, irrigation is needed for this specific situation.

3.3.2. Comparison of Irrigation Water Requirement, Yield Reduction and Cropping Intensity for Maize and Sorghum Simulated in Dry Season Condition in Nioro

In this section, the results obtained previously on irrigation water requirement, yield reduction and cropping intensity simulated in dry season will be considered as well for the maize than sorghum. The results obtained are summarized in the following tables to facilitate comparison.

Table 4- Comparison of Irrigation Water Requirement, Yield Reduction and Cropping Intensity for Maize Simulated in Dry Season

		Dry season	
Type of crop	**Parameter of comparison**	**November**	**March**
Maize	Total Gross irrigation (mm)	553.4	770.6
	Total net irrigation (mm)	387.4	539.4
	Actual water use by maize (mm)	387.2	549.8
	Potential water use by maize (mm)	387.2	550.6
	Yield reduction (%)	0.0	0.2

Looking this table, the amount of water needed by maize in March is more than the amount of water needed in November. In the same way, the irrigation water requirement (total gross irrigation and total net irrigation), cropping intensity (actual water use and potential water use) and yield reduction increase by seeding in March than seeding in November. In this condition the best choice for saving more water is to seed in November than March because water in dry area scarce and farms do not have technical to make water harvesting.

Seeding in November can save water and the yield reduction of maize equal to 0.0%; it means that this value could be neglected, and practically maize plantation still produces its maximum.

In conclusion, the best choice for seeding in dry season in Nioro area is to seed in November. Indeed, seeding in November can be beneficial for both crop as maize and sorghum. In this situation, plantation still produces its maximum and yield reduction equal 0.0%.

Chapter IV - Conclusions and Recommandations

Water represents life. All human economic activities depend on this more and more scarce natural resource. Agriculture is the sector where water represents the main production factor. Agriculture is fundamental for life since is the main source of food for the world population; at the same time, is the largest consumer of water. Almost 70% of the water withdrawn from rivers and groundwater is used for irrigation.

In a period where saving water represents a fundamental factor in order to maintain a proper level of population well being, the controlled water application in the agricultural sector plays a key part towards the growth and stabilization of agricultural productivity along the years. A sustainable water management contributes to guarantee a good and more stable quality production. Improving irrigation efficiency is very important for farmers in order to have a more correct water use and, for that reason, before thinking about irrigation as alternative water source, they have to establish if irrigation is really needed or not in their specific environmental conditions. For this purpose, a preliminary analysis is very useful.

The planning stage of an irrigation project design actually implies a survey of all factors which could influence CWR (climate, soil and crop itself). Then CWR need to be compared with available water coming from the rain (effective rainfall) and from the soil (initial soil water available). In case of a water deficit, the technician can evaluate the possibility of introducing irrigation, assessing if the water source will be able to cope with all aspects of demand. This survey is of paramount importance in order to establish if irrigation is effectively needed or not. The first three parameters that have to be considered during a so described survey are: climate, soil and crop.

If effective rainfall during the considered time period is enough to cover the entire crop cycle, soil infiltration rate and permeability are low and soil water holding capacity is high, irrigation system construction wouldn't be a necessary choice. This kind of situation is perfectly normal in the case of a tropical humid or sub-humid climate with a heavy soil, where both relative humidity and precipitation rate are high and often constant along the year. Frequently, where precipitations are high but not well distributed and therefore concentrated just in certain months of the year, farmers use to plant or transplant their crops in the period coinciding with the beginning of the rainy season. By doing so, they avoid using irrigation as alternative water source during the crop cycle, since all the amount of water they need for the proper cultivation of their crops comes from the rainfall events. That is the situation simulated and presented in this work.

The objective of the study was to assess the potential need of irrigation to achieve maximum production of maize in the ISRA Research of Nioro area, Region of Kaolack, Republic of Senegal. The first step was to create a climate database allowing a good level of statistical accuracy; for this purpose, a seven-year time period (January 2001 - December 2007) with daily data has been selected.

During the considered seven-year time period, in almost all cases, total rainfall is over **760.6 mm per year**. It means that effective rainfall (computed utilizing the USDA S.C. Method) is around **536.4 mm**.

In order to better understand the local situation, two methods as New_LocClim and meteorological station data of Nioro are using for estimating CWR and Irnet in two condition as in rainy season and in dry season. This two methods have been utilized for maize simulations in order to have the best information about water requirements in this two seasons.

In rainy season, CWR for maize was 414.0 mm and 417.6 mm obtained respectively from New_LocClim method and Meteorological station method. And his Irnet was 9.9 mm and 5 mm obtained respectively from New_LocClim method and Meteorological station method.

In rainy season condition for maize , yield reduction has been equal to 0.0%. Knowing the CROPWAT approximation level, for practical purposes those values can be neglected and both crops can be assumed to produce at their maximum.

Given that in rainfed conditions no water stress is practically observed along the entire crop cycle, we can affirm that no irrigation system is needed to be designed in such a specific climate and soil conditions.

In dry season as November for maize, his total gross irrigation was 553.4 mm, his total net irrigation was 387.4 mm and his yield reduction was 0.0% obtained from New_LocClim method.

The same approach was applied in March. The simulation for maize in March gives total gross irrigation was 770.6 mm, total net irrigation was 539.4 mm and yield reduction was 0.2%.

In this situation, knowing the CROPWAT approximation level, yield reduction simulated in March is always greater than 0,0% ; it means that this value could be affected the real yield, and the production of maize decrease. The observed water stress during these periods was practically present and so, irrigation is needed for the whole maize cycle.

The best choice for seeding in dry season in Nioro area is to seed in November. Indeed, seeding in November can be beneficial for maize. In this situation, plantation still produces its maximum and yield reduction equal 0.0%.

References

AGETIP, 1995.Programme de réhabilitation des stations ISRA. Informations pédologiques et étude cartographique des sols de la station de Nioro.

ANSD, 2009. Situation economique et sociale du Senegal en 2009

Bresci, E. 2011. Irrigation with saline water Course, Power-Point presentations. Florence, Italy.

CSE, 2009. Rapport GAA Nioro du Rip : évaluation locale de la dégradation des terres.

Falciai, M. 2011. Irrigation Principles Course, Power-Point presentations. Florence, Italy.

Falciai, M. 2011. Irrigation Methods Course, Power-Point presentations. Florence, Italy.

FAO. 1971. Water and the environment. By: M. Holý *FAO* Irrigation and Drainage Paper 8. Rome, Italy.

FAO. 1973. Man's influence on the hydrological cycle. By: UNESCO/FAO working group on the International Hydrological Decade Unesco. *FAO* Irrigation and Drainage Paper 17.Rome, Italy.

FAO. 1977. Crop Water Requirement (revised ed.) FAO Irrigation and Drainage Paper 24. Rome, Italy.

FAO. 1979. Yield Response to Water. By: J. Doorenbos and A.H. Kassam. *FAO* Irrigation and Drainage Paper 33. Rome, Italy.

FAO. 1984. Crop Water Requirements. By: J. Doorenbos and W.O. Pruitt. *FAO* Irrigation and Drainage Paper 24. Rome, Italy.

FAO. 1992. CROPWAT - A computer program for irrigation planning and management. Developed by: M. Smith. *FAO* Irrigation and Drainage Paper 46. Rome, Italy.

FAO. 1998a. Crop evapotranspiration: Guidelines for computing crop water requirements. By: R. Allen, L. Pereira, D. Raes and M. Smith. *FAO* Irrigation and Drainage Paper 56. Rome, Italy.

FAO. 2002. Crop Water Requirements and Irrigation Scheduling. Developed by: A.P. Savva and K. Frenken. *FAO* Irrigation Manual Module 4. Harare, Zimbabwe.

FAO. 2006. World reference base for soil resources 2006. By: IUSS working group. World Soil Resources Reports 103. Rome, Italy.

FAO. 2009. Aquacrop - The FAO crop model to simulate yield response to water. Developed by: D. Raes, P. Steduto, T. C. Hsiao and E. Fereres. Ag. Journal (in press).

FAO. 2009. ETo Calculator - Version 3.1. By: D. Raes. Rome, Italy.

FAO. 2010. AquaCrop - Version 3.1 Reference Manual – Chapter *2*. By: D. Raes. Rome, Italy.

Hussein. M., 2011. Applied hydrology Course, Power-Point presentations. Florence, Italy.

ICRISAT, 2008. Concepts and Techniques for Breeding Hybrid Sorghum and Pearl Millet. Proceedings of the West African Training Workshop on Hybrid Sorghum and Pearl Millet Breeding.

Nsome P.A., 1999. Régénération des sols dégradés dans le Bassin arachidier : optimisation de l'eau et des éléments nutritifs du maïs, mémoire d'ingénieur ENCR

Paul L.M. & al.1988. Production Guide for grain sorghum. www.aces.edu/pub/docs/A/ANR-0502/ ANR-0502.html

ProCR, 2003. Plan Local de Développement de la communauté rurale de Keur Madiabel.

Solinas, I. 2011. Information Technology in Irrigation and Drainage Course, Power-Point presentations. Florence, Italy.

Séne. M., & al.2001. Effet of manure and P and Ca Source fertilizer on the optimization of soil water and nutrient use in the corn/ Peanut rotation system in the Peanut Basin of Senegal.

Sertoli. P., 2010. Estimation of net irrigation requirements for maize and cotton plantations in the Piracicaba area, São Paulo (Federal Republic of Brazil), Master Thesis.

Tassinari, G. 1976. Manuale dell'agronomo - V Edizione. Ed. REDA, edizioni per l'agricoltura. Torino, Italia.