MASTER THESIS ON:

Sowing Dates as a Strategy for Water Saving in Rice (*Oryza sativa*) Production on Semi-Arid Regions: Study Case of Chókwè District, Mozambique

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To my little baby girl, Aninha

Daddy loves you more than anything

To my girlfriend, Melita,

Which I love with my all heart

To my brother, Edy and its fiancé, Rosy

Love you guys (see you in the weeding).

To my youngest brothers, Melvy and Dexter

May this thesis inspire you all to never give up studying...
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LIST OF ABBREVIATION AND ACRONYMS

- AEZ – Agro-Ecological Zones
- CAP – Agriculture and Cattle breeding Census
- CWR – Crop Water Requirements
- FAO – Food and Agriculture Organization of the United Nations
- OPV – Open Polinization Variety
- TIA – Inquiry Work of Agriculture
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ABSTRACT

This work study was for study sowing dates as one of the methods for water management in irrigation systems to reduce the yield losses in rice production in Chókwè District, Gaza Province, in Southern Mozambique.

The study was done using a model of crop growing and water balance, CROPWAT model, version 8, which simulated four varieties of rice crop (varieties ITA 312, BR IRGA 409, BR IRGA 417 and Limpopo) in an irrigated perimeter, the Eduardo Mondlane Irrigation System of Chókwè. The sowing strategy used was the variation of the sowing dates, in decades, where for all decades along the year, during 30 years, the yield was determined. The criteria of decision for choosing the best sowing period were defined in the basis of production level. For the present study, the identification of more adequate sowing period were made accordingly with the presented yield for each sowing date, where the decades which presented minor yield losses and major crop yields were selected as best sowing period. The data used was the climatic data, crop data and soil data. The results were given as percentage of yield losses.

The results of the study showed that the decades which were presented as the best sowing period to avoid major yield losses or even crop harvesting failure, in rice production, were the decades 1, 32, 33, 34, 35 and 36, such is from the second decade of November to the first decade of January, if a loss in yield up to 30% can be accepted or the decades 1 to 12 and 26 to 36, such is from the second decade of September to the third decade of April, if a loss in yield up to 50% can be accepted. The results also showed that the best variety for water saving were the variety Limpopo.

Thus, as conclusion for the present study, the best sowing period for water saving in rice production in the district of Chókwè goes from the second decade of November to the first decade of January (for yield losses up to 30%) or the from the second decade of September to the third decade of April (for yield losses up to 50%) and as Limpopo variety as the best.

The present study can be done in other regions of the country, for complementation and to get more information for the practice and development of rice production in the country. Field researches in different types of soil are necessary to confirm the results of the study and must it include socio-economic aspects.
I. INTRODUCTION

1.1. General profile

The upper limit of crop production is set by the climatic conditions and the genetic potential of the crop. The extent to which this limit can be reached will always depend on how finely the engineering aspects of water supply are in tune with the biological needs for water in crop production. Therefore, efficient use of water in crop production can only be attained when the planning, design and operation of the water supply and distribution system is geared toward meeting in quantity and time, including the periods of water shortages, the crop water needs required for optimum growth and high yields FAO (1994).

Water is the main cause of yield fluctuation for all crops, because of its bad distribution through space and time, due to scarcity or excess. That’s why all farmers’ interventions are linked directly or indirectly to the behavior of water in the soil and atmosphere (Éliard, 1995).

Rainfall is the main climatic factor that frequently restricts the crop growth, because the distribution along the year and from year to year it’s not equal. This behavior has more impact in the sub-tropical or semi-arid climate countries like Mozambique.

Cereals constitute the base for human alimentation, contributing with around half of energetic proteins and ingestion for the human being (Young and Pellet, 1994, cited by Naves et al, 2004). Naves et al (2004) go further saying that in Brazil, rice is the most consumed cereal, generally, in the mixed form with beans.

In fact, this is the reality in most of development countries such as Mozambique, where rice is the daily diet of almost all of the population, all across the country, and more than 95% of the population living in the cities. The site AllAfrica.com (2010), publish that currently, Mozambique consumes around 600 thousand tons of rice a year. Domestic rice production only covers 285 thousand tons, while the remaining 315 thousand tons are imported. The district of Chókwè, in Gaza province, southern Mozambique, produced in 2008-2009 agricultural season, 22 thousand tons of rice, according to MocMagazine site (2009).
The use of models plant-soil-water, according to Schouwenaars (1990), could help to analyze sowing strategies in semi-arid regions, such as southern Mozambique. By this way, the present study will contribute to adopt crop water use strategies to help to reduce major yield losses in rice cultivation.

1.2. Problem and justification

Agriculture is the basis for the subsistence of the rural families in Mozambique. But it depends of the water coming from rainfall, which causes yield reduction of the crops and, most of the time, it gets worst when it comes without technical support on crop production.

In Mozambique, the practice of rainfed agriculture is a risky activity, because of the wandering and irregularity of the rain, which causes the lower yields. So a good strategy for maximizing the use of available water is necessary.

Alonço et al. (2005), says that rice is cultivated and consumed in all the continents around the world and is one of the most important grain crops, in terms of the economic value. Rice is the food with the best nutritional balance and, because it’s an extremely versatile crop, which can adapt to different conditions of soil and climate, it's considered the species which presents the major potential to fight the hunger in the world.

Rice is considered the food crop of major importance in many development countries such as Mozambique. The site MocMagazine (2009), posted that the region where the country is inserted (southern Africa) imports more than 800 thousand tons of rice every year. Besides that, Mozambique and Tanzania (and a small part of Madagascar) are the only countries in the region which have the possibility to produce rice, but Mozambique have a large advantage than the other ones because of the country’s border with the major importer and market for rice consumption country, that is South Africa. The other countries in the region that imports big quantities of rice are Zimbabwe, Malawi, Zambia and Swaziland and all of them have borders with Mozambique.

According to MocMagazine site (2009), António Mutombeni, interviewed farmer in the Chókwè irrigation system, Eduardo Mondlane Irrigation System, the region was once called “nation barn”, meaning that that region was once able to feed the all
country, especially with the rice production. The same site continues saying that, Mozambique as at least one million hectares of hydrologic soils, which are suitable for rice cultivation only.

Thus, given the great importance of the rice crop, from the both economic and nutritional point of view, the necessity of increasing its cultivation area and/or yields to answer to the market demand and reduce the import of this precious grain, the present study will contribute for the identification of the best sowing period.

1.3. Objectives

1.3.1. General

- Identify the best sowing period to save water in rice (Oryza sativa) cultivation, in Chókwè district.

1.3.2. Specifics

- Determine the crop water requirements for different sowing dates, for four different varieties of rice in Chókwè district;

- Simulate actual yields for four varieties of rice, basing in the water deficit, for different sowing dates in Chókwè district;

- Identify the sowing dates more adequate, according with the expected yields.
II. SITE DESCRIPTION

2.1. General characterization of Chókwè

According to Ferro (2005), the district of Chókwè\(^1\) is located in the west in southern Mozambique\(^2\), precisely in southwest of Gaza province, between the geographic coordinates 24°05’ and 24°48’ latitude south and 32°31’ and 33°35’ longitude east. With an area of approximately 2435 km\(^2\), the district is limited at north by the Limpopo river. This river separates the district with Mabalane and Gujá districts. In the south, the limits are Bilene district and Mazichopes river, which separates the Chókwè district with Magude district, Maputo province. In the east it’s limited by Chibuto district and a small part of Xai-Xai district. In west, Massingir and Magude districts.

The district is divided in four administrative posts: Macarretane, Lionde, Chókwè city and Xilembene, eight localities and thirty six villages (Ferro, 2005).

The main social-economic activity in the district is agriculture and cattle. The greater irrigated perimeter of the country is located in the district, with an area of 26 thousand hectares, in which more than half is apt to rice cultivation and around 5% is now inapt for agriculture because of soil salinization problems. Although 90% of the area is irrigated by gravity, the structures in the system are in higher state of degradation (FAEF, 2001). The recuperation of the system is being done gradually, year after year, and in the year 2010 it reached at seven thousand hectares in good conditions for rice production, only.

2.2. Climatic characterization of Chókwè

Mozambique lies largely within the tropics, and much of the coastline is subject to the regular seasonal influence of the Indian Ocean monsoon rains. The monsoon influence is strongest but is modified somewhat by the island barriers of Madagascar, the Comoros, and the Seychelles.

According to FAEF (2001), the climate of the Chókwè district is semi-arid and dry, characterized by high pluviometric variations along the year and from year to year, that

\(^1\) See illustration A2 in appendix 1.2.

\(^2\) See illustration A1 in appendix 1.1.
makes the rainfed agriculture of high risk. The annual precipitation is 620 mm, essentially from November to March and the annual reference average evapotranspiration is 1500 mm. The pluviometric regime allows only one growing season with around 90 days, giving the region the status of high harvest loss for rainfed agriculture crops. According with Intersectorial Group for Evaluation of Vulnerability and Mapping, cited by FAEF (2001), the probability of drought in this areas is more than 30%. The probability of harvest loss in the region is more than 50% (Reddy, 1986). The average annual temperature is 23.6°C and the risk of an frost event is none, even in the cold season.

Daily temperatures throughout the country average in the mid-to upper 20°C, with the highest temperatures occurring between October and February and the lowest in June and July. Humidity varies widely throughout the country. The semi-arid southern regions receive only about 75 mm of precipitation per month in the wet season, from November to February, and almost none in the dry season, between April and October (Britannica Encyclopedia Online, 2011). Cyclones are also common during the wet season in the coastal area, in the southern and center region of the country.

2.3. Soil characterization of Chókwè

Mozambique is a coastal country, crossed by many rivers running to the Indian Ocean. Beach ridge complexes, beach plains and coral reefs extended along the coast. The swales between the beach ridges are generally swampy (Brito et al., 1998, cited by Azevedo, 2004).

According to Britannica Encyclopedia Online (2011), Mozambique’s soils3 are diverse in quality and type, but the northern and central provinces have generally more fertile, water-retentive soils than does the south, where sandy, infertile soils prevail.

South of Beira, fertility is largely limited to alluvial soils in the valleys of Save, Limpopo, Incomáti, Umbeluzi, and Maputo rivers, although several pockets of fertile but heavy soil occur southwest of Inhambane.

According to FAEF (2001), in Chókwè, the distribution of the main types of soil is strongly influenced by the geomorphology of the district area. Gomes et al. (1998) and

3 See illustration A3 in appendix 1.3.
INIA DT (1995), both cited by FAEF (2001), the district soils can be grouped in the following way (see appendix 1.3.):

- Soils of the internal sand-hill;
- Soils of the marine sediments from Pleistocene in highlands;
- Soils of the marine sediments from the Pleistocene in depressions or basins;
- Soils of the recent fluvial sediments which were developed over the recent sediments from the Limpopo River, in between the river’s winding.

It’s important to say that, the different types of soil can occur in the form of complex or association of one or more types of soils described above.

Azevedo (2004) says that, according to Mona (1985) and Shrier (1985), referring to Coutinho (1949), the organic (peat) soils called machongos⁴ are generally fertile and have a very good soil structure for plant growth. These kinds of soils are common in the south, where semi-arid climatic conditions predominate.

According with Vilanculos (2005), the district of Chókwè have, generally speaking, mainly heavy and clayey soils.

2.4. Agriculture and production systems

In Mozambique, most of agricultural production comes from family farming operations, which produce the two staple crops of corn (maize) and cassava, as well as beans, rice, and a variety of vegetables and oilseeds such as peanuts (groundnuts), sesame, and sunflowers. Family labour is also responsible for gathering a large part of cashew nut crop and produces cotton for the local market and for export.

According with Sitoe (2005), based on CAP (2000) and TIA (2002), in the rural zones, the familiar agriculture is basically constituted by small exploitations, with less than 5 ha. This sector concentrates around 99% of agricultural units and extends to more than 95% of the cultivated area in the country.

⁴ Machongos are soils which, because of their origin and formation, particularly, the drainage can’t be made in the classic way. Drainage in this kind of soils it’s watertable control, and not water removal, because, once the draining process starts, the processes of subsidence and oxidation are shown guiding to the mineralization of the organic material (Munguambe & Brito, 1998).
Chókwè is basically an agricultural district, with an area of around 80 thousand hectares, which are exploited by two types of agriculture, irrigated and rainfed (Ferro, 2005).

Sitoe (2005) says that, nevertheless the importance in production of food crops in every region of Mozambique, some differences in crop type’s production exist. That can be explained with the agro-ecological and socio-cultural differences along the country. The proportion of families which produce maize and cassava is dominant in all regions, while sweet potato is important in the center and south of the country. In the south, peanut is also an important crop. The use of cattle for plowing it’s concentrated in the south.

In Chókwè district, the rainfed agriculture is characterized by crop mixing with emphasis to maize, peanut and cassava, in the hot season, and maize, nhemba bean or beans and cassava, in the fresh season. In this kind of agriculture, farmers practically don’t use inputs like chemical fertilizers and pesticides and consequently the yields are, in generally, too low (FAEF, 2001).

Irrigation in Mozambique occurs particularly in the former settler areas in the south, particularly along the Limpopo River, that are irrigated by schemes developed in the 1950s and 60s. The south is the region with the major irrigation area (28% of the exploitations).

Inside the Chókwè irrigated perimeter, farmers are classified, according to FAEF (2001), in three categories, referring to the exploited area:

- Small farmers, with an area between 0.25 and 3 ha;
- Medium farmers, with an area between 3 and 20 ha;
- Big farmers, with an area major than 20 ha.

The small farmers use fewer inputs than medium and big farmers, make consociation of crops and the production activities are more oriented to subsistence than to commercial ends.

The medium and big farmers use almost the same kind of agriculture. They do almost all of the recommended crop field operations, use higher level of inputs and
labor. The production is oriented to commercial ends. They cultivate mostly two crops: rice, in hot season, cultivated in monocrop, and tomato, in fresh season. Besides this two crops, they produce, with some consideration, maize, beans, french beans, onions and cabbage, in rotation.
III. LITERATURE REVIEW

3.1. Yield and water deficit relations

Before implementing a deficit irrigation programme, it is necessary to know crop yield responses to water stress, either during defined growth stages or throughout the whole season (Kirda and Kanber, 1999, cited by Kirda, 2002). This means that yield and water deficit is related.

According to Kirda (2002), agronomic measures such as varying tillage practices, mulching and anti-transpirants can reduce the demand for irrigation water. Another option is deficit irrigation, with plants exposed to certain levels of water stress during either a particular growth period or throughout the whole growth season, without significant reduction in yields.

High-yielding varieties (HYVs) are more sensitive to water stress than low-yielding varieties; for example, deficit irrigation had a more adverse effect on the yields of new maize varieties than on those of traditional varieties (FAO, 1979, cited by Kirda, 2002). Crops or crop varieties that are most suitable for deficit irrigation are those with a short growing season and are tolerant of drought (Stewart and Musick, 1982, cited by Kirda, 2002).

In order to ensure successful deficit irrigation, it is necessary to consider the water retention capacity of the soil. In sandy soils plants may undergo water stress quickly under deficit irrigation, whereas plants in deep soils of fine texture may have ample time to adjust to low soil water matric pressure, and may remain unaffected by low soil water content. Therefore, success with deficit irrigation is more probable in finely textured soils (Kirda 2002).

Under deficit irrigation practices, agronomic practices may require modification, e.g. decrease plant population, apply less fertilizer, adopt flexible planting dates, and select shorter-season varieties (Kirda 2002).

According to FAO (1994), the relationships encountered between crop, climate, water and soil are complex and many biological, physiological, physical and chemical processes are involved. A great deal of research information on these processes in relation to water is available; however, for practical application this knowledge must be
reduced to a manageable number of major components to allow a meaningful analysis of crop response to water at the field level.

The calculation of reference evapotranspiration ($ET_o$) is based on the FAO Penman-Monteith method (FAO, 1998, cited by Smith & Kivumbi, 2002). Input data include monthly and ten-daily for temperature (maximum and minimum), humidity, sunshine, and wind-speed. Crop water requirements ($ET_c$) over the growing season are determined from $ET_o$ and estimates of crop evaporation rates, expressed as crop coefficients ($K_c$), based on well-established procedures (FAO, 1977, cited by Smith & Kivumbi, 2002), according to the following equation:

$$ET_c = K_c \times ET_o$$  \(1\)

According to Smith & Kivumbi (2002), FAO (1998) has presented updated values for crop coefficients. Through estimates of effective rainfall, crop irrigation requirements are calculated assuming optimal water supply. Inputs on the cropping pattern will allow estimates of scheme irrigation requirements.

Figure 1 presents the rate of reduced crop evapotranspiration, $ET_a/ET_c$, as estimated according to soil moisture depletion (FAO, 1992).

**Figure 1:** Crop evaporation rate under soil moisture stress
For application in planning, design and operation of irrigation schemes, it is possible to analyse the effect of water supply on crop yields. The relationship between crop yield and water supply can be determined when crop water requirements and crop water deficits, on the one hand, and maximum and actual crop yield on the other can be quantified. Water deficits in crops, and the resulting water stress on the plant, have an effect on crop evapotranspiration and crop yield. Water stress in the plant can be quantified by the rate of actual evapotranspiration (ETa) in relation to the rate of maximum evapotranspiration (ETm). When crop water requirements are fully met from available water supply then ETa = ETm; when water supply is insufficient, ETa < ETm. For most crops and climates ETm and ETa can be quantified (Kassam & Doorembos, 1994).

According to Kassam & Doorembos (1994), in order to quantify the effect of water stress it is necessary to derive the relationship between relative yield decrease and relative evapotranspiration deficit given by the empirically-derived yield response factor (Ky), or:

\[
1 - \frac{Y_a}{Y_m}, 1 - \frac{ET_a}{ET_m}
\]

where:

\(Y_a\) = actual harvested yield

\(Y_m\) = maximum harvested yield

\(K_y\) = yield response factor

\(ET_a\) = actual evapotranspiration

\(ET_m\) = maximum evapotranspiration

\(1 - Y_a/Y_m\) = the fractional yield reduction as a result of the decrease in evaporation rate

\(1 - ET_a/ET_m\)

The value of \(K_y\) for different crops is based on the evaluation of numerous research results, given in the bibliography, which cover a wide range of growing conditions.
Extensive use has also been made of related known yield responses to soil salinity, depth of groundwater table and crop management practices. Based on experimental evidence, the relationship is given for the total growing period and the individual growth periods of the crops. Other than for different crops and crop growth periods, attempts to separate crop response to water according to climate, magnitude of maximum evapotranspiration and soil did not add to the accuracy obtainable (Kassam & Doorembos, 1994).

Kassam & Doorembos (1994), say that since the relationship is also affected by factors other than water, such as crop variety, fertilizer, salinity, pests and diseases, and agronomic practices, the relationships presented refer to high producing varieties, well-adapted to the growing environment, growing in large fields where optimum agronomic and irrigation practices, including adequate input supply, except for water, are provided.

According to Kassam & Doorembos (1994), with the presented relationships it is possible to plan, design and operate irrigation supply systems taking into account the effect of different water regimes on crop production.

3.2. The rice crop

3.2.1. Generalities

The cultivated rice plant, *Oryza sativa* (see appendix 1.3), is an annual grass of the Graminae family. The leaves are long and flattened, and its panicle, or inflorescence is made up of spikelets bearing flowers that produce the fruit, or grain (Britannica Encyclopedia online, 2011).

According with the site Wikipedia.org (2011), rice is the seed of the monocot plants. As a cereal grain, it is the most important staple food for a large part of the world's human population, especially in East and South Asia, the Middle East, Latin America, and the West Indies. It is the grain with the second-highest worldwide production, after maize (corn).

Since a large portion of maize crops are grown for purposes other than human consumption, rice is the most important grain with regard to human nutrition and caloric intake, providing more than one fifth of the calories consumed worldwide by the human species.
A traditional food plant in Africa, its cultivation declined in colonial times, but its production has the potential to improve nutrition, boost food security, foster rural development and support sustainable landcare.

Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial and can produce a ratoon crop for up to 30 years. The rice plant can grow up to 1 to 1.8 m tall, occasionally more depending on the variety and soil fertility. It has long, slender leaves 50 to 100 cm long and 2 to 2.5 cm broad. The small wind-pollinated flowers are produced in a branched arching to pendulous inflorescence 30 to 50 cm long. The edible seed is a grain (caryopsis) 5 to 12 mm long and 2 to 3 mm thick.

3.2.2. **Rice cultivation**

With the exception of the type called upland rice, the plant is grown on submerged land in the coastal plains, tidal deltas, and river basins of tropical, semitropical, and temperate regions. The seeds are sown in prepared beds, and when the seedlings are 25 to 50 days old, they are transplanted to a field, or paddy that has been enclosed by levees and submerged under 5 to 10 cm of water, remaining submerged during the growing season (Britannica Encyclopedia online, 2011).

Rice cultivation is well-suited to countries and regions with low labor costs and high rainfall, as it is labor-intensive to cultivate and requires ample water. Rice can be grown practically anywhere, even on a steep hill or mountain. Although its parent species are native to South Asia and certain parts of Africa, centuries of trade and exportation have made it commonplace in many cultures worldwide (Wikipedia, 2011).

According to the site Wikipedia.org (2011), the traditional method for cultivating rice is flooding the fields while, or after, setting the young seedlings. This simple method requires sound planning and servicing of the water damming and channeling, but reduces the growth of less robust weed and pest plants that have no submerged growth state, and deters vermin. While flooding is not mandatory for the cultivation of rice, all other methods of irrigation require higher effort in weed and pest control during growth periods and a different approach for fertilizing the soil.
3.2.3. Rice production


Unmilled rice, known as paddy, is usually harvested when the grains have a moisture content of around 25%. In most Asian countries, where rice is almost entirely the product of smallholder agriculture, harvesting is carried out manually, although there is a growing interest in mechanical harvesting. Harvesting can be carried out by the farmers themselves, but is also frequently done by seasonal labour groups. Harvesting is followed by threshing, either immediately or within a day or two. Again, much threshing is still carried out by hand but there is an increasing use of mechanical threshers. Subsequently, paddy needs to be dried to bring down the moisture content to no more than 20% for milling. A familiar sight in several Asian countries is paddy laid out to dry along roads. However, in most countries the bulk of drying of marketed paddy takes place in mills, with village-level drying being used for paddy to be consumed by farm families. Mills either sun dry or use mechanical driers or both. Drying has to be carried out quickly to avoid the formation of moulds. Mills range from simple hullers, with a throughput of a couple of tons a day, that simply remove the outer husk, to enormous operations that can process 4,000 tons a day and produce highly polished rice. A good mill can achieve a paddy-to-rice conversion rate of up to 72% but smaller, inefficient mills often struggle to achieve 60%. These smaller mills often do not buy paddy and sell rice but only service farmers who want to mill their paddy for their own consumption.

3.2.4. Rice pests and diseases

According to Jahn et al. (2007), rice pests include weeds, pathogens, insects, rodents, and birds. A variety of factors can contribute to pest outbreaks, including the overuse of pesticides and high rates of nitrogen fertilizer application. Weather conditions also contribute to pest outbreaks. For example, rice gall midge and army worm outbreaks tend to follow periods of high rainfall early in the wet season, while thrips outbreaks are associated with drought.
Major rice pests include the brown planthopper, the rice gall midge, the rice bug, the rice leafroller, rice weevils, stemborer, panicle rice mite, rats, and the weed Echinochloa crusgali (Jahn et al., 2007).

Major rice diseases include Rice ragged stunt, Sheath Blight and tungro. Rice blast, caused by the fungus Magnaporthe grisea, is the most significant disease affecting rice cultivation. There is also an ascomycete fungus, Cochliobolus miyabeanus, that causes brown spot disease in rice (IRRI, 2011).

Rice is parasitized by the weed eudicot Striga hermonthica. This parasitic weed is a devastating pest on the crop.

3.2.5. Rice varieties

While most rice is bred for crop quality and productivity, there are varieties selected for characteristics such as texture, smell, and firmness. Cultivars exist that are adapted to deep flooding, and these are generally called "floating rice" (cigar.org, 2011).

There are four major categories of rice worldwide: Indica, japonica, aromatic and glutinous. The different varieties of rice are not considered interchangeable, either in food preparation or agriculture, so as a result, each major variety is a completely separate market from other varieties. It is common for one variety of rice to rise in price while another one drops in price (Childs & Burdett, 2000).

For the purpose of the present study, four varieties of rice will be described, that is: ITA 312, BR IRGA 417, BR IRGA 409 and Limpopo (refer to tables 1 and 2 for specifications). This are the rice variety seeds that are produced and supplied by Mozfoods S.A. (see Mozfoods site in the sites list, in the bibliography), a Mozambican company that invests actively in the agricultural production in Mozambique, since 2004 with the objective of growing, supplying and trading agricultural goods. Farmers all over the country are using these varieties, among others traditional from Mozambique, India, China, Pakistan and Vietnam.
Sowing dates as a strategy for water saving in rice (Oryza sativa) production on semi-arid regions: study case of Chókwè district, Mozambique

<table>
<thead>
<tr>
<th>Rice Variety</th>
<th>Type of seed</th>
<th>Seeding density (kg/ha)</th>
<th>Yield (tons/ha)</th>
<th>Sowing schedule</th>
<th>Maturation</th>
<th>Pest resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITA 312</td>
<td>OPV</td>
<td>120</td>
<td>7</td>
<td>From September 15 to the end of December</td>
<td>130</td>
<td>Resistant</td>
</tr>
<tr>
<td>IRGA 417</td>
<td>OPV</td>
<td>120</td>
<td>6</td>
<td>From October to December</td>
<td>115</td>
<td>Resistant</td>
</tr>
<tr>
<td>IRGA 409</td>
<td>OPV</td>
<td>120</td>
<td>6</td>
<td>From October to December</td>
<td>126</td>
<td>Resistant</td>
</tr>
<tr>
<td>Limpopo</td>
<td>OPV</td>
<td>120</td>
<td>6</td>
<td>From September 15 to the end of December</td>
<td>104</td>
<td>Resistant</td>
</tr>
</tbody>
</table>

Table 1: Technical specifications of rice varieties

Source: Mozfoods product brochure in Mozfoods site
**Table 2:** Technical specifications of rice varieties

<table>
<thead>
<tr>
<th>Rice Variety</th>
<th>Irrigation type</th>
<th>Plant high (cm)</th>
<th>Drying rate (%)</th>
<th>Soils</th>
<th>Seeding mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITA 312</td>
<td>Flooding</td>
<td>78</td>
<td>13</td>
<td>Heavy or clay</td>
<td>Direct seeding (with lines of 0.2 m); Transplantation; and Throw (seeding density of 200 Kg/ha).</td>
</tr>
<tr>
<td>IRGA 417</td>
<td>Flooding</td>
<td>67</td>
<td>13</td>
<td>Heavy or clay</td>
<td>Direct seeding (with lines of 0.2 m); Transplantation; and Throw (seeding density of 200 Kg/ha).</td>
</tr>
<tr>
<td>IRGA 409</td>
<td>Flooding</td>
<td>74</td>
<td>13</td>
<td>Heavy or clay</td>
<td>Direct seeding (with lines of 0.2 m); Transplantation; and Throw (seeding density of 200 Kg/ha).</td>
</tr>
<tr>
<td>Limpopo</td>
<td>Flooding</td>
<td>66</td>
<td>13</td>
<td>Heavy or clay</td>
<td>Direct seeding (with lines of 0.2 m); Transplantation; and Throw (seeding density of 200 Kg/ha).</td>
</tr>
</tbody>
</table>

*Source:* Mozfoods product brochure in Mozfoods site

**ITA 312**

This variety is a mid-cycle variety, requiring 135 days until maturity. The plant is a medium growth with panicles protected by leaves. It is very resistant to most diseases and to leaning over. The grain is long, thin with high percentage of chalkiness. Note that this variety is very well adapted to Mozambique and to low fertilizer regimes.
BR IRGA 417

This variety originates in Brazil. The grain is a very high quality translucent grain, long and thin. It is a high yielding variety. The seeds should be sown under high seed density regime and transplantation should occur at maximum distance of 10 cm between plants. The production cycle is 120 to 123 days and loses grain with some relative easiness.

BR IRGA 409

This variety is similar to BR IRGA 417, but it is taller and with tendency to fall down. It affiliates more than BR IRGA 417, and so the seeding density should be less, with a distance of transplant of around 15 cm. It is a high yield variety with a good grain quality.

Limpopo

It is a selected Mozambican variety. It is an early variety, with the maturity cycle of 120 days. It provides good yields in dry conditions, in the northern highlands, such as in the provinces of Nampula and Cabo Delgado. This variety is also well adapted in the central provinces, such as Zambézia and Sofala, and further southern provinces, through flooding irrigation. The productivity is lower than ITA 312 variety, however, the grain quality is superior. The grains aren’t totally smooth, providing greater defense against bird attacks.

3.3. The CROPWAT model

According to Smith & Kivumbi (2002), CROPWAT is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO (FAO, 1992). Its basic functions include the calculation of reference evapotranspiration, crop water requirements, and crop and scheme irrigation. Through a daily water balance, the user can simulate various water supply conditions and estimate yield reductions and irrigation and rainfall efficiencies. Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, the evaluation of irrigation practices, as well as rainfed production and drought effects. Calculations and outputs are based on the CROPWAT version 8.0, available at the FAO Web site (link: http://www.fao.org/nr/water/ infores_databases_cropwat.html).
According to Sandhu (2003), CROPWAT is meant as a practical tool to help agrometeorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation.

3.3.1. Data used by the CROPWAT model

According to Smith & Kivumbi (2002), calculations of water and irrigation requirements utilize inputs of climatic, crop and soil data, as well as irrigation and rain data. The climatic input data required are reference evapotranspiration (monthly/decade) and rainfall (monthly/decade/daily). Reference evapotranspiration can be calculated from actual temperature, humidity, sunshine/radiation and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998, cited by Smith & Kivumbi, 2002). The CLIMWAT-database provides monthly climatic data for CROPWAT on 144 countries (FAO, 1993, cited by Smith & Kivumbi, 2002).

The crop parameters used for the estimation of the crop evapotranspiration, waterbalance calculations, and yield reductions due to stress include: $K_c$, length of the growing season, critical depletion level $p$, and yield response factor $K_Y$. The program includes standard data for main crops and it is possible to adjust them to meet actual conditions (Smith & Kivumbi, 2002).

Smith & Kivumbi (2002), say that the soil data include information on total available soil water content and the maximum infiltration rate for runoff estimates. In addition, the initial soil water content at the start of the season is needed.

The impact on yield of various levels of water supply is simulated by setting the dates and the application depths of the water from rain or irrigation. Through the soil moisture content and evapotranspiration rates, the soil water balance is determined on a daily basis. Output tables enable the assessment of the effects on yield reduction, for the various growth stages and efficiencies in water supply (Smith & Kivumbi, 2002).
3.3.2. **CROPWAT limitations**

According to Boleta *et al* (2005), the CROPWAT model have limitations to be used in real time, because it uses monthly values of precipitation and ET$_0$, though is a good tool for planning and further control.

Sandhu (2003) says that the CROPWAT model, when it comes to choose proceedings to simulate simultaneous processes at same time, its limited.

3.3.3. **CLIMWAT 2.0 for CROPWAT model**

According to FAO site, CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT and allows the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide.

CLIMWAT 2.0 for CROPWAT is a joint publication of the Water Development and Management Unit and the Climate Change and Bioenergy Unit of FAO. It offers observed agro climatic data of over 5000 stations worldwide and provides long-term monthly mean values of seven climatic parameters, namely:

- Mean daily maximum temperature in °C;
- Mean daily minimum temperature in °C;
- Mean relative humidity in %;
- Mean wind speed in km/day;
- Mean sunshine hours per day;
- Mean solar radiation in MJ/m$^2$/day;
- Monthly rainfall in mm/month;
- Monthly effective rainfall in mm/month;
- Reference evapotranspiration calculated with the Penman-Monteith method in mm/day.

The data can be extracted for a single or multiple stations in the format suitable for their use in CROPWAT. Two files are created for each selected station. The first file contains long-term monthly rainfall data (in mm/month). Additionally, effective rainfall is also included calculated and included in the same file. The second file consists of
long-term monthly averages for the seven climatic parameters, mentioned above. This file also contains the coordinates and altitude of the location.

In compiling the data, an effort was made to cover the period 1971 - 2000, but when data for this period were not available, any recent series that ends after 1975 and that has at least 15 years of data have been included.
IV. METHODOLOGY

4.1. Input data

The methodology used for this section was adapted from Sandhu (2003).

The following table lists the input data required for CWR and irrigation scheduling calculations:

<table>
<thead>
<tr>
<th>Data Item</th>
<th>CWR</th>
<th>Irrigation scheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>$\text{ET}_0$</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>Crop data</td>
<td>Optional</td>
<td>Optional</td>
</tr>
<tr>
<td>Cropping pattern</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Soil data</td>
<td>Not required</td>
<td>Required</td>
</tr>
<tr>
<td>Scheduling criteria</td>
<td>Not required</td>
<td>Required</td>
</tr>
</tbody>
</table>

Table 3: CROPWAT input data requirements

Source: Sandhu (2003)

4.1.1. Crop water requirements (CWR) calculation and water deficit

To calculate CWR, measured values of the reference evapotranspiration ($\text{ET}_0$) can be directly entered. In this case, any other climatic data can be omitted. If however, no measured values of reference evapotranspiration exist, then CROPWAT calculates it from the climate data using the revised FAO Penman-Monteith equation.

The data used for this study case were temperature (maximum and minimum), humidity, radiation and wind velocity (monthly means). CWR (or $\text{ET}_c$) were determined for the whole growing season from the $\text{ET}_0$ and the crop evapotranspiration rate, expressed in crop coefficients ($K_c$), based in well established procedures, according to the equation (1).
The values of crop coefficient (Kc) are tabled in FAO (1998). For this study this values are presented in the appendix 2.1. (tables A1, A2, A3 and A4), for the different rice varieties.

The necessary data for the calculation of CWR were:

1. Monthly ET0 values;
2. Crop and sowing dates;
3. Monthly precipitation data.

The water deficit is directly presented as percentage after the equation (2) resumed in the table form.

4.1.2. Climate data

The climate data used for this study were acquired in the FAO database in FAO CLIMWAT 2.0 for CROPWAT for the district of Chókwè climatic station, as monthly pre-calculated means (see table A5 in the Appendix 2.2.).

The calculations for the ET0 were based on the Penman-Monteith method.

4.1.3. Rainfall data

According to Clarke (1998), In CROPWAT model, the precipitation is divided in number of rains per day in each month. The precipitation data used for the present study were acquired in the FAO database in FAO CLIMWAT 2.0 for CROPWAT from the district of Chókwè climatic station and divided in decades, totalizing 36 decades per year (see table A6 in Appendix 2.3.).

The formula used for the calculation of effective precipitation was the USDA soil conservation service formula, inside of the CROPWAT model.

4.1.4. Cropping pattern

A cropping pattern is necessary, because CROPWAT version 4.3 calculates the CWR for each crop planted as a function of the total area available (%) upon which the crop is grown for that period as:

\[
CWR = ET_0 \times K_c \times \text{Area Planted} \quad (3)
\]

The following cropping pattern was entered for all simulations:
Percentage of total area planted to crop | 100% (because only one crop was planted throughout the year on one specific plot of land)

**Table 4:** Cropping pattern

**Source:** Adapted from Sandhu (2003) cropping pattern table

4.1.5. **Soil data**

According to Sandhu (2003), CROPWAT requires soil data to calculate the following:

*Total available moisture (TAM)*

As the water content above field capacity cannot be held against the forces of gravity and will drain, and as plant roots cannot extract the water content below wilting point, the total available water in the root zone is the difference between the water content at field capacity and wilting point (FAO Irrigation and Drainage Paper No.56, 1998, cited by Sandhu, 2003). Total available soil water (TAW in mm/m) in the root zone, equal to TAM (mm/m) in this case.

TAM is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth. CROPWAT only accepts a maximum value of 300 mm/m (see table A7 in Appendix 2.4. for soil data).

4.1.6. **Scheduling criteria**

Before any irrigation requirements can be carried out a scheduling criteria must be defined. The table below lists the scheduling criteria used for simulating the current scenario:
Sowing dates as a strategy for water saving in rice (Oryza sativa) production on semi-arid regions: study case of Chókwè district, Mozambique

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Calculation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Evapotranspiration ($ET_0$) as per Penman-Monteith</td>
<td>$ET_0$ distribution model: fit curve to monthly averages</td>
</tr>
<tr>
<td></td>
<td>Angstrom’s coefficients (default values from CROPWAT):</td>
</tr>
<tr>
<td></td>
<td>$a = 0.25$</td>
</tr>
<tr>
<td></td>
<td>$b = 0.50$</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Rainfall distribution model: fit a curve to monthly averages</td>
</tr>
<tr>
<td></td>
<td>Aggregate interpolated daily rainfall into individual storms every 5 days (default value in CROPWAT)</td>
</tr>
<tr>
<td>Effective rain</td>
<td>Effective rainfall calculation method: USDA soil conservation method (CROPWAT model)</td>
</tr>
<tr>
<td>Scheduling criteria</td>
<td>Application timing: no irrigation</td>
</tr>
<tr>
<td></td>
<td>Application depths: refill to a specified % of RAM (100%)</td>
</tr>
<tr>
<td></td>
<td>Start of scheduling: various planting dates (decades) of each rice variety</td>
</tr>
</tbody>
</table>

Table 5: Scheduling criteria input data

Source: Adapted from Sandhu (2003)

4.2. Determination of actual yields ($Y_a$)

The effect of water stress was quantified relating the relative yield losses with the relative evapotranspiration directly through the yield response coefficient ($K_y$) derived empirically from the equation (2), in the CROPWAT model.

4.3. Identification of most adequate sowing dates

The identification of the most adequate sowing dates was done accordingly with the presented yields for each planting day. The sowing decade which presented the lower yield loss was the best sowing decade.
V. RESULTS AND DISCUSSION

5.1. Rice crop water requirements (CWR)

The following graph (figure 2) presents the values of CWR for rice crop varieties according to the planting decade. The original data is tabled in the Appendix 3.1., table A8, and it was obtained through CWR calculations in the CROPWAT model.

![Crop water requirements according to sowing decades for the rice varieties](image)

Figure 2: CWR variation according to the sowing decades for the rice varieties

From this graph it is possible to see that the highest value for the CWR for rice is from the month of January to middle April and from July to December, leaving the lowest values in between the decades 11 and 18, in the months April, May and June with the bottom values in the decades 13 to 15 in the month of May. This is because of the ET\(_0\) values which are also lower in these months because, in these months of the year, the climate is fresh in Mozambique.

In the graph above is also possible to make a comparison between the rice varieties CWR values. It can be seeing that the variety Limpopo has the lowest CWR value for the same decade of the year, in comparison with the other three varieties. The variety ITA 312 presents the highest values for CWR. This difference of CWR values is due the differences of the maturation cycle (see table 1 in section 3.2.5.), which are lowest for
the variety Limpopo (104 days), followed by IRGA 417 (115 days), IRGA 409 (126 days) and ITA 312 (130 days).

According to the tendency, described above, it’s possible to say that, in order to save water in rice cultivation, for all varieties, the sowing decades should be from 11 to 18, in the months of April, May and June respectively, with the Limpopo variety as best and ITA 312 as worst.

5.2. Sowing period and yields

In the tables A9 and A10 in the appendix 3.2., there are described the yield losses according to the sowing decade for each rice variety resulting from the CROPWAT model simulations. These tables were resumed in one graph (figure 3) that shows the variation of the yield losses during the decades of the year for the rice varieties.

It’s possible to see, in the graph, that in the decades one and 32 to 36, first decade of January, second to third decade of November and first to third decade of December respectively, the yield losses are less than 30% for all varieties of rice, although there are a small differences among them. From the second decade of January to the third decade of October, decades two to 30 respectively, the yield losses are higher than 30%. This behavior is due to the concentration of the lack of rain in those months, because, in Mozambique, the rainy season starts from October and ends in February, in the hot season.

In the graph it’s possible to see that the sowing period that presented less yield losses, are in the months of November and December, decades 32 to 36 respectively. This is because, although the wet season starts in October, the great concentration of water is in these two months.

In the opposite case, the months of June, July and August, decades 16 to 24, they represent the high risk sowing period, with yield losses greater than 50%, because in this period, in some years there is no rain or the rain is too low.
Yield losses according to sowing decade for each rice variety

Figure 3: Yield losses variation according to the sowing decade for each rice variety.
It means that, with good water management, it’s possible to cultivate rice in rainfed subsistence agriculture sowing from January to April and from September to December, accepting losses in yield up to 50%, for all rice varieties. In the case of rice cultivation for industry it this is not possible, because according to Mozfoods rice cultivation brochure, the yield loss higher than 30% is not acceptable. For this case it can be said that the best sowing period goes from the first decade of November to the first decade of January, passing thru December, because the yield losses are lower than 30%, for all rice varieties, in this period.

5.3. Choosing the best sowing period

The choice of the best sowing period, in the case of rainfed agriculture can be done looking at the yield losses graph, which the discussion was already made in the previous section (section 5.2.). This scenario goes in according with FAEF (2004), which says that the sowing date for semi-arid regions in the south of Mozambique, for rainfed agriculture, it’s when the first rains start (first weeks of October) until November 30. According to Reddy (1986), the sowing dates that present less crop harvest failure (total yield loss) goes from week 46 (second week of November) until week 10 (second week of March) and the risk increases from moderate (interior zone of Gaza province) to high or much higher in the coastal zone. The Mozfoods products brochure table, presented in section 3.2.5. (table 1) says that, the best sowing period for all varieties of rice crop they produce goes from September 15 to the end of December.

A different scenario can be seeing when irrigation arrives. As was said before, the district of Chókwè has the larger irrigated perimeter in Mozambique and the great majority of the farmers of the district produce irrigated rice. For this case, water is no longer a limited factor, but the good management of the water can help save the amount of water spent on rice production. For this new scenario, the graph in figure 3 is no longer valid because it considers only rainfed agriculture. But the graph in figure 2, about CWR, is valid. Thus, the same discussion of section 5.1., can be used to justify this new scenario. So, in this case, it is necessary to take in account that the rice yield doesn’t only depends on the water as a prime factor, but other meteorological elements can arise.

Silva & Assad (2001) says that, to explain the effect of meteorological elements in rice production, it’s necessary to study their effect in rice yield. The mean value of
temperature for rice production is 22°C and in the regions where this kind of values is predominated the development of rice is not affected. According to FAEF (2004), the mean temperature during the month of April and May in the southern zone of Mozambique is below 20°C. Saucedo (2009) said that, with these temperatures, the flowering phase of the rice plant will not start and even if it starts, the rice grains will be empty. Thus, even if the lowest CWR values for rice is in between the decades 13 to 15 in the month of May, it can be said that this cannot be selected as the best sowing period in the case for rice production.

Nunes et al (1986), cited by Schouwenaars (1990), says that in the southern Mozambique, the growing crops in the months of high temperature (November to February), which coincides with the wet season, they are more vulnerable to pests and diseases. This could be one disadvantage when you grow rice in this period.

In comparison between rice varieties in the present study, it can be said that, in order to save water for rice production, it’s better to use the variety Limpopo because the CWR values are lowest than the other varieties. The reason for this behavior where discussed in section 5.1..
VI. CONCLUSION

The crop water requirements (CWR or ET$_c$) are relatively higher in relation with the rainfall quantity in the District of Chókwè. Comparing the rice varieties, it can be concluded that the variety Limpopo has the lowest value for the CWR, followed by BR IRGA 417, BR IRGA 409 and, with the highest value, ITA 312.

The rice yields are affected by the rainfall distribution along the crop season and particularly by the water deficit in the rice crop growing phases.

The present study indicates that the best sowing decades for water saving in rice production, in rainfed agriculture, in the district of Chókwè, are the decades 1, 32, 33, 34, 35 and 36, such is from the second decade of November to the first decade of January, if a loss in yield up to 30% can be accepted or the decades 1 to 12 and 26 to 36, such is from the second decade of September to the third decade of April, if a loss in yield up to 50% can be accepted.

The best rice variety for water saving in rice cultivation is the Limpopo variety.
VII. RECOMMENDATIONS

The decision for the choice of the variety to use not only depends on the yield loss and the water consumption of the variety. For instance, the yield of the variety ITA 312 is higher than the other varieties, but it presents high level of broken grains when harvested (paddy). The variety Limpopo is better than the other varieties when it comes to defense against birds, but has the same problem of quality as ITA 312 and the yield is lower than ITA 312. The varieties BR IRGA 409 and BR IRGA 417 present high grain quality but presents high level of grain loss (grain drop) in the maturation phase (BR IRGA 417 more than BR IRGA 409, but its grain quality is higher than BR IRGA 409).

The sowing process must be well planned, because it determines the beginning a process that goes for around four months and will affect all involved operations, beyond the determination of the possibilities of successful or unsuccessful production. For best results it is better to sow after one good rainfall (in case of rainfed agriculture).

It’s not recommendable to sow rice in the months from April to July in the district of Chókwè, even when water is not a problem.

This study was based in a computer model and the variables in the model were the rainfall and the rice varieties. For further studies, other variables should include climatic data and soil data. Complementarily a field study should be done.

Also the present study should be done in different regions of the country, to collect more information rice production along the country, taking in account:

- Field research;
- Different soil types;
- Socio-economics considerations.
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APPENDIX
I. Illustrations

1.1 Map of Mozambique

Illustration A1: Map of Mozambique with provinces, districts, capital cities, and borders.

Source: http://www.africa-turismo.com/imagens/mozambique-mapa.gif
1.2. Chókwè district

Illustration A2: Chókwè district
1.3. Mozambique’s soil map

Illustration A3: Soil Map of Gaza Province

Source: Drought Impact Mitigation and Prevention in the Limpopo River Basin, FAO-SAFR Initiative

Learning to Live with Drought and Climate Variability 2004
1.4. Rice plant

![Diagram of rice plant](http://pcp.oxfordjournals.org/content/46/1/23/F1.expansion(right), and http://www.freepatentsonline.com/6616924.html(left))

**Illustration A4:** General rice plant description

**Source:** [http://pcp.oxfordjournals.org/content/46/1/23/F1.expansion](http://pcp.oxfordjournals.org/content/46/1/23/F1.expansion) (right), and [http://www.freepatentsonline.com/6616924.html](http://www.freepatentsonline.com/6616924.html) (left)
II. Used data

2.1. Crop data

*ITA 312*

<table>
<thead>
<tr>
<th>Growing stage</th>
<th>Initial</th>
<th>Development</th>
<th>Mid-season</th>
<th>Late-season</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration [days]</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>130</td>
</tr>
<tr>
<td>Crop coefficients dry season ($K_c$)</td>
<td>1.10</td>
<td>-</td>
<td>1.20</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Crop coefficients wet season ($K_c$)</td>
<td>1.10</td>
<td>-</td>
<td>1.20</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Rooting depth [m]</td>
<td>0.10</td>
<td>-</td>
<td>0.60</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td>Critical depletion (fraction)</td>
<td>0.20</td>
<td>-</td>
<td>0.20</td>
<td>0.20</td>
<td>-</td>
</tr>
<tr>
<td>Yield response ($K_y$)</td>
<td>1.00</td>
<td>1.09</td>
<td>1.32</td>
<td>0.50</td>
<td>1.10</td>
</tr>
</tbody>
</table>

**Table A1:** Rice crop var. ITA 312 used by CROPWAT ver. 8.0 for each growing stage

**Source:** CROPWAT version 8.0

*IRGA 417*

<table>
<thead>
<tr>
<th>Growing stage</th>
<th>Initial</th>
<th>Development</th>
<th>Mid-season</th>
<th>Late-season</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Crop coefficients wet season ($K_c$)</td>
<td>1.10</td>
<td>-</td>
<td>1.20</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Rooting depth [m]</td>
<td>0.10</td>
<td>-</td>
<td>0.60</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td>Critical depletion (fraction)</td>
<td>0.20</td>
<td>-</td>
<td>0.20</td>
<td>0.20</td>
<td>-</td>
</tr>
<tr>
<td>Yield response ($K_y$)</td>
<td>1.00</td>
<td>1.09</td>
<td>1.32</td>
<td>0.50</td>
<td>1.10</td>
</tr>
</tbody>
</table>

**Table A2:** Rice crop var. IRGA 417 used by CROPWAT ver. 8.0 for each growing stage

**Source:** CROPWAT version 8.0
**Sowing dates as a strategy for water saving in rice (Oryza sativa) production on semi-arid regions: study case of Chókwè district, Mozambique**

**IRGA 409**

<table>
<thead>
<tr>
<th>Growing stage</th>
<th>Initial</th>
<th>Development</th>
<th>Mid-season</th>
<th>Late-season</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration [days]</td>
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<td>30</td>
<td>126</td>
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<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Crop coefficients wet season ((K_c))</td>
<td>1.10</td>
<td>-</td>
<td>1.20</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Rooting depth ([m])</td>
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<td>-</td>
<td>0.60</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td>Critical depletion (fraction)</td>
<td>0.20</td>
<td>-</td>
<td>0.20</td>
<td>0.20</td>
<td>-</td>
</tr>
<tr>
<td>Yield response ((K_y))</td>
<td>1.00</td>
<td>1.09</td>
<td>1.32</td>
<td>0.50</td>
<td>1.10</td>
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**Table A3:** Rice crop var. IRGA 409 used by CROPWAT ver. 8.0 for each growing stage

**Source:** CROPWAT version 8.0

**Limpopo**

<table>
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<tr>
<th>Growing stage</th>
<th>Initial</th>
<th>Development</th>
<th>Mid-season</th>
<th>Late-season</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration [days]</td>
<td>10</td>
<td>24</td>
<td>40</td>
<td>30</td>
<td>104</td>
</tr>
<tr>
<td>Crop coefficients dry season ((K_c))</td>
<td>1.10</td>
<td>-</td>
<td>1.20</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Crop coefficients wet season ((K_c))</td>
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<td>-</td>
<td>1.20</td>
<td>1.05</td>
<td>-</td>
</tr>
<tr>
<td>Rooting depth ([m])</td>
<td>0.10</td>
<td>-</td>
<td>0.60</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td>Critical depletion (fraction)</td>
<td>0.20</td>
<td>-</td>
<td>0.20</td>
<td>0.20</td>
<td>-</td>
</tr>
<tr>
<td>Yield response ((K_y))</td>
<td>1.00</td>
<td>1.09</td>
<td>1.32</td>
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<td>1.10</td>
</tr>
</tbody>
</table>

**Table A4:** Rice crop var. Limpopo used by CROPWAT ver. 8.0 for each growing stage

**Source:** CROPWAT version 8.0
2.2. Climatic data

In the following table are presented the climate data for the district of Chókwè.

<table>
<thead>
<tr>
<th>Month</th>
<th>Min. temp. (°C)</th>
<th>Max. temp. (°C)</th>
<th>Humidity (%)</th>
<th>Wind (Km/day)</th>
<th>Sun (hours)</th>
<th>Rad. (MJ/m²/day)</th>
<th>ET₀ (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>21.0</td>
<td>33.7</td>
<td>70</td>
<td>164</td>
<td>7.3</td>
<td>22.3</td>
<td>5.43</td>
</tr>
<tr>
<td>February</td>
<td>21.1</td>
<td>33.0</td>
<td>73</td>
<td>164</td>
<td>7.1</td>
<td>21.0</td>
<td>5.03</td>
</tr>
<tr>
<td>March</td>
<td>19.5</td>
<td>32.1</td>
<td>74</td>
<td>138</td>
<td>7.3</td>
<td>19.5</td>
<td>4.43</td>
</tr>
<tr>
<td>April</td>
<td>17.6</td>
<td>30.7</td>
<td>75</td>
<td>121</td>
<td>7.0</td>
<td>16.5</td>
<td>3.55</td>
</tr>
<tr>
<td>May</td>
<td>14.2</td>
<td>28.6</td>
<td>75</td>
<td>147</td>
<td>7.6</td>
<td>14.5</td>
<td>3.00</td>
</tr>
<tr>
<td>June</td>
<td>11.5</td>
<td>26.2</td>
<td>75</td>
<td>104</td>
<td>7.0</td>
<td>12.7</td>
<td>2.24</td>
</tr>
<tr>
<td>July</td>
<td>10.9</td>
<td>26.1</td>
<td>75</td>
<td>112</td>
<td>7.0</td>
<td>13.3</td>
<td>2.32</td>
</tr>
<tr>
<td>August</td>
<td>12.6</td>
<td>27.9</td>
<td>74</td>
<td>147</td>
<td>7.1</td>
<td>15.4</td>
<td>3.04</td>
</tr>
<tr>
<td>September</td>
<td>15.3</td>
<td>30.2</td>
<td>67</td>
<td>181</td>
<td>7.3</td>
<td>18.5</td>
<td>4.24</td>
</tr>
<tr>
<td>October</td>
<td>17.5</td>
<td>31.8</td>
<td>66</td>
<td>199</td>
<td>7.0</td>
<td>20.2</td>
<td>5.00</td>
</tr>
<tr>
<td>November</td>
<td>19.3</td>
<td>32.6</td>
<td>67</td>
<td>181</td>
<td>6.4</td>
<td>20.5</td>
<td>5.14</td>
</tr>
<tr>
<td>December</td>
<td>20.3</td>
<td>33.3</td>
<td>65</td>
<td>181</td>
<td>6.9</td>
<td>21.8</td>
<td>5.54</td>
</tr>
<tr>
<td>Average</td>
<td>16.7</td>
<td>30.5</td>
<td>71</td>
<td>153</td>
<td>7.1</td>
<td>18.0</td>
<td>4.08</td>
</tr>
</tbody>
</table>

Table A5: Chókwè district climate data used in CROPWAT model.

Source: FAO CLIMWAT 2.0 for CROPWAT

2.3. Rainfall data

In the following table are presented the rainfall data for the district of Chókwè.
Table A6: Rainfall data used in the CROPWAT model

<table>
<thead>
<tr>
<th>Month</th>
<th>Rain (mm)</th>
<th>Effective rain (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>111.0</td>
<td>91.3</td>
</tr>
<tr>
<td>February</td>
<td>91.0</td>
<td>77.8</td>
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<tr>
<td>March</td>
<td>76.0</td>
<td>66.8</td>
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<td>April</td>
<td>40.0</td>
<td>37.4</td>
</tr>
<tr>
<td>May</td>
<td>40.0</td>
<td>37.4</td>
</tr>
<tr>
<td>June</td>
<td>22.0</td>
<td>21.2</td>
</tr>
<tr>
<td>July</td>
<td>23.0</td>
<td>22.2</td>
</tr>
<tr>
<td>August</td>
<td>19.0</td>
<td>18.4</td>
</tr>
<tr>
<td>September</td>
<td>31.0</td>
<td>29.5</td>
</tr>
<tr>
<td>October</td>
<td>46.0</td>
<td>42.6</td>
</tr>
<tr>
<td>November</td>
<td>65.0</td>
<td>58.2</td>
</tr>
<tr>
<td>December</td>
<td>93.0</td>
<td>79.2</td>
</tr>
<tr>
<td>Total</td>
<td>657.0</td>
<td>582.0</td>
</tr>
</tbody>
</table>

Source: FAO CLIMWAT 2.0 for CROPWAT
2.4. Soil data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total available soil moisture (TAM = FC – WP) [mm/m]</td>
<td>120</td>
</tr>
<tr>
<td>Maximum rain infiltration rate [mm/day]</td>
<td>40</td>
</tr>
<tr>
<td>Maximum rooting depth [cm]</td>
<td>900</td>
</tr>
<tr>
<td>Initial soil depletion (as % TAM) [%]</td>
<td>0</td>
</tr>
<tr>
<td>Initial available soil moisture [mm/m]</td>
<td>140</td>
</tr>
<tr>
<td>Drainable porosity (Saturation – FC) [%]</td>
<td>7</td>
</tr>
<tr>
<td>Critical depletion for puddle cracking</td>
<td>0.60</td>
</tr>
<tr>
<td>Maximum percolation rate after puddling [mm/day]</td>
<td>3.4</td>
</tr>
<tr>
<td>Water availability at planting [mm of water depth]</td>
<td>20</td>
</tr>
<tr>
<td>Maximum water depth [mm]</td>
<td>600</td>
</tr>
</tbody>
</table>

**Table A7:** Soil data used in the CROPWAT model

**Source:** CROPWAT version 8.0
III. Results

3.1. Crop water requirements (CWR)

<table>
<thead>
<tr>
<th>Month</th>
<th>Sowing decades</th>
<th>ITA 312</th>
<th>BR IRGA 417</th>
<th>BR IRGA 409</th>
<th>Limpopo</th>
</tr>
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<tbody>
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<td>758,6</td>
<td>653,8</td>
</tr>
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<td>2</td>
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<td>663,8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>718,7</td>
<td>673,2</td>
<td>706,9</td>
<td>633,3</td>
</tr>
<tr>
<td>February</td>
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<td>640,9</td>
<td>672,2</td>
<td>604,0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>648,2</td>
<td>610,0</td>
<td>638,4</td>
<td>575,5</td>
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<td>614,7</td>
<td>577,9</td>
<td>604,9</td>
<td>546,2</td>
</tr>
<tr>
<td>March</td>
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<td>579,2</td>
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<td>521,4</td>
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<td>530,5</td>
<td>492,3</td>
<td>519,7</td>
<td>463,1</td>
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<tr>
<td>April</td>
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<td>507,1</td>
<td>464,2</td>
<td>495,1</td>
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<td></td>
<td>11</td>
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<td>484,3</td>
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<td>393,3</td>
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<tr>
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<td>611,1</td>
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<td>789,9</td>
<td>653,8</td>
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<td>October</td>
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<td>787,4</td>
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</tr>
<tr>
<td></td>
<td>28</td>
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<td>798,2</td>
<td>859,3</td>
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<tr>
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<td>884,1</td>
<td>804,1</td>
<td>863,3</td>
<td>738,7</td>
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<td>880,7</td>
<td>805,4</td>
<td>861,1</td>
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<td>801,1</td>
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<td>736,2</td>
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<td>728,9</td>
</tr>
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<td>718,5</td>
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<td>806,4</td>
<td>751,3</td>
<td>792,1</td>
<td>703,6</td>
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Table A8: Crop water requirements for four varieties of rice
3.2. Yield losses

<table>
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<tr>
<th>Month</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety \ Decade</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>ITA 312</td>
<td>29.5</td>
<td>30.0</td>
<td>31.2</td>
<td>34.6</td>
<td>35.4</td>
<td>37.5</td>
</tr>
<tr>
<td>BR IRGA 417</td>
<td>29.5</td>
<td>30.5</td>
<td>31.5</td>
<td>34.8</td>
<td>35.7</td>
<td>37.8</td>
</tr>
<tr>
<td>BR IRGA 409</td>
<td>29.7</td>
<td>30.3</td>
<td>31.3</td>
<td>34.7</td>
<td>35.6</td>
<td>37.7</td>
</tr>
<tr>
<td>Limpopo</td>
<td>27.0</td>
<td>27.9</td>
<td>29.3</td>
<td>32.8</td>
<td>34.0</td>
<td>35.9</td>
</tr>
</tbody>
</table>

Table A9: Yield losses

<table>
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<tr>
<th>Month</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety \ Decade</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
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<tr>
<td>ITA 312</td>
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<td>61.0</td>
<td>59.3</td>
<td>56.6</td>
<td>53.7</td>
<td>50.3</td>
</tr>
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<td>61.8</td>
<td>59.6</td>
<td>57.7</td>
<td>54.8</td>
</tr>
<tr>
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<td>62.2</td>
<td>61.3</td>
<td>59.6</td>
<td>57.2</td>
<td>54.5</td>
<td>51.3</td>
</tr>
<tr>
<td>Limpopo</td>
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<td>61.4</td>
<td>61.7</td>
<td>60.4</td>
<td>58.6</td>
<td>55.0</td>
</tr>
</tbody>
</table>

Table A10: Yield losses