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Full Length Research Paper

Assessing Water Availability for Sustainable Agriculture in Burkina Faso Using Evapotranspiration and Rainfall Data

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Agriculture in Burkina Faso is largely dominated by 75% of rainfed crop production, which is characterized by short and unevenly distribution of annual rainfall. The shortage of water for crop production is not only a consequence of water scarcity, but also the mismatch between water supply and demand. The cropping calendar approach has been widely suggested as a strategy management to mitigate the water shortage to crop. This study introduces a new agriculture water management plan in two important areas; Banfora and Ouagadougou based on evapotranspiration reference model and rainfall contribution index. The results showed that Banfora has a higher agricultural potential than Ouagadougou, and also proposed a suitable cropping calendar under rainfed condition for the study areas. Furthermore, from the index estimated for Banfora, it is found that, after the first crop, the rainwater can possibly contribute 39.1 and 42.4% to the water requirements of maize and bean respectively while the plating date is September 1st. The new water management plan recommended for Burkina Faso in this study may increase agricultural production for solving part of the local food shortage problem.

Key words: Evapotranspiration, water scarcity, rainfed, cropping calendar, irrigation efficiency, food production.

INTRODUCTION

Water resources are confronted to great challenge of its scarcity. Water scarcity is increasingly becoming the most important environmental constraint limiting plant growth in many regions (Tognetti et al., 2006). For exam-ple, over 30 arid and semi-arid countries are expected to have water scarcity in 2025, consequently will slow down the development, threaten food supplies and aggravate rural poverty (Smith, 2000). According to Issar (2008), for many countries in the Developing World where agriculture still plays a significant economic role, a severe reduction in precipitation will cause famine. The situation is expected to be worst in Sub-Saharan Africa, where 90% of food production is based on rainfed agriculture (Mdemu et al., 2004). These regions, usually experience low, short and unevenly distributed rainfall pattern that are the major limiting factors of increasing crop production (Ingram et al., 2002; Ogindo et al., 2005). Schumacher et al., (2009) highlighted the importance of a comprehensive strategy for managing and enhancing the use water resources. The effect of water shortage on crop production is exacerbated by the mismatches bet-ween resources availability and demands (Tefaye et al., 2004). Therefore, as a mitigation strategy, the cropping calendar has been suggested by several authors in order to alleviate low crop production (Lee et al., 2005; Poussin et al., 2006).

Hence lately, in Burkina Faso, a continental landlocked country located in the semi-arid zone in the heart of West Africa with a dry tropical climate, has launched the small scale irrigation project as a supplementary production strategy. Rainfed crop production occupies 75% of the agriculture, which is the main source of food and income for the majority of people (Badini et al., 1997; SSI, 2001).

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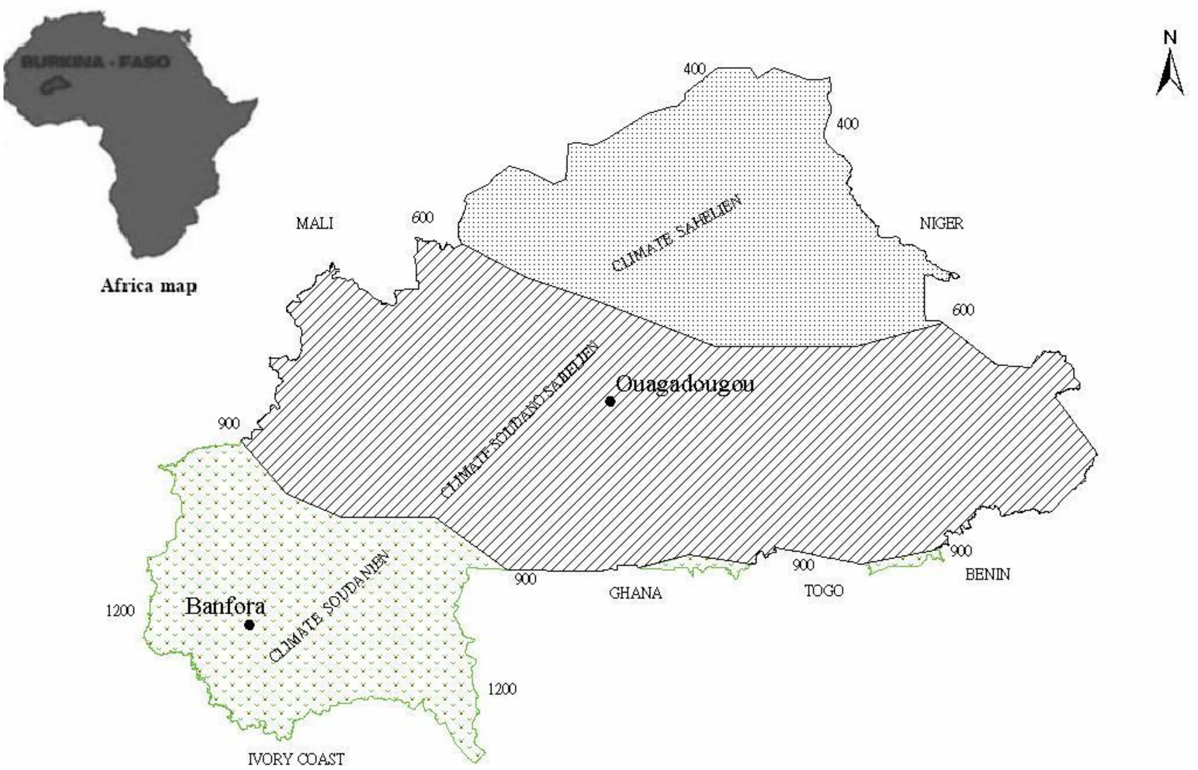

Figure 1. Sketch of the present study areas.

Although the small scale irrigation has been widely adopted, a full benefit could not be achieved because of the untimely succession system between rainy and non rainy season. Previous study Perret (2006) reported that, there is missing information on crop water balances and rainfall variability in Burkina Faso which is important for further technology development and farmer decision making. Similarly, several authors in Burkina Faso revealed that, the low output were also from delay planting due to the lack of information (Dakuo et al., 1993; Kambire et al., 1999). In order to have an efficient use of water in African semi-arid region, the study Tesfaye et al. (2004) suggested that there is a need for a management practice based on matching water supply and crop demand.

Recently, the application of modeling process has been widely investigated and outstanding results reported in several areas of water resources engineering, including rainfall-runoff (Cheng et al., 2006), drought simulation (Yurekli and Kurunc, 2006), evapotranspiration modeling (Wang et al., 2008), and CROPWAT water- based compu-ter model (Clarke et al., 1998). The low availability of complete climate data for reference evapotranspiration (ETo) determination with the recommended Penman-Monteith equation has been found to limit the estimation of crop water demands in Burkina Faso through the existing CROPWAT simulation model. Therefore, our previous study (Wang et al., 2007) determined a reliable reference model for evapotranspiration estimation based on limited data set for the production sites of Banfora and Ouagadougou of Burkina Faso. Beside the evapotranspiration reference model, this study introduced the rainfall contribution index (RCI) for exploring the contribution of rainfall to 10 different crops by simulating the crop water demands and rainwater availability for both Banfora and Ouagadougou. The objectives of this study were to examine the crop water balance and to establish a new cropping calendar for both rainfed and irrigated agriculture based on water supply and crop demands relationship under natural environmental constraints.

MATERIALS AND METHODS

Meteorological data

The meteorological data were collected from two stations located in the small scale irrigation project area in Burkina Faso (Figure 1). In North Sudano-Sahelian region at 800 mm isohyets, Ouagadougou Airport Meteo-rological station located at $12^{o}37'$N latitude, $-1^{o}52'$W longitude and 306 m altitude. In South Sudano-Sahelian region at isohyets 1200 mm, National Sugar Company Agro-meteorological station (SN- SOSUCO) located in Banfora, Western part of Burkina Faso at $10^{o}63'$N lati-tude, $-4^{o}77$W longitude and 302 m altitude. The weather decadal data of both locations from 1996 to 2005 were collected for this study. The data are composed of preci-pitation (mm), minimum and maximum temperature (°C),

Table 1. Length of growing stages for selected crops in the study area.

Crop	Growing length (days)	Crop growing stages (days)			
		Initial	Development	Mid season	Late season
Maize Massongo	105	20	30	35	20
Maize Espoir	105	20	30	35	20
Bean KVX61-1	95	15	25	35	20
Sorghum	130	20	35	45	30
Millet	140	20	30	55	35
Groundnut	130	25	35	45	25
Cassava	210	20	40	90	60
Onion 'Voilet de galmi'	150	15	25	70	40
Rice FKR-28	125	30	30	35	30
Rice FKR-19	120	30	30	30	30
Potato	130	25	30	45	30

wind speed (Km/day), relative humidity (%) and sunshine duration (hour).

Estimation of reference evapotranspiration

According to the suggestion of Wang et al., 2007, the ETo estimation model for the study sites can be described as the following:

$$ET_o = p(0.23T_{mean} + 4.065) + \\ + 0.0023(T_{max} - T_{min})^{0.5}(0.5T_{mean} + 8.9)R_a \quad (1)$$

Where ET_o is the daily reference evapotranspiration (mm/day); p is the mean daily percentage of annual daytime hours according to the latitude; T_{max} and T_{min} are the maximum and minimum temperature (°C); T_{mean} is the mean temperature (°C) and R_a is the extraterrestrial radiation (mm/day).

Soil and crop information

Soil water depletion factors for no stress, and yield response factors were based on the procedures given by Allen et al. (1998) and Clarke et al. (1998). According to Mermoud et al. (2005), for Ouagadougou in North Soudano-Sahelian zone, the surface layer (0-30 cm) is loamy which has 20% clay, 30% silt and 40% sand, approximately. The soil bulk density varied from 1.6 to 1.7 g/cm^3. In South Soudano-Sahelian zone where Banfora is located, the surface layer (0-30cm) is clay loam which has 31.1% clay, 33.7% silt and 20% sand approximately. The bulk density varied between 1.4 - 1.5 g/cm^3 (Savadogo et al., 2007).

The main cultivated crops selected in the study were maize, dry bean, sorghum, millet groundnut, cassava, onion, rice and potato. The crop growth parameters such as duration, height and rooting depth suggested by Brouwer et al. (1986) were obtained from agricultural extension services. Then, the crop coefficients were derived by the numerical determination approach and adjusted as proposed by Allen et al. (1998):

$$k_{ci} = k_{c.prev} + \frac{i - (L_{prev})}{L_{stage}}(k_{c.next} - k_{c.prev}) \quad (2)$$

Where; i is the day number within the growing season; k_{ci} is the crop coefficient on day i; L_{stage} is the length of the stage under consideration (days); $k_{c.prev}$ is the crop coefficient at the previous stage; $k_{c.next}$ is the crop coefficient at the next stage and (L_{prev}) is the sum of the length of all previous stages (days).

The relative impact of climate on crop required the adjustment of kc. For specific adjustment of kc for mid and late season in climates where the minimum relative humidity differs from 45% or where wind speed is larger or small than 2.0 m/s, the procedure is given by Allen et al. (1998) as:

$$k_{c.mid} = k_{c.mid(Tab)} + \left[0.04(u_2 - 2) - 0.004(RH_{min} - 45)\right]\left(\frac{h}{3}\right)^{0.3} \quad (3)$$

Where; $k_{c.mid(Tab)}$ is the value of kc for mid season taken from Allen et al. (1998); u_2 is the mean value of wind; RH_{min} is the mean value of relative humidity and h is the mean plant height during the mid-season. Tables 1 and 2 detailed the length of growing stages and adjusted crop coefficients for the selected crops in the study areas.

Crop water balance

Computerized crop water balance analyses were carried out by using the Food and Agriculture Organization procedures, as described by Doorenbos et al. (1977) and Allen et al. (1998), and implemented in the CROPWAT

Table 2. Adjusted crop coefficients for Ouagadougou and Banfora.

Crop	Initial		Development		Mid season		Late season	
	Oua.	Ban.	Oua.	Ban.	Oua.	Ban.	Oua.	Ban.
Maize Massongo	0.30	0.30	0.84	0.84	1.16	1.15	0.53	0.53
Maize Espoir	0.30	0.30	0.84	0.84	1.16	1.15	0.53	0.53
Bean KVX61-1	0.40	0.40	0.75	0.75	1.14	1.14	0.33	0.33
Sorghum	0.30	0.30	0.60	0.60	0.93	0.92	0.48	0.48
Millet	0.30	0.30	0.53	0.53	0.94	0.93	0.24	0.24
Groundnut	0.40	0.40	0.61	0.61	1.12	1.11	0.56	0.55
Cassava	0.30	0.30	0.80	0.80	0.77	0.77	0.33	0.33
Onion 'Voilet de galmi'	0.70	0.70	0.70	0.70	1.03	1.02	0.72	0.72
Rice FKR-28	1.05	1.05	1.05	1.05	1.16	1.16	0.85	0.85
Rice FKR-19	1.05	1.05	1.05	1.05	1.17	1.15	0.85	0.85

software (Clarke et al., 1998). This study applied the CROPWAT to estimate the crop water and irrigation requirements from the above evapotranspiration reference model.

Rainfall contribution index

In order to understand the potential of cultivation by considering only rainwater availability, the rainfall contribution index (RCI) is introduced as the following:

$$RCI = \sum_{i=1}^{n} \frac{PE_i / ETm_i}{n} \tag{4}$$

Where PE is effective rainfall (mm); ETm is crop water requirements (mm); i is the time step and n is the total time step for the growing period. The ratio in the above model is to express the contribution of rainwater to the crop water demands. Consequently, a suitable planting date for each selected crop is determined by choosing the highest RCI value.

The effective Rainfall (PE) representing the portion of total rainfall that plants use to help meet their con-sumptive water requirements has been calculated by the USDA soil conservation method as followed:

$$PE = P_{tot}\frac{125-0.2P_{tot}}{125} \quad \text{for} \quad P_{tot} < 250mm \tag{5}$$

$$PE = 125 + 0.1P_{tot} \quad \text{for,} \quad P_{tot} > 250mm \tag{6}$$

Where PE is the effective rainfall (*mm*) and P_{tot} is the total rainfall (*mm*).

RESULTS AND DISCUSSION

Crop water requirements

The main climatic features of Burkina Faso are low rainfall and high temperature. The rainy season starts officially in May coinciding with the period of field preparation. The traditional cropping calendars practiced by farmers are between May, 20 to August, 20, and June, 30 to August, 1 for Banfora and Ouagadougou, respec-tively. Maize, dry bean, sorghum, millet, groundnut, cassava, onion, rice (FKR-28 and FKR-19) and potato are the main crops cultivated in the study areas. This study defines a wide range of planting dates from May to June under the rainfed condition, which the effective rainfall, crop water and supplementary irrigation require-ments are estimated without considering the availability of irrigation facility. The monthly average of reference evapotranspiration was estimated based on the model presented by Wang et al. (2007). The rainfall contribution indexes determined were used for the comparison between effective rainfall and crop water demands.

Figures 2a and b shows the average and maximum values of the rainfall contribution index from different simulating planting dates. Further observations of RCI showed that the effective rainfall is insufficient for most of the crops to fully meet their water requirements in Ouagadougou, while it is considered to be sufficient in Banfora particularly for maize, bean, sorghum, millet and groundnut. This is in agreement with the conclusion drawn by Perret (2006) in the Southwestern part of country where water requirements for cereal crops and groundnut are easily met by the rainfall, while in the North Sudano-Sahelian and Sahelian regions with the water deficit, supplementary irrigation is needed to enable cereal crops to complete their growth cycle normally.

There is therefore a much higher necessity for irrigation practice in Ouagadougou. The crop water requirements (ETm) and irrigation water requirements (IWR) estimated for Ouagadougou and Banfora varied between crops and locations which corresponds to the highest rainfall contri-bution index are illustrated in Figures 3a and b. From the figure, it can be observed that the maize and dry bean have the lowest seasonal water demands and could be the most suitable crops for these low rainfall areas. Velaquez (2006) indicated that, it is very reasonable to recommend the crops with low water requirements for the

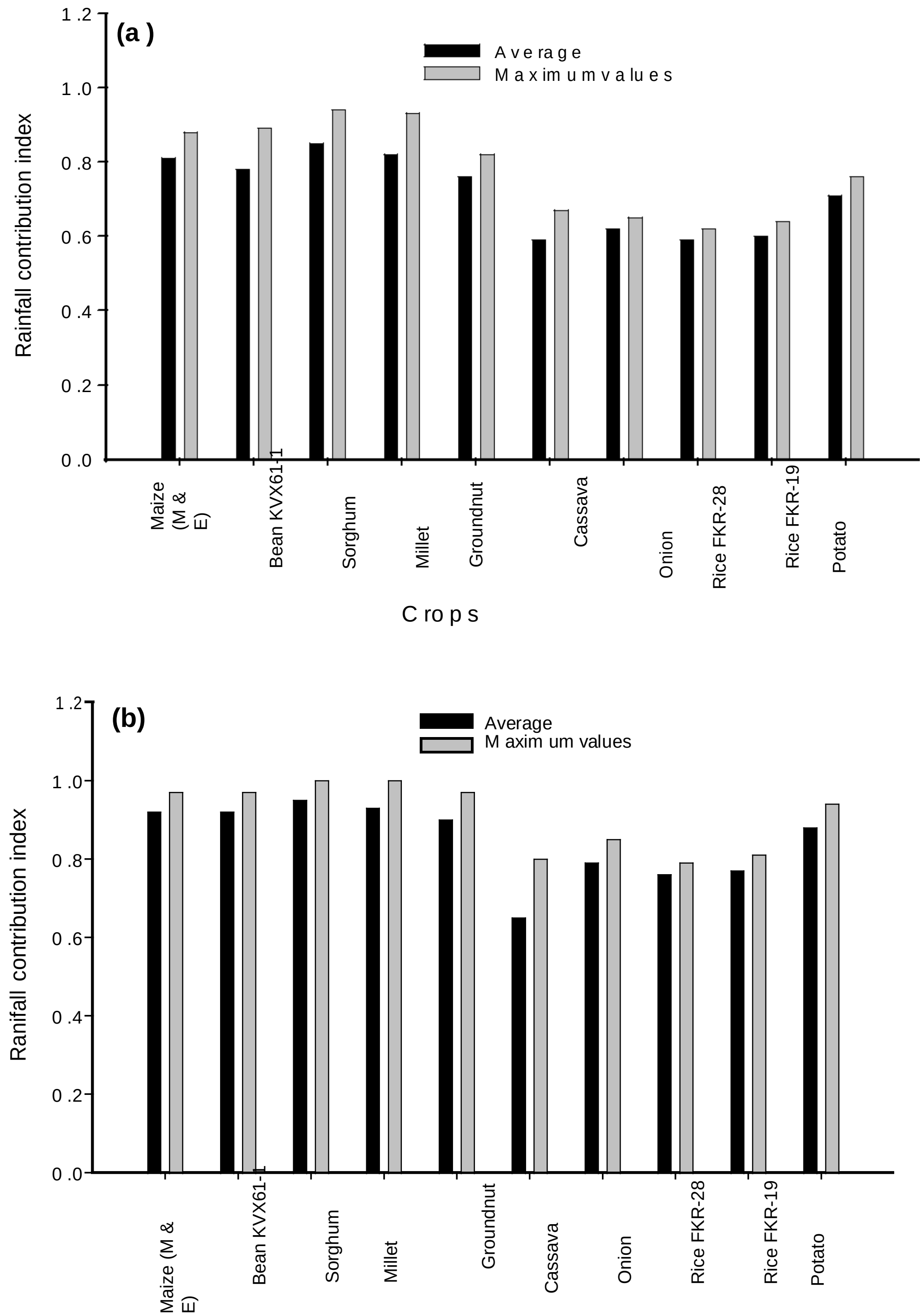

Figure 2. Plot of the average and maximum values of the rainfall contribution index from different simulating planting dates in Ouagadougou (a) and Banfora (b).

the water scarcity regions. Rice, onion, potato and cassava have high water demands when compared to other crops, and could be under higher water stress while rainfed irrigation is applied. Based on the results of rainfall contribution index, rice, onion, potato and cassava are not suitable for production in Ouagadougou without supplementary irrigation. It did not make much sense to grow crops that require more water in countries with water de-

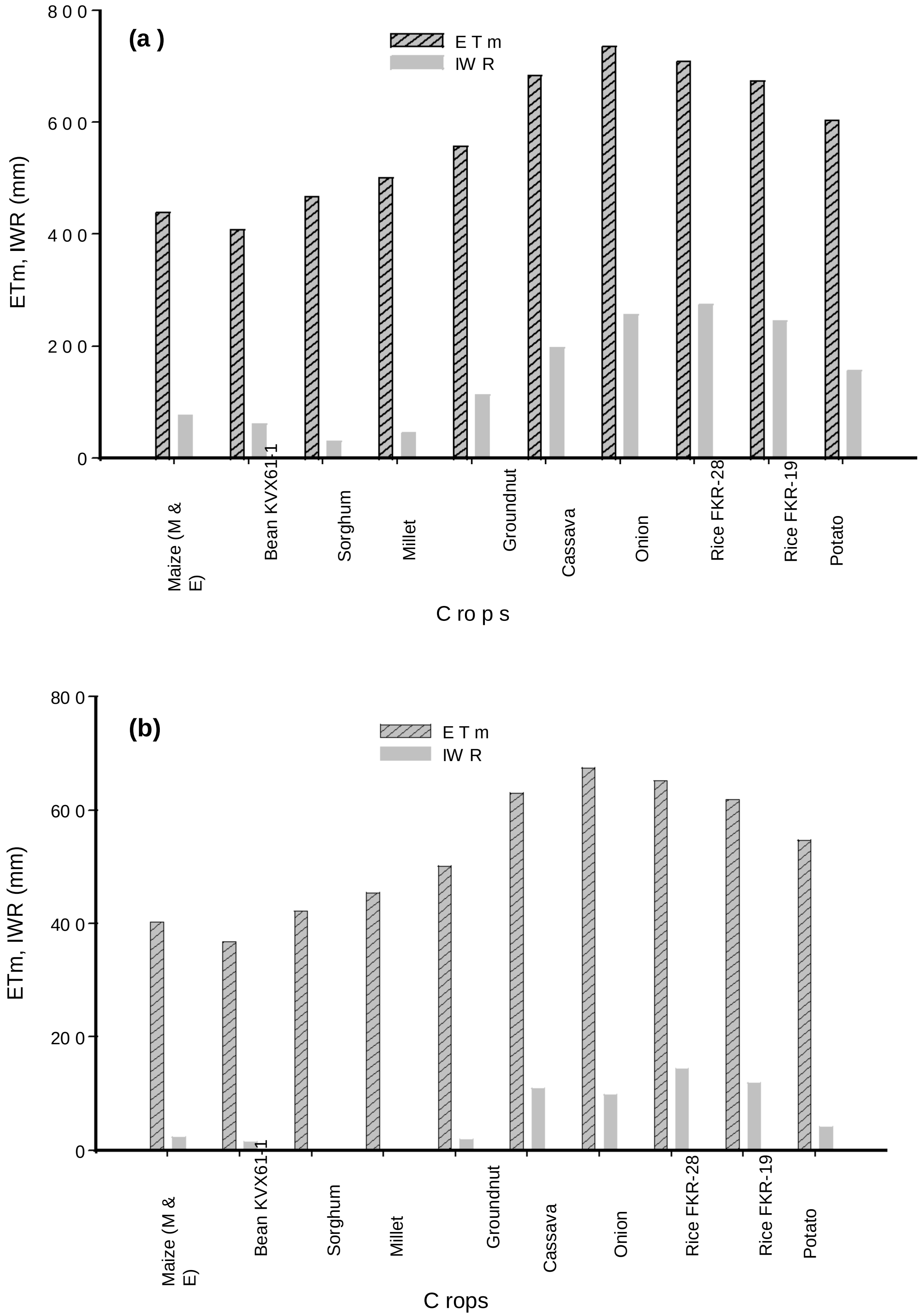

Figure 3. Plot of Crop water requirements (ETm) and irrigation water requirements (IWR) under the highest RCI condition in Ouagadougou (a) and Banfora (b).

Table 3. Suitable cropping calendar under rainfed condition.

Crop	Ouagadougou		Banfora	
	Rainy season			
	Sowing	Harvest	Sowing	Harvest
Maize (Massongo and Espoir)	5-June	18-September	15-June	28-September
Bean KVX61-1	20-June	23-September	15-June	18-September
Sorghum	25-May	2-October	15-May	22-September
Millet	25-May	12-October	20-May	7-October
Groundnut	25-May	2-October	20-May	27-September
Cassava	1-May	27-November	1-May	27-November
Onion 'Violet de galmi'	10-May	7-October	10-May	7-October
Rice FKR-28	25-May	27-September	20-May	22-September
Rice FKR-19	5-June	3-October	30-May	27-September
Potato	30-May	7-October	15-May	22-September

ficits (Fishelon, 1989) . But, cassava has the lowest ETm when considering its water demand by growing stages; that is, initial, development, mid season and late season. However, its cumulated seasonal water demand remains high because of the long growth duration that is 210 days. Cassava could be an appropriate crop for the agro-ecological condition of the reported study areas, if the cultivation density was reduced.

ETm were higher in Ouagadougou than Banfora regardless of the crop or planting date. These differences in ETm could be associated with regional agro-ecological variation between Banfora at 1200 mm isohyets and Ouagadougou at 800 mm isohyets. It has been documented at least by Izaurralde et al. (2003) and Goyal (2004) that, the geographical difference in the temperature and precipitation could explain these differences in crops water demands. Hence, Banfora in the South Sudano-Sahelian zone with a low ETm potentially has the most favorable agricultural conditions compared to Ouagadougou in the North Sudano-Sahelian zone. A study coordinated by the CEEPA for the World Bank in Burkina Faso, reported that, the crop water demands varies with the climate pattern, that is, ETm increases from Southwestern area towards Northeastern Sahelian conditions (Perret, 2006).

Cropping calendar

Crop water demands and water resources availability have been explored for determining the cropping calendar. Figures 4 and 5 compare the crop water requirements to effective rainfall under the highest RCI condition in Banfora and Ouagadougou, respectively. It can be seen that, the seasonal effective rainfall was characterized in the study areas by a short period with peak precipitation between July and September. It is known that, crops yield reduces with water stress during the critical growth stage (Kashyap et al., 2002; Tolk et al., 2002). Thus, this study considers the rainfall distribution and crop sensitivity stages for the cropping calendar determination. The maximum effective rainfall occurred during the development and mid- season stages at a period of high crop water demands. From Figures 4a, 4b, 5a and 5b, under the highest RCI condition, crops could be under less water stress in Banfora than in Ouagadougou. Table 3 gives suitable planting dates for maize, bean, onion, cassava, rice, sorghum, millet, groundnut and potato for the study areas. In Banfora, these dates were 15/6, 15/6, 15/5, 20/5, 20/5, 1/5, 10/5, 20/5, 30/5 and 15/5 for maize, dry bean, sorghum, millet, groundnut, cassava, onion, rice FKR-28, rice FKR-19 and potato, respectively. The corresponding rainfall contribu-tion index were0.97, 0.97, 1.00, 1.00, 0.97, 0.80, 0.85, 0.79, 0.81 and 0.94 for maize, dry bean, sorghum, millet, groundnut, cassava, onion, rice FKR-28, rice FKR-19 and potato, respectively.

For Ouagadougou, the suitable planting dates were 5/6, 20/6, 25/5, 25/5, 25/5, 1/5, 10/5, 25/5, 5/6 and 30/5 for maize, dry bean, sorghum, millet, groundnut, cassava, onion, rice FKR-28, rice FKR-19 and potato, respectively. The rainfall contribution indexes were 0.88, 0.89, 0.94, 0.93, 0.82, 0.67, 0.65, 0.62, 0.64 and 0.76, respectively. Generally, under rainfed condition, May was the most favorable month for planting sorghum, millet, groundnut, cassava, onion, potato, rice FKR-28 and rice FKR-19; and June for planting maize and dry bean. In general, the yield reduction in Burkina Faso is the cumulative effect of low precipitation and inappropriate cropping calendar. Several studies in Burkina Faso have revealed low output from the latest seedling (Dakuo et al., 1993; Kambire et al., 1999) . By examining Figure 2, it is found that the difference between RCI averages and maximum values were 4 - 12%, and 4 - 19%, respectively in Ouagadougou

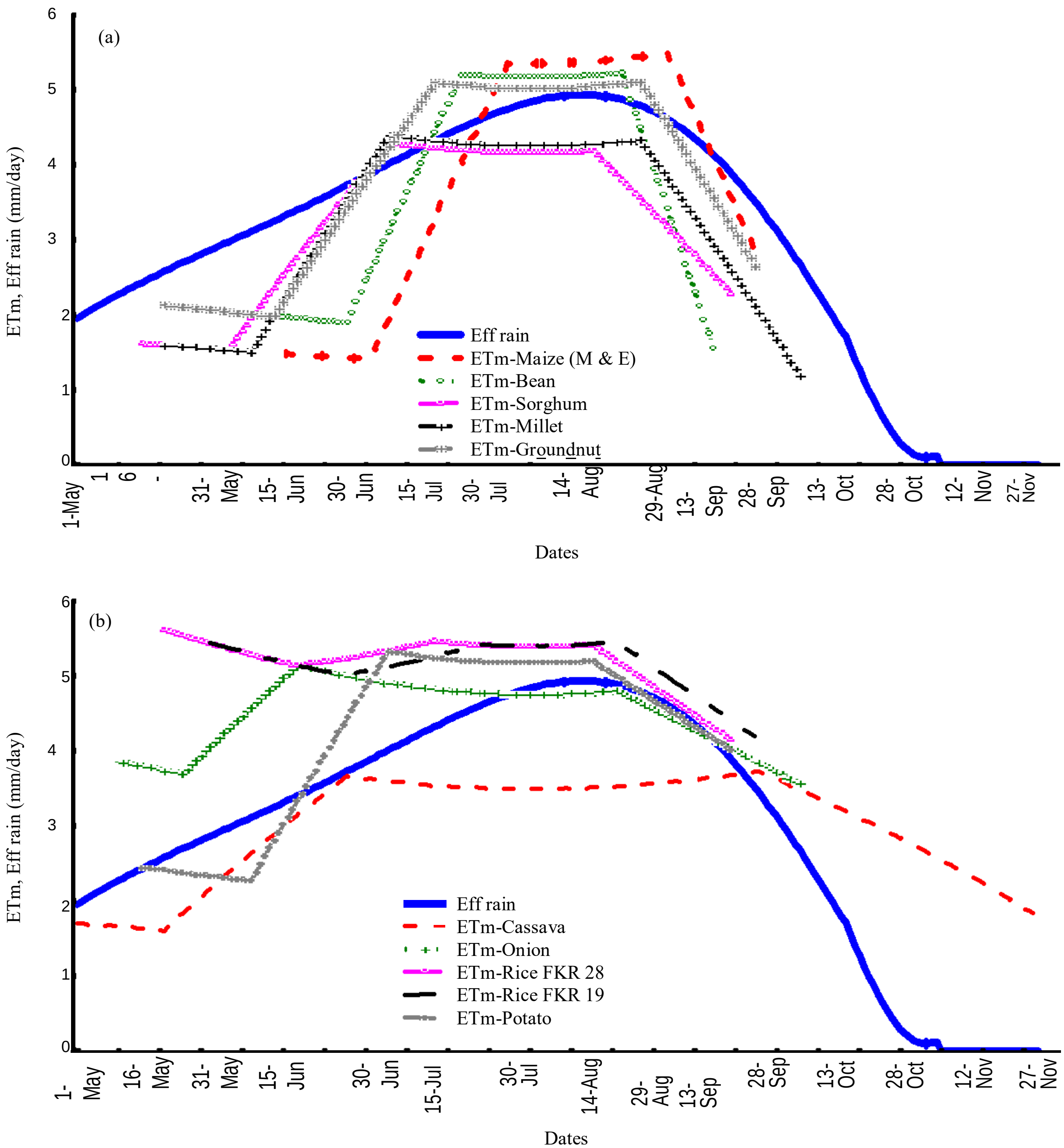

Figure 4. Comparison of simulated crop water requirements (ETm) to the effective rainfall under the highest RCI condition in Banfora; (a): maize, bean, sorghum, millet and groundnut, (b): cassava, onion, rice and potato.

and Banfora. Thus, for better rainfed agriculture water management, the cropping calendars determined in Table 3 which may provide higher rainfall contribution, could be a less water stress option leading to high yield in both Banfora and Ouagadougou. Previous studies done by Wopereis et al. (1999) and Ingram et al. (2002) revealed that, Burkinabe farmers need more information for stagger planting to avoid exposing crops to water deficit during vulnerable crop growth stages.

Consecutive crops

In the study areas, the main crops under irrigation in dry season are; maize Massongo (M) and Espoir (E), and dry bean KVX61-1. In general, the traditional cropping sy-stem practiced by farmers in Burkina Faso is based on a fixed calendar. The fixed planting calendar could impact negatively the yield of several crops due to the variability of crop sensitivity period. According to Dingkuhun (1994),

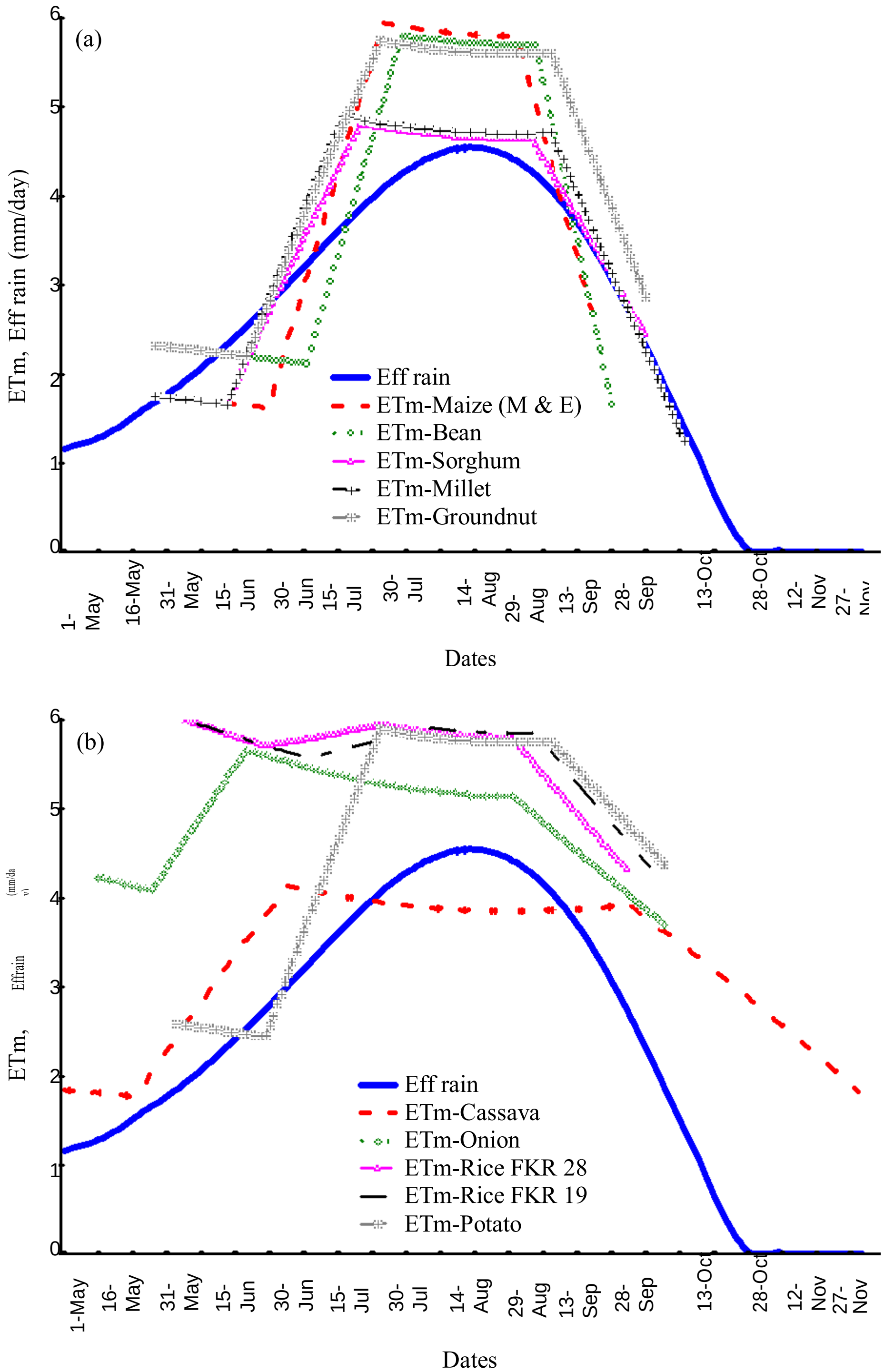

Figure 5 Comparison of simulated crop water requirements (ETm) to the effective rainfall under the highest RCI condition in Ouagadougou; (a): maize, bean, sorghum, millet and groundnut, (b): cassava, onion, rice and potato.

the variability in crops growth duration is a limiting factor to the options in calendrical Sahel regions.

The long term meteorological parameters have been collected in this study to provide accurate information for rainy season and second crop production in dry season. According to the rainfall contribution index, as Banfora presents sufficient rainwater for cereals; the planting dates have been shifted to the earliest possible time

Table 4. Cropping calendar for a consecutive cycle of production in rainy and dry season in Banfora.

Crop	Banfora			
	Rainy season		Dry season	
	Sowing	Harvest	Sowing	Harvest
Maize (M & E)	20-May	30-August	1-September	15-December
Bean KVX61-1	30-May	31-August	1-September	5-December
Sorghum	1-May	8-September	1-September	9-January
Millet	1-May	18-September	1-September	19-January
Groundnut	10-May	17-September	1-September	9-January

which covering at least 95% of crop water demands. These earliest planting dates were 1/5; 1/5; 10/5; 20/5; and 30/5 for sorghum, millet, groundnut, maize and dry bean, respectively. The rainfall contribution indexes to these planting dates were 0.97, 0.96, 0.95, 0.95 and 0.95. The early planting has been suggested in some regions as a mean to reduce water consumption by shifting crop growth into early time periods (Tasumi et al., 2006) . Considering the early planting periods, the first crops will have at least 95% of their water requirements met from the rainwater supply. High yield could be expec-ted from this high covering of crop water requirements as reported by Oktem et al. (2003); Goksoy et al. (2004) and Payero et al. (2006). From the results of this study, it is found that in Banfora after the rainy season, if groundnut, millet, sorghum, maize and bean are cultivated in September 1st, the rainwater contribute 30.2, 33.4, 36.1, 39.1 and 42.4% to their water requirements, respectively. Based upon these results, the most suitable crop for the second cultivation to be suggested is bean from the view point of water availability. Table 4 presents a suitable cropping calendar for both rainy and dry season production in Banfora.

In Ouagadougou, after the rainy season, if groundnut, millet, sorghum, maize and bean are cultivated in October 1st the rainwater contributed only 5.0, 5.6, 6.0, 6.5 and 7.1% to their water requirements, respectively. Under rainfed condition, whatever the planting dates, the effective rainfall does not fully satisfy the crop water demands. This insufficiency of rainwater does not favor the shifting of planting dates forward in rainfed condition, owing to the fact that higher water stress could occur during sensitive crop growth periods. Any water shortage impacts the final yield, whose response depends on crops sensitivity period (Kassam et al., 2001). Thus, the planting dates have the highest rainfall contribution index for this area is suggested in the study.

The short rainy season constitute the main limitation for two consecutives cycles of rainfed production in Burkina Faso. According to Ingram et al. (2002), the total seasonal rainfall is low with 90% of the rains falling during the months of July, August, and September. This agreed with the simulation results of this study as well as previously reported by Wang et al. (2007) and Savadogo et al. (2007). It is stated on the unimodal rainy season which does not allow two consecutives rainfed production without any supplementary irrigation. In order to have two production cycles in a season, sowing has to begin in a time when there is no rain to meet the crop water demands. This is not feasible since the water stress could impede severely on the yield in an eventual double production cycle in both locations. Therefore, the com-bination of improved early maturing varieties and a good cropping calendar planning could be suggested as recommendation to enhance the planning of agricultural water resources in the specific condition of Burkina Faso.

Summary and Conclusion

Water shortage is an important problem around the world for which one of the practical solutions are to make efficient use of water. Until now, it has been noticed that the Penman-Monteith, as well as ETo application for the irrigation purpose are still not used in Burkina Faso.

Based on the reference model of evapotranspiration estimation previously determined, an efficient agriculture water management can be carried out through compu-terized water balance analysis; thereby diminishing the high cost of water pumping, crop failure rate and yield decrease due to improper water supply.

The application of crop water balance simulation model is a decision making tool for farmers to stagger the planting and avoid exposing crops to water deficit during vulnerable crop growth stage. The RCI introduced in this study is a water balance analysis model based on the rainwater supply and crop demand.

From this present study, it showed that the crop water requirements (ETm) and their associated irrigation requirements of Ouagadougou were higher than Banfora without considering crop and planting date. In addition, the rainwater is insufficient for most of the crops in Ouagadougou, but is sufficient in Banfora. Consequently, one can say that the agricultural potential of Banfora is higher than Ouagadougou. In considering rainfall contri-bution during rainy season, May is the most favorable planting month for cassava, potato, sorghum, millet, groundnut and onion; and June for maize, dry bean, rice (FKR-28 and FKR-19). After the first crop, the suitable planting date for the second crop is September 1st in Banfora.

By following the suitable planting dates for Banfora suggested in this study, irrigation requirements of the second crops for bean, maize, sorghum, millet and groundnut can possibly need only 57.6; 60.9; 63.9; 66.6; and 69.8% to their water requirements, respectively.

Also, bean is the best second crop after the rainy season production. These conclusions could serve as basic information for farmer's decision on the choice of crop, the starting period of land preparation, sowing and harvesting period of their crops.

The present study highlights the low precipitation and short duration of rainy season with the maximum rain falling between July and September in Burkina Faso.

Beside the cropping calendar proposed herein, a careful selection of the crop and the variety more suitable to a given environment is of paramount importance for obtaining high and efficient production and enhancing the planning of agricultural water resources in this semi dry region.

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