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Mitigation effect of dry spells in Sahelian rainfed agriculture: Case study of supplemental irrigation in Burkina Faso

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This study aims to isolate the supplemental irrigation (SI) scenario from permeable rainwater harvesting basins (RWHBs) best suitable to mitigate the long dry spells (DSs) in Burkinabe Sahel (BS). The water flow in the soil was studied on corn crop during 2013 and 2014 depending on the available water in the monitored RWHB. The experimental design was a block Fisher with four treatments (one under rainfed regime and three under supplemental irrigation). Measurements of the soil water content revealed periods of corn water sufficiency in plots under SI. Average corn yields were respectively 4500 and 4600 kg ha^{-1} for 2013 and 2014 on plots under SI against 3700 and 3800 kg ha^{-1} for those in rainfed regime. The average contribution of the SI in increasing corn yield was respectively 24 and 26% in 2013 and 2014 for three supplemental irrigations (SIs), against 19 and 17% for two SIs. With these SIs, the water balance in the RWHB gave respectively at the end of 2013 and 2014, an available water of 60 and 81 mm. The suitable strategy of the SI to mitigate DSs effect in BS was applying two SIs with a dose at least 40 mm around the mid-season.

Key words: Supplemental irrigation, rainwater harvesting, dry spell mitigation, sustainable development, corn, Sahel.

INTRODUCTION

Rainfed agriculture remains the main way to produce the majority of food in the world and particularly in Sub-Saharan Africa. For this purpose, Valipour (2013a) reported that 54% of the world is suitable for rainfed agriculture whereas 80% of agricultural production comes from rainfed areas. For author, potentials for rainfed agriculture are low to moderate in Sahelian zone of Africa. This may be the great challenge to face in the

context of climate variability to meet the food needs of a constantly increasing African population. Indeed, rainfall in the Sudano-Sahelian zone of West Africa (WA) is characterized by a high spatial and temporal variability since several decades (Nicholson, 2001). Diouf et al. (2000) showed that rainfall variability has caused WA a shift in isohyets from 150 to 200 km southwards. According to Sissoko et al. (2011), a decrease of 20 to 40% in annual rainfall amount was observed in WA during the last four decades. Karambiri et al. (2011) highlighted that this climate variability will generate two major phenomena in the Sahel: i) frequent droughts and dry spells increasingly broad may be observed between two rain events and ii) a great uncertainty will concern the determination of the starting date and duration of the growing season. In Burkina Faso, the decrease in the annual rainfall amount was 15 to 30% between 1970 and 1980 (Servat et al., 1997) causing frequent dry spells (DSs) during the rainy season. These DSs occurring within the agricultural season can range from one week to several weeks between rain events (Fox et al., 2005). This situation led to uncertainties regarding the duration of the rainy season and negatively impacted the crops yield (Niemeijer and Mazzucato, 2002). For instance, the recent dry agricultural season of 2011-2012 was characterized in Burkina Faso by a decrease of 12% in corn production compared to the growing season of 2009-2010 (MASA, 2013).

Coping with the rainfall variability, Sahelian farmers have adopted several agricultural practices (*zaï* pitting, stone bunds, terracing, and mulching) to mitigate the negative impact of DSs on crops (Tiffen et al., 1994; Roose et al., 1995; Ouedraogo and Kabore, 1996; Hatibu and Mahoo, 2000; Lahmar and Yacouba, 2012). These practices are essentially based on good water resources management and the use of short-season varieties. Despite these efforts, Fox et al. (2005) reported that cereal yield levels remains low and oscillates around one tonne per hectare, e.g., less than 25% of potential on-station yields. Thus, to upgrade Sahelian rainfed agriculture, several studies recommend crop irrigation as best resilient alternative (Fox and Rockström, 2003). Basing on the status of the agricultural water management, studies by Valipour (2014a, 2014b, 2014c, 2014d, 2014e, 2014f, 2014g, 2015a), Valipour et al. (2015b) showed not only the necessity of increasing irrigated agriculture but also suggested to use deficit surface irrigation in small farms to increase irrigation efficiency. However, more than 90% of African countries have less than 10% of cultivated areas equipped in irrigation (Valipour, 2013b, 2014d). This situation is due to the lack of the water management in most of African countries and any innovation to improve the agricultural water management in areas characterized by the water scarcity like the Sahel is encouraged. It is in this sense that the program "Supplemental Irrigation" was initiated by the International Institute for Water and Environmental Engineering (2iE) in collaboration with the Research

Center for International Development of Canada (IDRC) and tested in the Sahelian Zone of Burkina Faso (SZBF). The approach of the project was to build the partially waterproofed basins named rainwater harvesting basins (RWHBs) intended to collect runoff. The stored water was used for the supplemental irrigation (SI) during DSs in order to avoid the crops water stress. However, the crop water requirements depend on the soil storage capacity, the frequency and the amplitude of DSs, the agricultural practices, the crop rooting depth and the available water in the rainwater harvesting basins (RWHBs). Thus, the establishing of SI scenarios in the SZBF must be based on the response of soils under irrigation at the evolution of DSs concomitantly with the crop phenology and the water availability in the RWHB. The research assumption used is that: having enough water is not an end by itself, but having it at good place and at good time is a suitable strategy. From this, shown that the SI from RWHBs improves crop yields is no longer a problem to search for, but seeking to assess the contribution of these partially waterproofed basins in mitigating the effects of frequent DSs in the Sahel is a challenge for research. This study specifically attempts to isolate the SI scenario from permeable RWHBs best suitable to mitigate DSs in Burkinabe Sahel (BS).

MATERIALS AND METHODS

This study, in relation with water balance in the RWHB, deals with water transfers in a leached ferruginous tropical soil (LFT) often tilled in BS because of their light texture. An appropriate experimental design was used to optimize the SI scenario suitable for corn (*Zea mays* L.), a cereal that has a water use efficiency (WUE) higher than those of millet (*Pennisetum glaucum* (L.) R.Br.) and sorghum (*Sorghum bicolor* L.) commonly grown in BS.

Study area and experimental design

The study was conducted in Kongoussi (13°16' N, 1°32' W) located in central northern of Burkina Faso in the Sahelian zone (Figure 1). Agricultural areas in the Province of BAM have experienced a continuing degradation of natural resources especially the soil (Rasmussen et al., 2001).

The climate is Sahelian, characterized by a dry season of eight to nine months and a rainy season of three to four months. Data on the length of the rainy season from 1960 to 2011 showed that it lasts on average 21 to 79 days.

The tillable horizon of dominant soils (LFT soil) is sandy loam, with low organic matter (Pallo et al., 2006). The main characteristics of the soil in the experimental site are presented in Table 1. This soil has a sandy loam layer (0 to 30 cm) and an underlying thicker clay loam with higher water content.

The experiment was conducted on a plot of 2000 m^2 sown in corn. The variety used is *Barka* (80 days), which is resilient to drought and has a potential yield of around 5000 kg ha^{-1}. The water availability for crop was controlled using tensiometric tubes placed at depths of 0.15, 0.30, 0.50, 0.70 and 0.90 m. The experimental design was a randomized Fisher block (Figure 2) with four repetitions corresponding to blocks and four irrigation treatments or supplemental irrigation scenarios (T0, T1, T2, and T3). All supplemental irrigations (SIs) were applied during the mid-season.
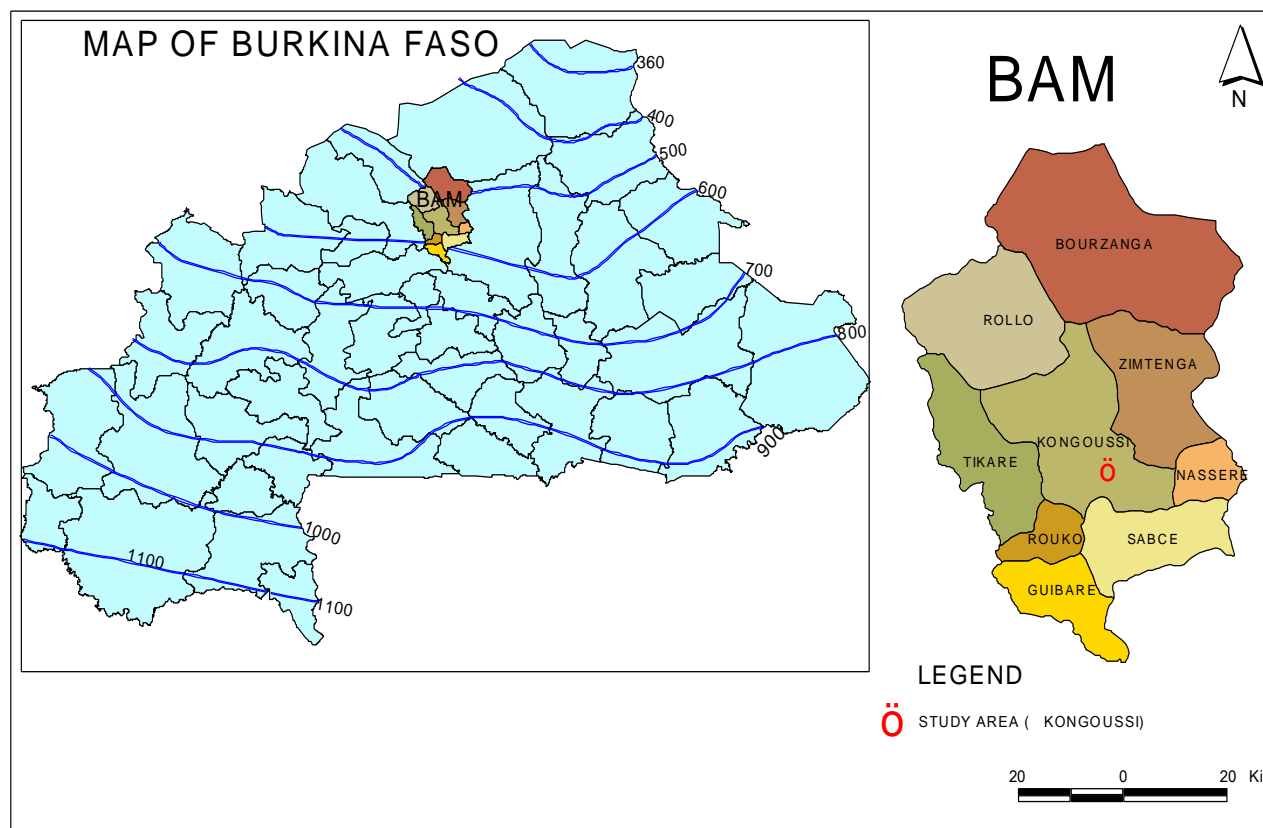
Figure 1. Localization of study area (Kongoussi) in BAM province, Burkina Faso.

Table 1. Physical and chemical properties at the experimental site soil.

Horizon (cm)	Clay %	Silt %	Sandy %	BD g.cm^{-3}	OM %	C/N	FC %	PWP %	pH	CEC cmole.kg^{-1}
0-30	10.45	32.2	57.35	1.58	1.02	13	13.72	5.22	6.46	8.58
30-100	34.55	30.73	34.72	1.73	0.80	13	24.49	10.02	6.12	7.5

Note: BD = bulk density, OM = organic matter, FC = water content at field capacity, PWP = water content at permanent wilting point, C/N = ratio of total percentage carbon and nitrogen, CEC = cation exchange capacity.

The treatment T0 was conducted under rainfed regime during the corn growing season. The SI scenarios and the targeted periods are summarized in Table 2. The irrigation depths varied between 30 and 51 mm according to the water availability in the RWHB and the corn water requirements for ten days. A device gauge was installed for daily monitoring of the temporal variation of the water depth in the RWHB.

These SI scenarios were chosen to coincide with phases of high sensitivity to water stress and also due to the low satisfaction of corn water requirements during the mid-season in the SZBF. Indeed, depending on the sowing dekad, water stress is very frequent during the mid-season over the last forty years as shown in Figure 3. Thus, with a daily reference evapotranspiration (ETo) of 8 mm, water requirements for 80-days maturity corn growth are totally met one year in ten years (10% probability) during the mid-season (Figure 3a) while they are the order of four to six years in ten years (40 to 60% probability) for 5 mm per day of ETo during the same growth stage (Figure 3b). Also, Figure 3 shows that the suitable sowing period is the third dekad of June (June_3). The term "dekad" in this study is a period of 10-days. Each month is divided into three dekads starting from the 1st, 11th, and 21st day of the month. The third dekad has sometimes more than 10 days (e.g. January, March, etc) or less (February). May_1 in Figure 3 is the third dekad of May, June_1, June_2, and June_3 are respectively the first, the second, and the third dekad of June, etc.

Implementation of the experiment and the soil water balance

Before corn sowing, the experimental field received 900 kg ha^{-1} of organic manure as compost before being plowed (animal traction) and ridges separated by 0.8 m were made manually, perpendicular
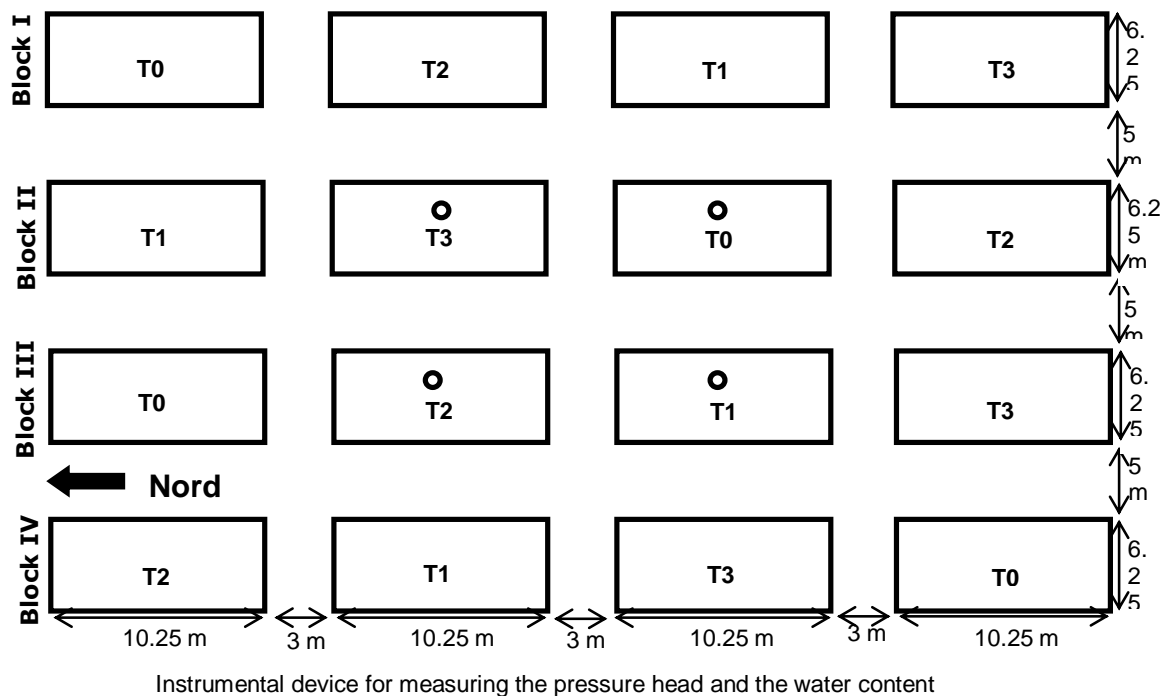
Figure 2. Experimental design showing plots and treatments or supplemental irrigation scenarios (T0, T1, T2 and T3) per block.

Table 2. Number of the supplemental irrigation (SI) applied by corn growth stages.

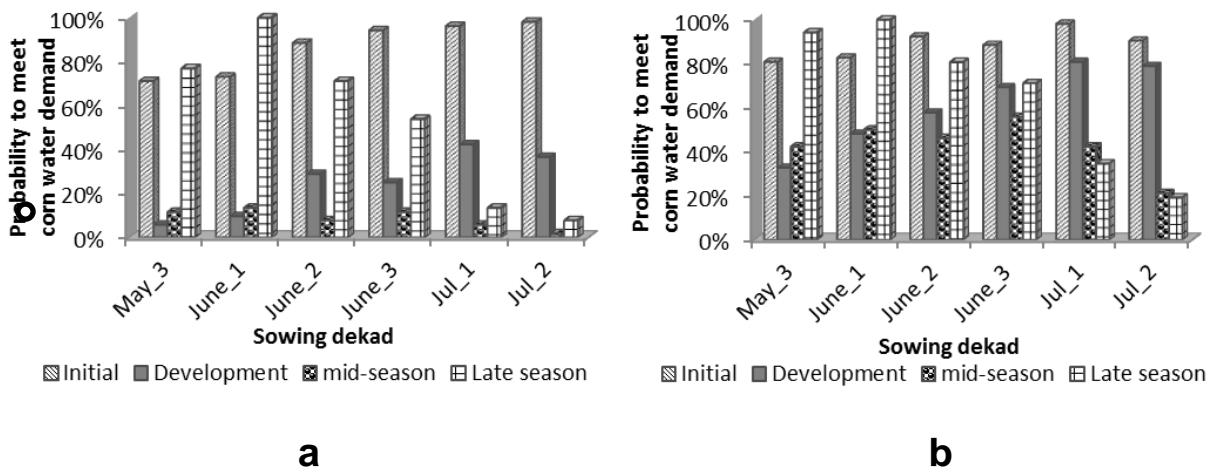| Treatment	Initial	Development	Mid-season			Late season	Total of SIs
			Flowering	Pollination	Grain filling		
T0	0	0	0	0	0	0	0
T1	0	0	1	1	0	0	2
T2	0	0	1	0	1	0	2
T3	0	0	1	1	1	0	3

Figure 3. Probability for which the rainfall meets corn water requirements per growth stage according to the sowing dekad under two values of ETo in Burkinabe Sahel (a) ETo = 8 mm d^{-1} (b) ETo = 5 mm d^{-1}.
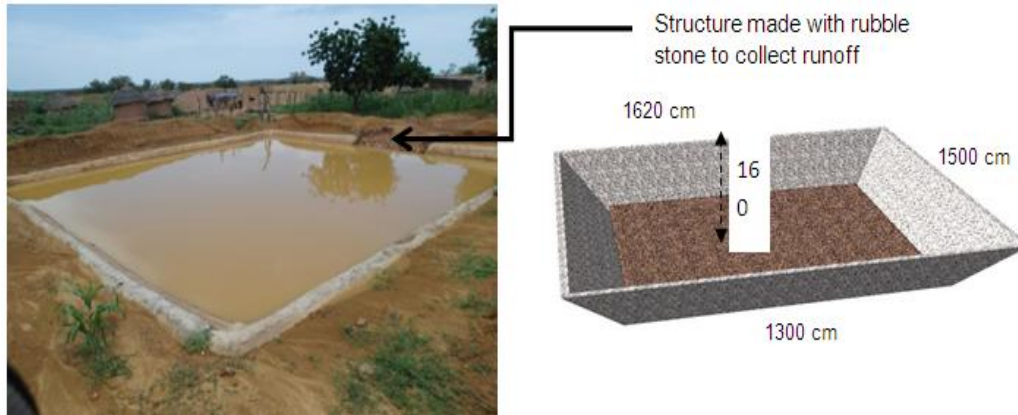
Figure 1. View of the studied rainwater harvesting basin (left) and its dimensions (right).
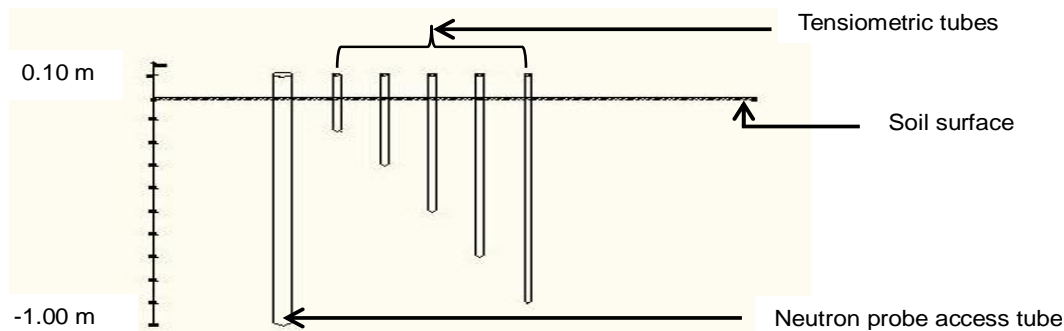

Figure 5. Measurement device of the soil water content and the pressure head.

to the steepest slope. Corn grains were sown manually in holes on a 0.4 m by 0.8 m grid on June 30, 2013 and June 23, 2014.

The mineral fertilization consisted in the application of 200 kg ha^{-1} NPK (Nitrogen, phosphorus, potassium) the 12th day after sowing (DAS) followed by 100 kg ha^{-1} of urea (46%) the 25th DAS and 50 kg ha^{-1} of urea (46%) the 35th DAS. The thinning to two plants per hole was made at plant emergence. Weeding and ridging were performed for each weed emergence. Irrigation was made from a surface irrigation system. The variant was the semi-Californian constituted of a main pipe and four secondary pipes supporting valves installed upstream of each experimental unit. Furrow irrigation was the technique used to irrigate plots. Irrigation water came from a partially permeable RWHB with a total capacity of 283 m[3] (Figure 4a and b). Only sides of the RWHB were concreted.

Monitoring of the soil water content and the pressure head was performed daily during the rainy seasons of 2013 and 2014 at 7 a.m. Each experimental unit was equipped with neutron probe access tube ($\emptyset$50 mm) and five tensiometric tubes placed at depths of 0.10, 0.30, 0.50, 0.70 and 0.90 m for monitoring respectively the soil water content and the pressure head (Figure 5). These depths were selected to monitor in real time the water availability in the corn root zone. The water content measurements were made every 0.10 m up to 1.00 m using the neutron probe "503DR Hydroprobe" (AIEA, 2003). The water content at 0.10 m was representative of the average water content in the layer 0-0.15 m.

The drainage was estimated using Darcy's law (Equation 1) at the maximum rooting depth of 0.80 m using the tensiometric measurements taken at 0.70 and 0.90 m.

$$q = -K(h)\frac{dH}{dz} \tag{1}$$

where q $[LT^{-1}]$ is the water flux, $K(h)$ $[LT^{-1}]$ is the unsaturated hydraulic conductivity and $\frac{dH}{dz}$ is the hydraulic gradient head in which H $[L]$ is the hydraulic head and z $[L]$ is the depth at which the pressure head h $[L]$ was measured. Unsaturated hydraulic conductivity was determined using a tension disc infiltrometer under two pressure heads (-2 cm and -4 cm).

H and z are connected by the Equation (2):

$$H = h - z \tag{2}$$

Thus, the water drained D $[L]$ at 0.80 m depth was estimated as follow:

$$D = \bar{q}\Delta t \tag{3}$$

where $\bar{q}$ is the average water flux over the time interval Δt = 86400 s corresponding to two successive measurements of the pressure head.

The soil water storage WS $[L]$ from the soil surface to 0.80 m was determined using Equation (4):
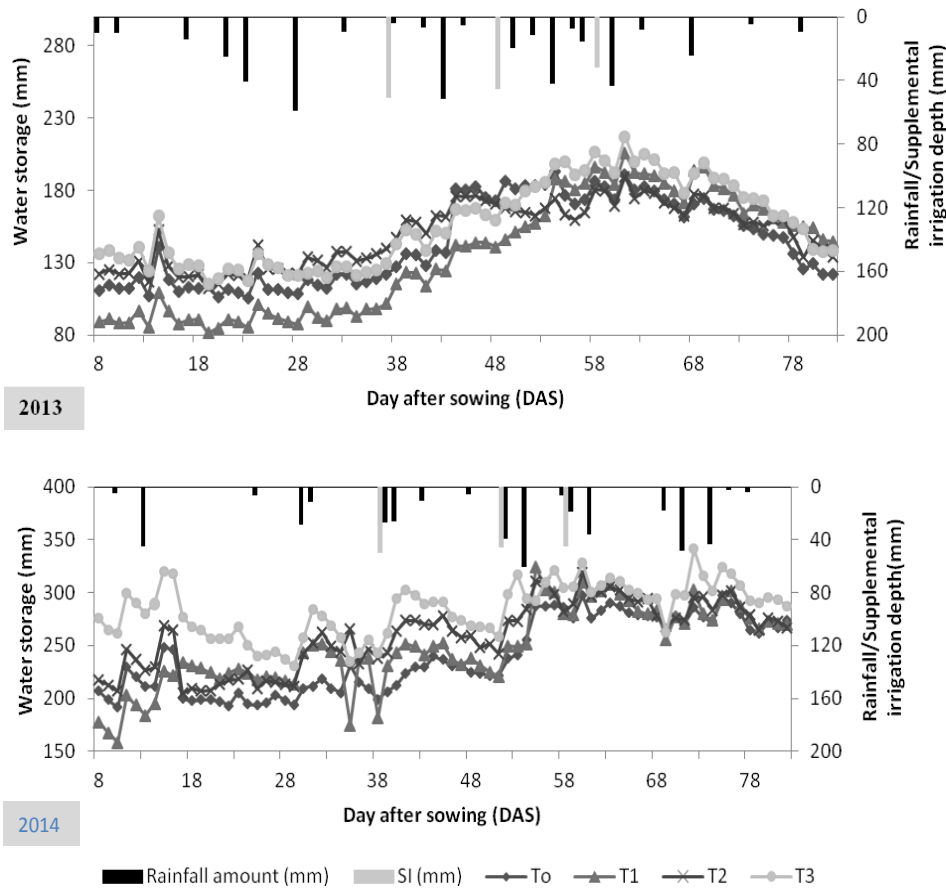
Figure 6. Temporal variation of the water storage at 0.80 m depth in corn root zone, the rainfall amount and the supplemental irrigation (SI) applied in 2013 and 2014.

$$WS = (\theta_{10} \times 150) + (\theta_{20} \times 100) + (\theta_{30} \times 100) + \ldots\ldots + (\theta_{80} \times 50) \quad (4)$$

where θ_i [$L^3 L^{-3}$] is the water content at the depth $i = 10, 20 \ldots, 80$.

The corn actual evapotranspiration (ETa) [L] was estimated from the simplified water balance in the soil through Equation (5).

$$ETa = P + I - (\Delta WS + D) \quad (5)$$

where P [L] is the rainfall amount, I [L] is the irrigation depth and ΔWS [L] is the change of the soil water storage. The crop yield was estimated using yield squares (1 m²) installed in three repetitions on each plot. The grains harvested in late season were air-dried and weighed with an accurate electronic scale.

Statistical analysis data

The Student's test (paired t-test) was used under SAS software (version 9.2) to assess statistically, the significance at 5% of the water drained at 0.80 m depth under the corn root zone. The analysis of variance was performed to test whether differences exist in the yield of the corn from different treatments.

RESULTS

Study of the water flow

The water dynamics was studied in each treatment on the basis of the soil pressure head and the soil water content especially regarding the water storage in the soil profile and the drainage at 0.80 m depth.

Temporal change of the water storage and analysis of dry spells

The corn growing season has been subdivided into four stages of different length: 10 days for the initial stage, 30 days for the development stage, 25 days for the mid-season or corn reproductive stage and 15 days for the late season. The temporal variation of the water storage in the root zone (0-0.80 m) according to the different treatments is represented in Figure 6.

In 2013, the water storage has fluctuated according to the rainfall regime from the 28th day after sowing (DAS) to the corn reproductive stage (40th to 65th DAS) where
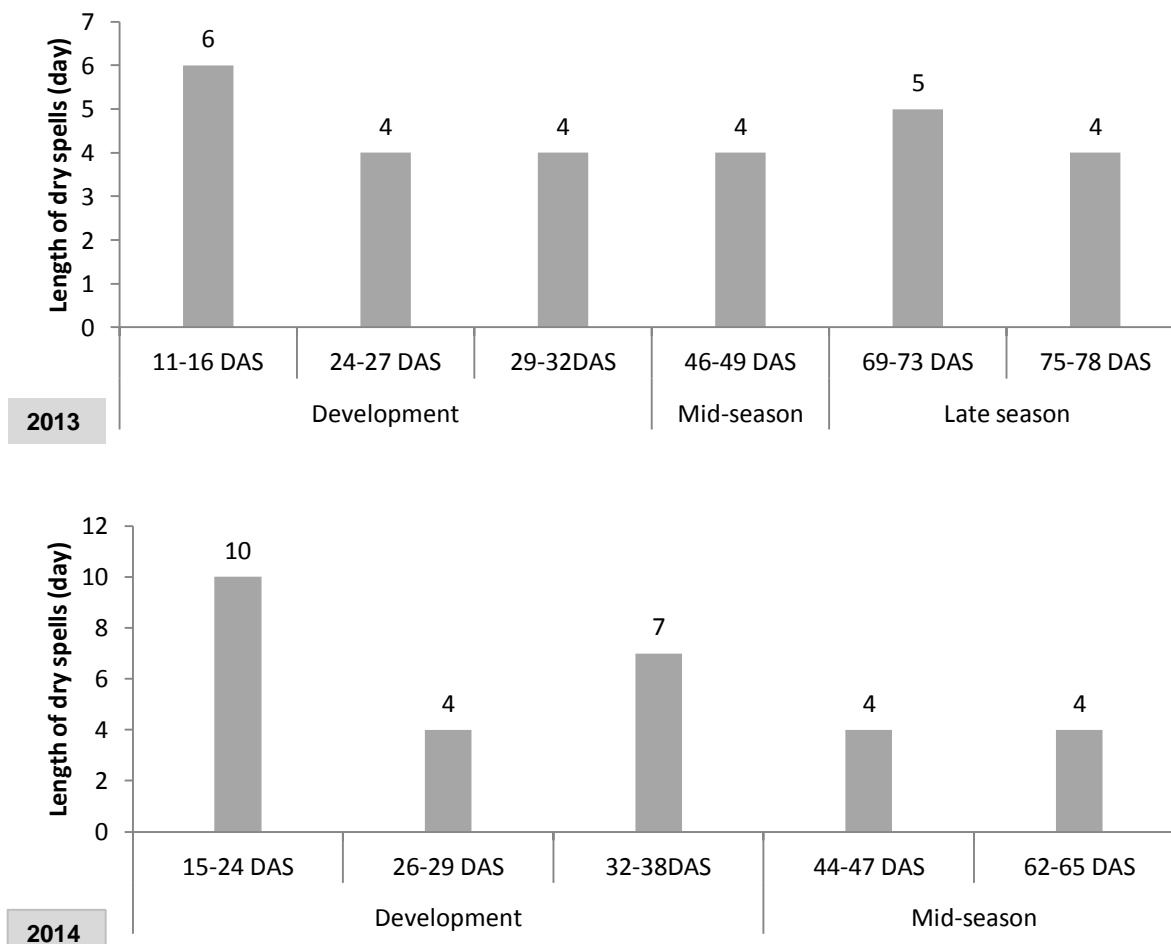
Figure 7. Length of dry spells of more than three days and the period of occurrence.

the available soil water reached its maximum value. The decrease in the water storage at the 55th DAS is due to the water redistribution in the soil. The water content measurements just performed at the end of the rain still do not detect a reaction at the 0.80 m depth because the infiltration front was still in the first soil horizon. The SI applied the 37th and the 48th DAS has caused a respective increase of the water storage from 17 to 46% and from 10 to 13%.

In 2014, the soil water storage from the surface to 0.80 m depth varied between 158 and 341 mm against 81 and 217 mm in 2013. This gap largely resulted from the difference in the rainfall during the two corn growing seasons (454 mm in 2013 against 493 mm in 2014) and the high frequency of the consecutive rainfall (30th and 31th DAS, 39th and 40th DAS, etc) in 2014. Also, the fact that furrows were blocked at their end in 2014 favored more water infiltration. An increase of 2 to 27% and 13 to 15%, respectively were obtained after the SI applied the 38th and 51th DAS in 2014. These low contributions compared to those obtained in 2013 are due to the initial soil water content before the SI which is higher in 2014.

Analysis of the temporal variation of the rainfall (Figure 6) has allowed determining the length of dry spells of more than 3 days. The DSs in this study correspond to the number of consecutive days with less than 1 mm d^{-1} of rain during the growing season. Results in Figure 7 show that the DSs of 6 days occurred once in 2013 between the 11th and the 16th DAS. During the mid-season (from 40th to 65th DAS), the longest DS was 4 days. In 2014, the longest DS was 10 days and occurred during the development stage from 15th to 24th DAS. The DSs of 7 days occurred at the end of the development stage. The second DS period of 4 days in the mid-season (62-65th DAS) was followed by 3 days DS (66-68th DAS). Thus, the SI applied at the 58th DAS in 2014 mitigated the effect of 7 days DS.

In short, the SI applied showed an increase of the soil water storage regardless crop year and treatments. The increase is higher with a SI depth at least equal to 40 mm. No DS more than 7 day occurred during the mid-season. Likewise, two SIs (T1 and T2) were worth as much as three (T3) in view of the water storage analysis in the different experimental units.

Table 3. Amount of water drained at 0.80 m depth under corn root zone according to irrigation treatment and the growing season.

Year	T0	T1	T2	T3
2013	8[a]	9[a]	13[a]	36[b]
2014	116[c]	120[c]	169[d]	169[d]

In row, values followed by the same letter are not significantly different at the 0.05 probability level.

Table 4. Corn actual evapotranspiration (ETa) and actual yields (Yact) for each experimental unit in 2013 and 2014
In row, values of ETa followed by the same letter are not significantly different at the 0.05 probability.

	T0	T1	T2	T3
Year 2013				
ETa (mm)	332	427	438	464
Yact (kg ha^{-1})	3600[a]	4400[a]	4400[a]	4600[a]
Year 2014				
ETa (mm)	390	446	457	489
Yact (kg ha^{-1})	3800[b]	4200[b]	4700[b]	4800[b]

Evaluation of the drainage under corn root zone

Table 3 summarizes amounts of water drained at 0.80 m depth under the different water treatments. We noted that the total water drained remain low in 2013 but higher in 2014. This result correlates with the increase of the water storage in 2014 compared to 2013 and showed the role of blocked furrows in the water management to favor infiltration. The water drained under corn root zone in 2014 was significant at 5% as shown in Table 3.

Corn actual evapotranspiration and grain yields

Table 4 summarizes corn water consumption (ETa) and grain yields (Yact) over the period from July 01 to September 18, 2013 and from June 23 to September 10, 2014. From that table, it can be inferred that the actual evapotranspiration (ETa) was higher in the experimental units under the SI.

Indeed, in 2013 Treatments T1, T2, and T3 have received respectively 96, 83 and 128 mm of SI. This was the basis of the largest water consumption reflecting a certain water sufficiency. The additional water depths relative to T0 in 2014 resulted from the SI that was 96 mm for T1, 95 mm for T2, and 145 mm for T3. The average daily consumption in rainfed regime was respectively 4.2 mm and 4.9 mm in 2013 and 2014 against an average of 5.5 mm and 5.8 mm in SI. The daily corn consumption under two SIs varied from 5.4 mm to 5.6 mm against 5.8 mm to 6.1 mm under three SIs. This result confirms that two SIs targeting the mid-season(flowering and grain filling) were worth as much as three (flowering, pollination and grain filling).

The highest yields were noted in Plots T1, T2 and T3 under SI and were due to the complementary water brought on these plots. However, the yields in 2013 and 2014 with two or three SIs were not significantly different (Table 4) from those obtained in rainfed regime. However, the SI has increased grain yield from 400 to 1000 kg ha^{-1}. The average contribution of the SI in increasing the yield was 21% in 2013 and 2014. The average contribution for three SIs was respectively 24 and 26% in 2013 and 2014 against 19 and 17% for two SIs. Thus, the flowering and grain filling stages were the important growth stages for applying the SI in the BS.

DISCUSSION

In Sub-Saharan Africa (SSA), the recurrent droughts observed from 1970 in most arid and semi-arid areas, have caused huge losses of land formerly fertile reinforcing thus the rural famine. This calamity resulted in implementations at national and international levels of programs and projects focusing on the conservation and the management of soils and freshwater resources. Among technologies considered, the rainwater harvesting (RWH) was listed as a specific adaptation measures to face future climate change (Mwenge Kahinda et al., 2010) especially in the Sahelian zone (Rockstrom et al., 2002) which is vulnerable to the CV impacts and where adaptive measures are needed. For now, the development of this technology is limited despite its great potential in reducing the CV impacts on the water security in many African regions (Mwenge Kahinda et al., 2010).

The risk of crop harvest loss decreases with RWH when they are intended for the agricultural production through the SI. However, this measure is very few adopted in the SZBF, an area where less than 1% of farms practice irrigation (Ouedraogo et al., 2010). The few instances of RWH (locally named *boulis*) are for pastoral and housewife purposes. Even when they are used for the SI, sorghum and millet are preferred (Fox and Rockström, 2000) to corn because this one has a high sensitivity to water stress. Nevertheless, corn is a cereal with high value-added that uses water efficiently and can diversify the cereal ration of Sahelian farmer. Under this approach, the present study breaks this barrier and exposes a technology of the SI development for corn production in the smallholders farming through the RWHB.

The objective of this study is to highlight the importance of the rainwater harvesting basins for practicing the SI in order to mitigate DSs in BS, an area characterized by erratic rainfall. It specifically attempts to isolate the suitable SI scenario to overcome DSs in rainfed agriculture. For this purpose, the analysis of the temporal evolution of the water storage in the corn root zone on loamy sand soil showed similar water behavior in all plots. Nevertheless, the SI has been instrumental in the corn water supply in the SZBF through RWHB. These SIs applied have allowed to meet the corn water requirements estimated between 450 mm and 750 mm (Doorenbos and Kassam, 1987; Er -Raki et al., 2007) in which irrigation has contributed up to 40 %. Such results are in agreement with those of Perret (2006) who showed that in the southwestern part of Burkina Faso, the cereal water requirements are easily satisfied in rainfed agriculture, while in the Sudano-Sahelian and Sahelian regions, SI is needed to enable crops to properly complete their development cycle without water deficit. Regarding this climatic stress, Velazquez (2007) suggested the use of precocious varieties which need less water in areas with water scarcity.

Actual evapotranspiration (ETa) determined in this study varied according to the irrigation treatment and was in agreement with those reported by Istanbulluoglu et al. (2002) in the climatic conditions of Tekirdag (Turkey). This author found that, under furrow irrigation, ETa of corn was 586 mm in full irrigation against 353 mm in rainfed regime. The grain yields reflect the satisfaction level of the corn water requirements during the agricultural season. For the rainfed regime, these yields are generally lower than those obtained with the SI but the gap is not different across the years. This situation is due to the variety of corn used that is an improved variety resistant to drought and the two agricultural seasons were wet. The DSs of more seven days were not observed during the sensitive period to water stress and the monitoring of the soil pressure head has not fallen below the threshold of 0.6 bars. Also, the sowing days in our study correspond to the suitable corn sowing period suggested by Wang et al. (2009) for the BS. This sowing

period suggested for corn helps the crop to avoid severe water stress during the agricultural season. The significance of the SI contribution in increasing grain yields in the Sahel region becomes noticeable in year with frequent DSs as observed by Oweis and Hachum (2004). The gap increases when DSs occur during the period most sensitive to water stress (Payero et al., 2009).

The analysis of the water transfers in the soil and the corn yields showed the necessity of the SI for the corn production in BS to increase rainfed output. However, the most important factor in the SI scenario adopted is the water depth for irrigation that depends on the physical soil properties and the total available water (TAW) in the RWHB. Nevertheless, monitoring the water level in the RWHB (Figure 8) during the experimentation showed an average water depth of 65.5 mm to irrigate a plot of 2000 m^2. Also, the available water varied between 36 and 88 mm at the mid-season. So, for more twenty days of DS, the scenario T2 can better mitigate the effect of this DS on the corn yield than scenario T3. The reason is that T2 needs at least 80 mm against 120 mm for T3 in assumption that 40 mm of SI is applied for each targeted stage at the mid-season. At the end of the agricultural season, the average water depth was 60 mm in 2013 and 81 mm in 2014. Such considerable difference between variations of total available water in the basin during 2013 and 2014 is due to the soil warping which occurred at the end of the agricultural season of 2013 since Niang et al. (2012) found that soil warping in the time can reduces significantly water infiltration. This water availability can enable for smallholders farming to diversify their agricultural production by introducing the market gardening. The rainwater harvesting technique for the SI is well known in Kenya, Tanzania and in many others countries of the SSA (Falkenmark et al., 2001). Its potential gains are for smallholder farmers higher yields and improved food self-sufficiency (Baron, 2004). Thus, if the water supply of RWHBs is reliable, smallholders are then encouraged to invest and their food security may improve. A large adoption of the RWHBs is very important for Burkinabe agriculture which is mainly rainfed and dominated by small-scale farmers. Besides, controlling the soil erosion and the groundwater recharge are additional advantages of this technique well adapted to the BS.

Conclusion

This study that aimed at analyzing the contribution of the SI in corn production from the small RWHBs partially waterproofed, showed the role of these basins in bringing water supply to the plant during dry periods. The water storage on the experimental units under SI was higher than those in rainfed regime especially during the periods where the SI was applied. The average contribution of
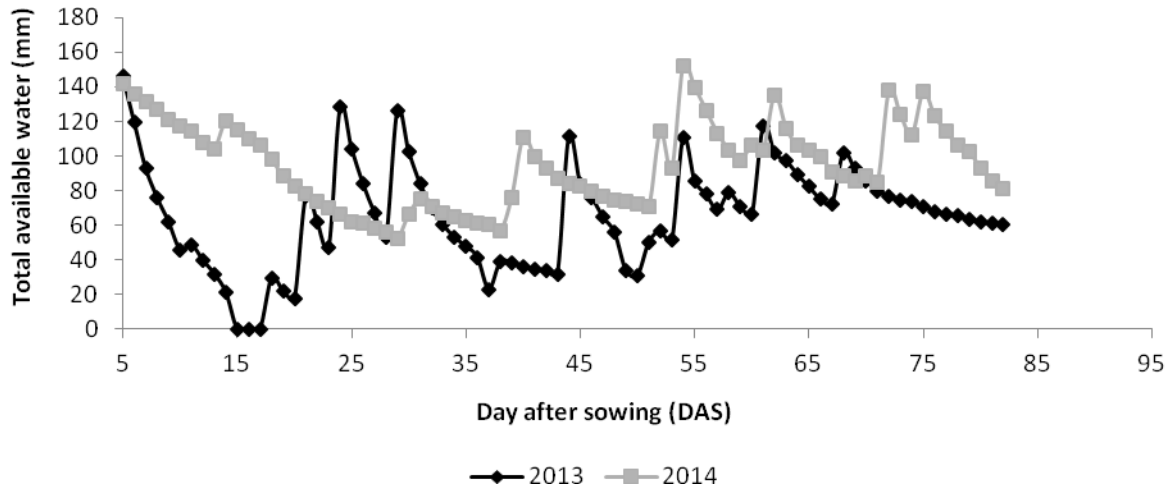
Figure 8. Fluctuation of the total available water depth in the RWHB during the corn growing seasons to irrigate a plot of 2000 m^2.

the SI to increase the corn yield was respectively 24 and 26% in 2013 and 2014 for three SIs against 19 and 17% for two SIs.

The coupling of the appropriate corn sowing date with its sensitive phase of water stress allowed finding the SI scenario suitable to the climatic conditions of BS for corn production. Thus, the scenario of two SIs with at least 40 mm of water depth and targeting the mid-season, especially flowering and grain filling stages, was the suitable strategy to mitigate DS effects in corn production at BS when the sowing is done in the third dekad of June. However, a complementary study may be conducted for refining this dose of the SI taking into account the crop water requirements and the soil features. In this sense, water flow simulation in the continuum soil-plant-atmosphere will be the best approach.

Conflict of Interest

The author(s) have not declared any conflict of interests.

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