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Full Length Research Paper

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

. *Corresponding author. E-mail: vichaim@yahoo.fr 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.

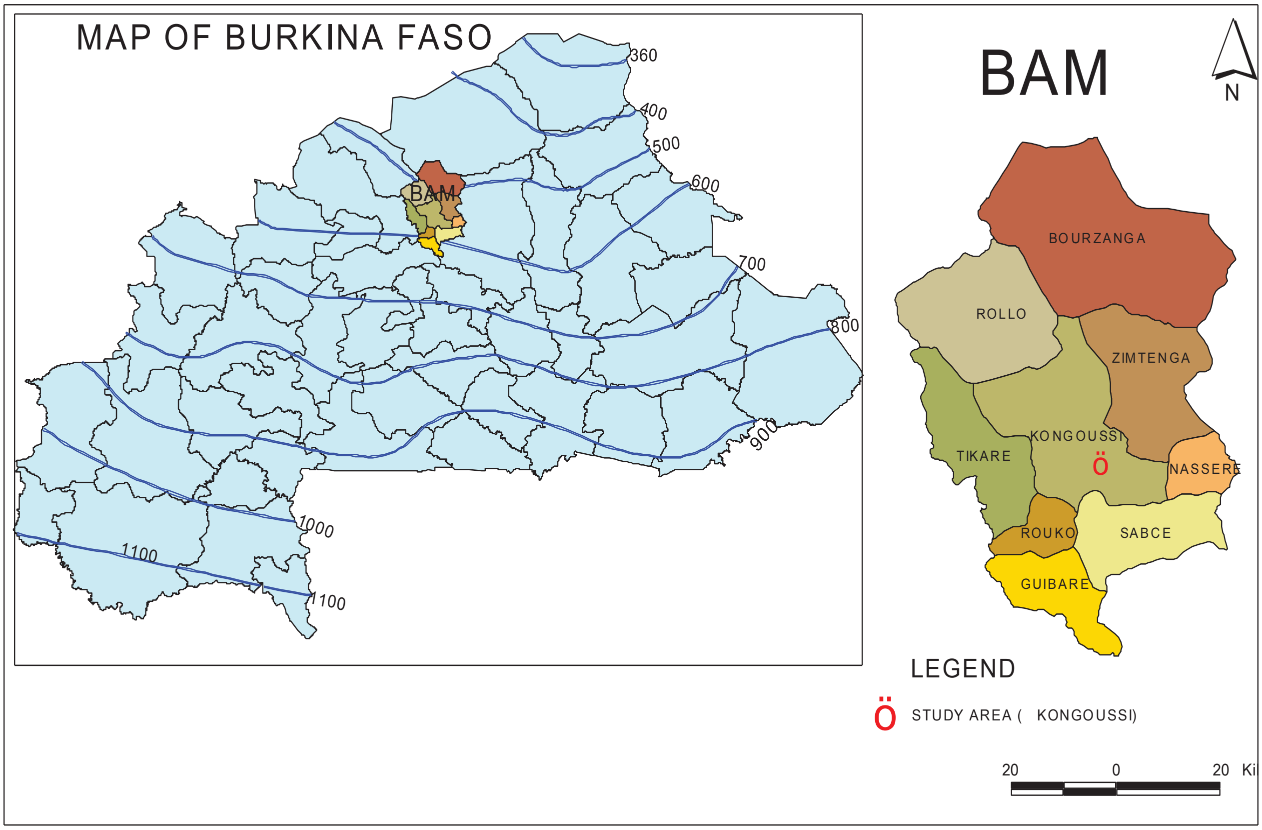

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Figure 1. Localization of study area (Kongoussi) in BAM province, Burkina Faso.

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

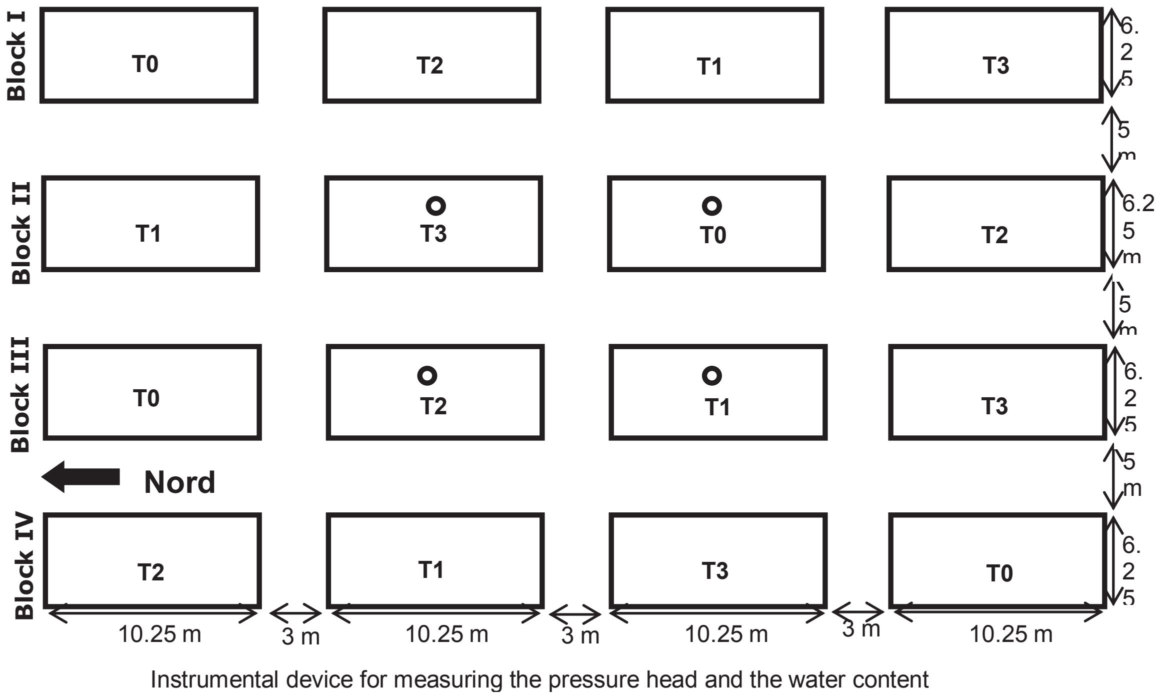

Figure 2. Experimental design showing plots and treatments or supplemental irrigation scenarios (T0, T1, T2 and T3) per block.

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

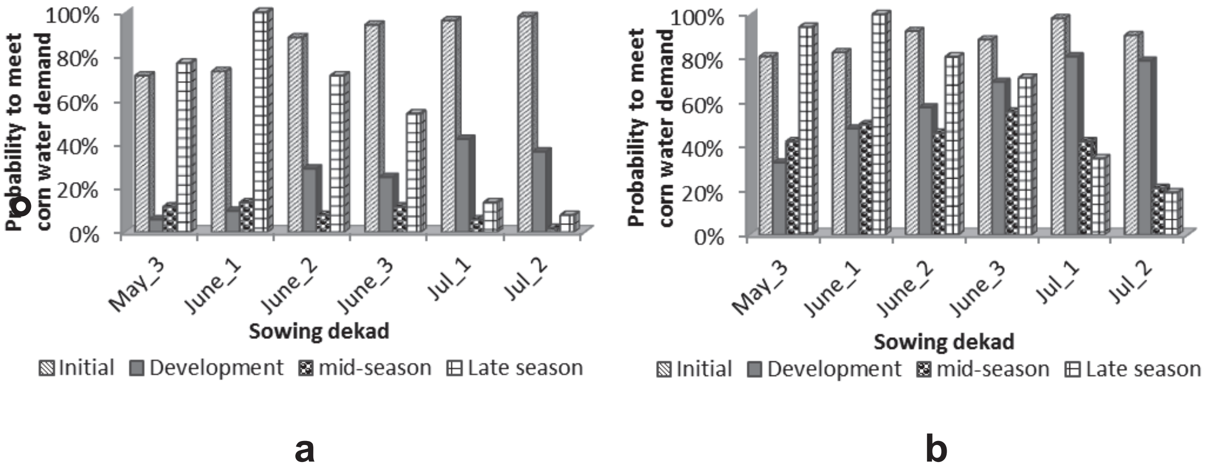

Figure 3. Probability for which the rainfall meets corn water requirements per growth stage according to the sowing dekad under two values of ETo in Burkinabe Sahel (a) ETo = 8 mm d^{-1} (b) ETo = 5 mm d^{-1}.

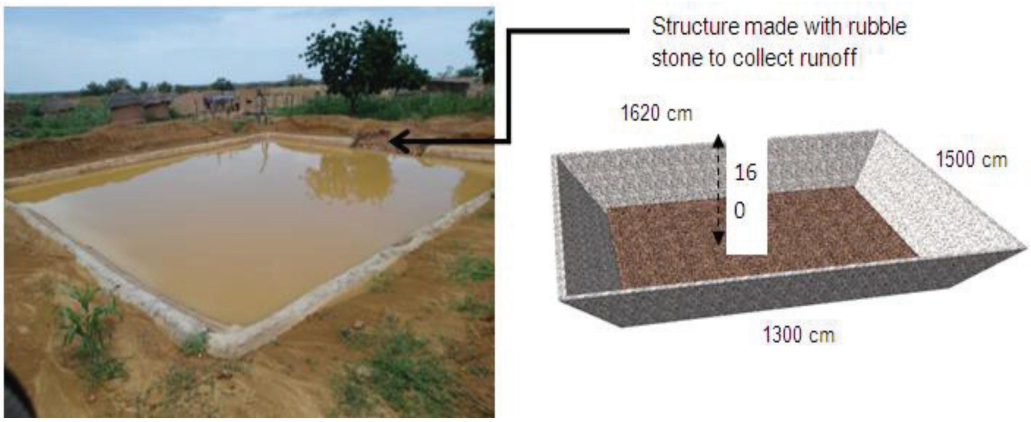

Figure 4. View of the studied rainwater harvesting basin (left) and its dimensions (right).

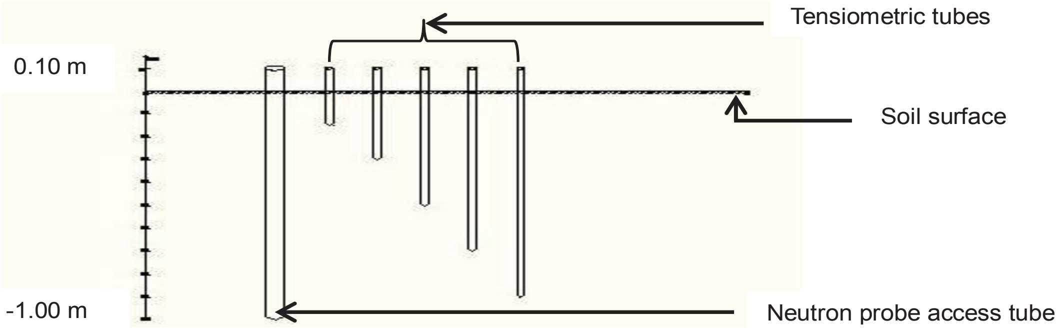

Figure 5. Measurement device of the soil water content and the pressure head.

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 (Ø50 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.

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

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):

$$H = h - z \qquad (2)$$

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

$$D = \overline{q}\Delta t \qquad (3)$$

where $\overline{q}$ 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):

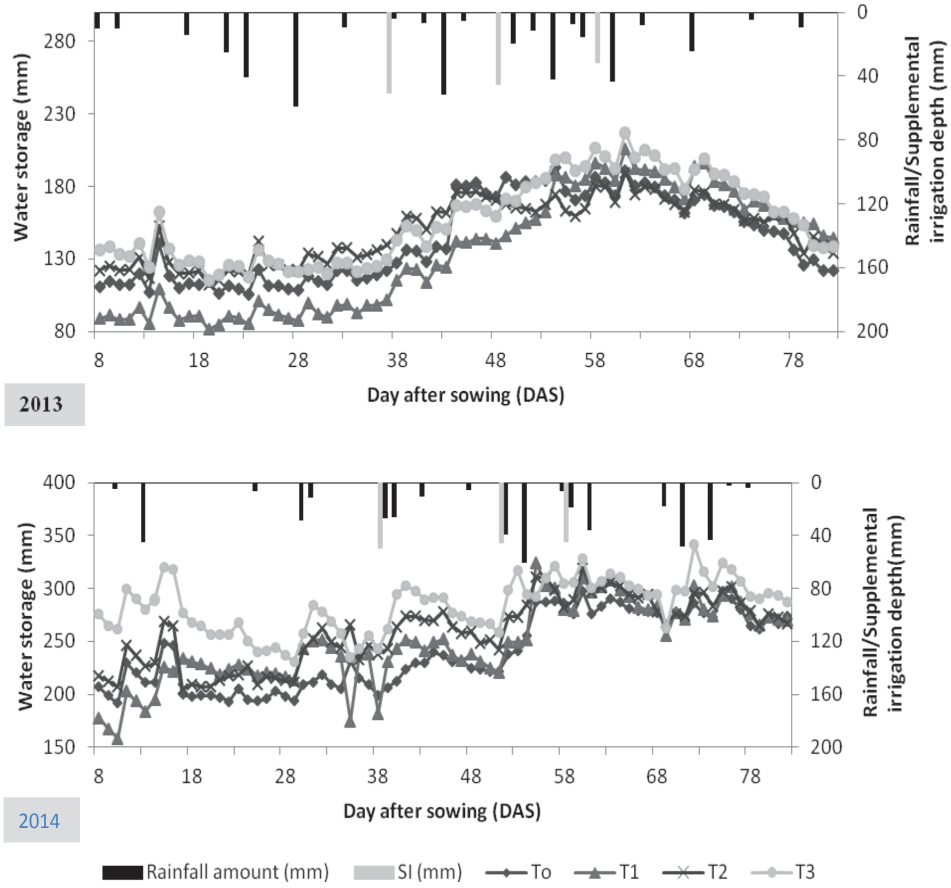

Figure 6. Temporal variation of the water storage at 0.80 m depth in corn root zone, the rainfall amount and the supplemental irrigation (SI) applied in 2013 and 2014.

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

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 m^2) 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

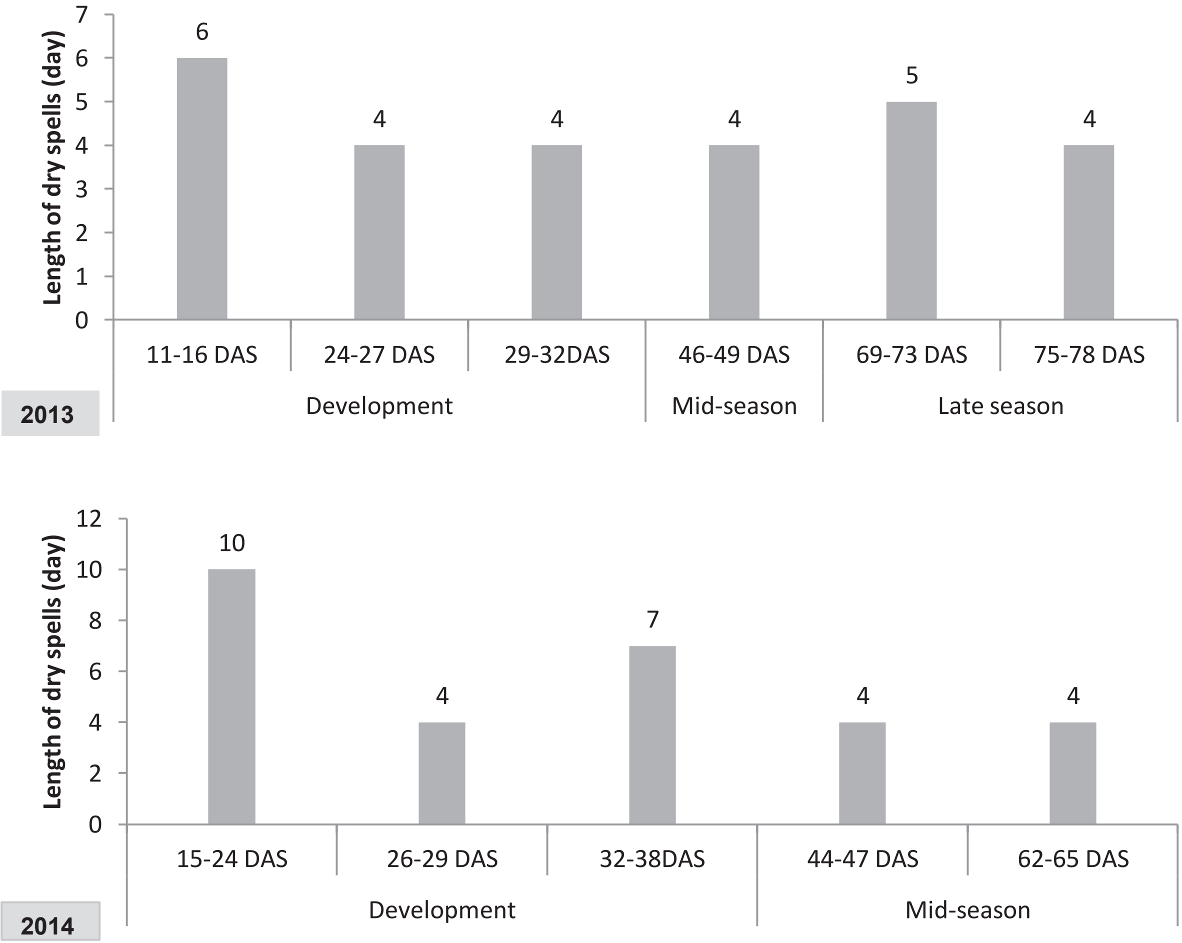

Figure 7. Length of dry spells of more than three days and the period of occurrence.

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

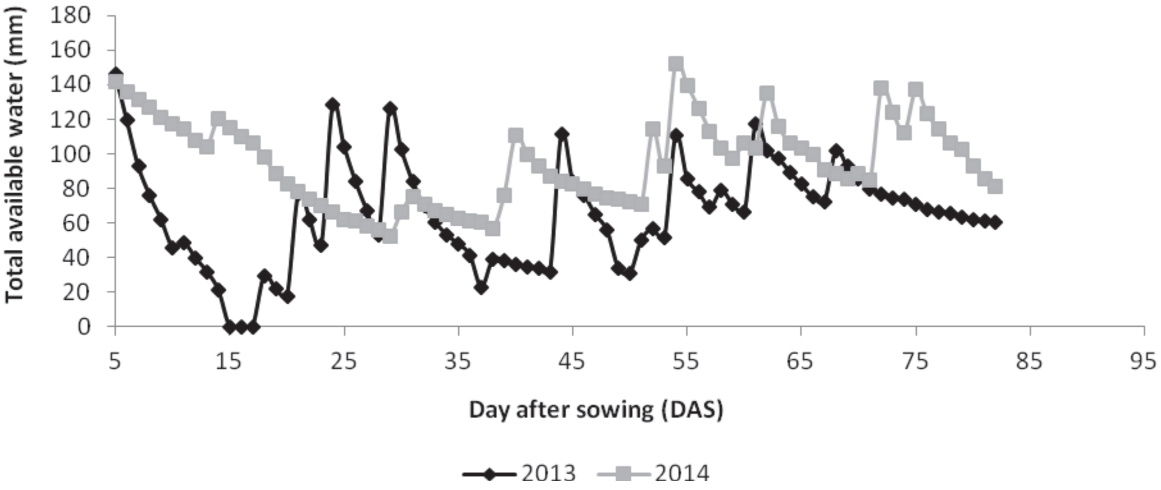

Figure 8. Fluctuation of the total available water depth in the RWHB during the corn growing seasons to irrigate a plot of 2000 m^2.

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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Full Length Research Paper

Evaluation of maize yield in flood recession farming in the Okavango Delta, Botswana

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Flood recession farming locally known as *molapo* farming in the Okavango Delta is practiced along the edges of the river channels or seasonally flooded depressions on its fringes. It relies on residual moisture and natural fertilization of the floodplains, and is promoted as being more productive than dry-land farming. However, the productivity of this low-input farming system has not been extensively investigated. The objective of this study was to evaluate the yield potential of hybrid maize (*Zea mays* L.) in *molapo* farming. Two *molapo* field experiments and one dry-land experiment were conducted at Matsaudi and Lake Ngami, and Shorobe, respectively, in a randomized complete block design with four replications. Maize grain yield and plant height were measured from six consecutive plants from the centre row. The results showed that maize grain yield and plant height were significantly ($P < 0.05$) higher at Lake Ngami than at either Matsaudi or Shorobe. Late planting at Lake Ngami coincided with rainfall in November providing even and abundant soil moisture which contributed to better productivity of maize. Similarly, soil fertility was also better at Lake Ngami. Maize grain yield although lower (2.41 t ha^{-1}) at Matsaudi and Shorobe (2.58 t ha^{-1}) than at Lake Ngami (3.4 t ha^{-1}), it is much higher than yields normally obtained by small-holder farmers in semi-arid zones in sub-Saharan Africa, where actual yields are often less than half of the potential yields. Similarly, plant height was significantly ($P < 0.05$) higher at Lake Ngami (235 cm) than either Matsaudi (194 cm) or Shorobe (192 cm). It could be concluded that timely planting of maize in *molapo* fields supplemented by rainfall is capable of producing better yields in semi-arid regions where water is the most limiting resource to crop production

Key words: Flood recession farming, dry-land farming, Okavango Delta, maize, yield.

INTRODUCTION

Flood recession agriculture involves reliance on moisture left in the soil as flood water recede (Barrow, 1999). It is based on residual moisture and natural fertilization of the floodplain. Many rivers around the world sufficiently large with seasonal flooding to support flood recession farming (Adams, 1993). In Southeast Asia, dry-season flood-recession rice is an ancient land-use system that, taking advantage of the fertile silt deposited by the annual floods, is both extremely productive and sustainable (Fox and Ledgerwood, 1999). In the Sahel, there is the river Niger in Mali and Lake Chad, and in semi-arid Africa, there is the Sudd in Sudan and the Okavango Delta

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in Botswana (Adams, 1993).

The Okavango Delta of northern Botswana is possibly the most pristine of Africa's large wetlands (Gumbricht et al., 2004; Kgori et al., 2006), and supports a major tourism industry and rural community livelihood (Gumbricht et al., 2004; Wolski and Murray-Hudson, 2008; Magole and Magole, 2009; Kgathi et al., 2012). It was declared a Ramsar site-a wetland of international importance in 1997 and was recently inscribed as a Natural World Heritage site in 2014. This wetland is supplied by the Okavango River, which flows from the tropical highlands of Angola into the Kalahari basin (Bauer et al., 2004). The river discharges about 10 km^3 of water onto the Delta each year, supplemented by about 6 km^3 of rainfall, which supports about 2500 km^2 of permanent wetland and up to 8000 km^2 of seasonal wetland (McCarthy, 2006).

Flood recession farming is an important livelihood activity for the poor riparian communities in Africa and some parts of Asia. This farming system provides moisture conditions similar to irrigated farming and utilises residual moisture retained within the root zones of crops. The unlimited moisture in flood recession farming makes it more sustainable and profitable as it produces more yield than dry-lands farming. It has no costs associated with inputs other than land and labour, and consequently, has a very high net return to energy expenditures (Saarnak, 2003). In the Ngamiland district of Botswana flood recession farming locally known as *molapo* farming is practiced along the edges of the river channels or seasonally flooded depressions on fringes of the Okavango Delta (Bendsen, 2002).

Planting of crops start in September when floods start to recede. Maize is the main crop grown in *molapo* farms, with secondary crops such as sweet sorghum, sorghum, beans, pumpkin and watermelons (Bendson, 2002; Vanderpost, 2009). Maize is the main staple food for countries in Southern Africa as people depend on it for more than half of their calorie intake (Setimela et al., 2010). In Botswana, it is the cereal most consumed and supplies a larger percentage of the daily calories in most of the diets of Batswana (Lekgari and Setimela, 2002). DAR (2011) report indicated that the total hectarage for Ngamiland was 9,899 hectares of which 10% (987) was under *molapo* farming. Yields from *molapo* farms, although lower than the potential yield, are much more than those obtained from dry-land farms (Molefe et al., 2014). In sorghum for instance, grain yield ranges from 1,800 to 2,900 kg ha^{-1} (Bendsen, 2002; Arntzen, 2005); whereas, under rain fed it can be as low as 121 kg ha^{-1}. Literature on maize grain yield in *molapo* farms is currently not available, probably due to the fact that most *molapo* farmers prefer to grow maize as a cash crop where it is sold as green mealies early in the season to get better price before produce from the dry-land farms enter the market.

The climate of the Okavango Delta makes *molapo* farming much more suitable and sustainable than dry-land farming in semi-arid savannah due to low (~490 mm) and erratic rainfall in the area (Molefe et al., 2014) with high potential evaporation of 2172 mm a^{-1} (McCarthy, 2006; Wolski and Savenije, 2006). In addition, most of the Delta is covered by infertile sandy soils with low moisture retention capacity (Mubyana et al., 2003; Motsholapheko et al., 2011). These harsh climatic conditions are the major causes of crop failure in semi-arid dry-land farming. Soils in *molapo* farms are fertile because of the annual deposits of organic matter and silt laid down by the retreating floods, and that partly explains why *molapo* farming is more productive than dry-land farming.

Molapo farming in the Okavango Delta is an important land use and the basis for subsistence livelihoods of the local poor and vulnerable communities (Motsumi et al., 2012) (Figures 1 and 2A, B and C). Despite its significant contribution to rural livelihoods, the productivity of *molapo* farming has not been extensively investigated. The objective of this study was to evaluate yield potential of maize in *molapo* farming.

Study area

The study was conducted in the Okavango Delta (Figure 3) situated in the northern part of Botswana. The Okavango Delta is a large (12 000 km2) alluvial fan formed by the Okavango River. The inundated area of the delta varies dramatically from year to year depending primarily on the rainfall in Angola (Kgomotso and Swatuk, 2006; Wolski and Murray-Hudson, 2006). The area covered by water expands from its annual low of 2500 to 4000 km^2 in February–March to its annual high of 6000 to 12000 km^2 in August–September (McCarthy et al., 2004). The variation is closely linked to rain fall in the catchment area of Cuito and Cubango rivers in central Angola, which respectively receives mean annual rainfall of 876 and 983 mm (McCarthy et al., 2000; Wolski and Murray-Hudson 2008). Local rainfall also contributes significantly to the delta with an annual average of 490 mm (Anderson et al., 2003; Gumbricht et al., 2004), and it falls in one distinct rainy season from November to March (Wolski and Savenije, 2006).

As stated earlier, the inundated area varies in size from year to year. This seasonality of inundation gives rise to three major hydro-ecological zones, namely: permanent swamp, seasonal (regularly flooded) floodplains and occasional floodplains (Wolski and Savenije, 2006). The seasonal floodplains are areas where *molapo* farming (Figure 2) is practiced (Oosterbaan et al., 1986).

The actual study sites were Matsaudi (19°49'31.2''S, 023°36'19.5''E) and Shorobe (19°44'34.8''S, 023°41'27.7''E) along the Thamalakane river and Lake Ngami (20°30'28.1''S, 022°47'06.7''E) (Figure 3). The sites were selected because of their contrasting hydrology. Lake Ngami is the terminal end of the

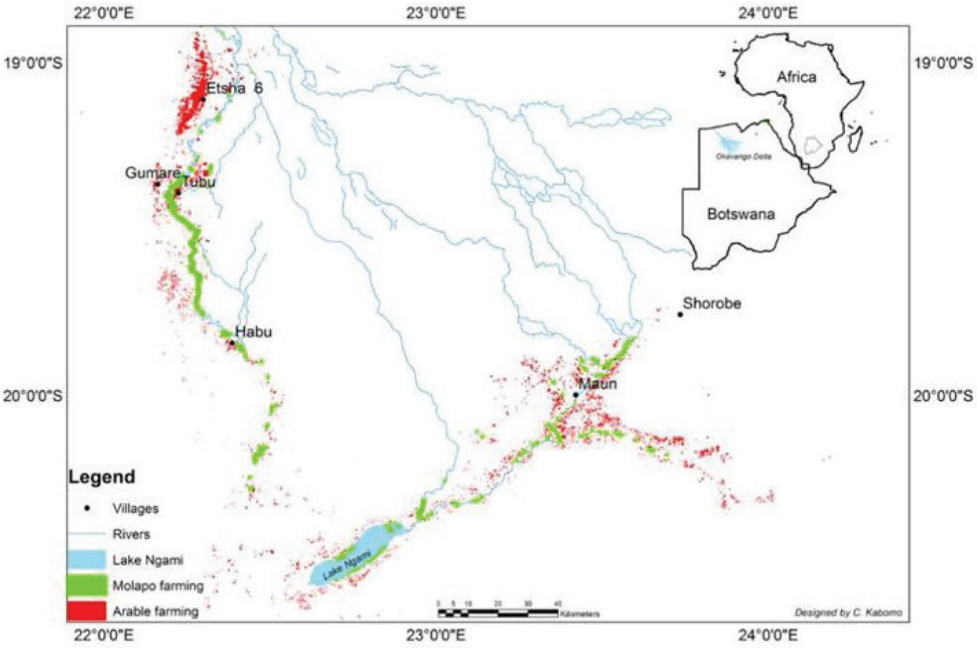

Figure 1. Map showing main *molapo* farming areas in the Okavango Delta (Chimbari et al., 2009).

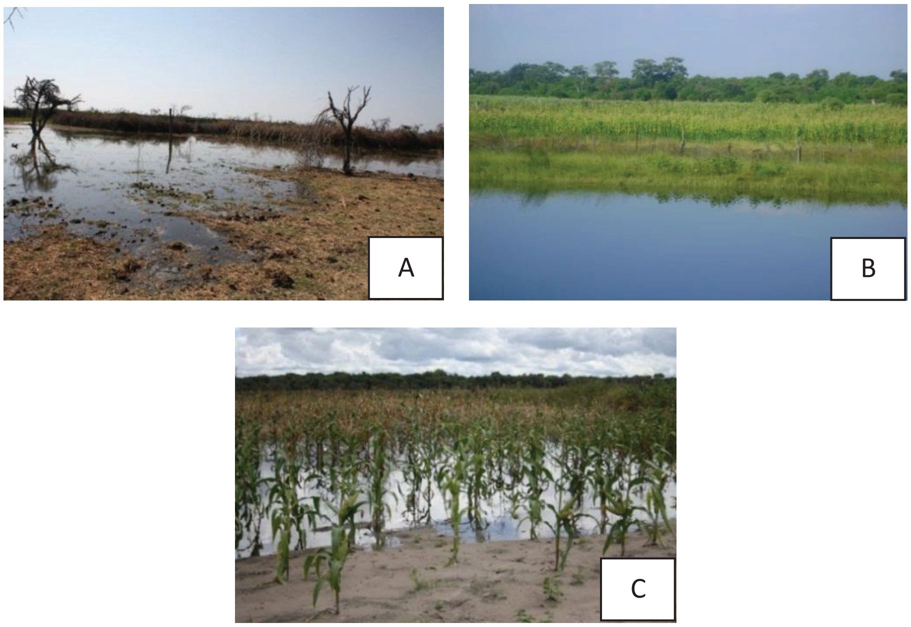

Figure 2. *Molapo* field flooded (A), maize in *molapo* field ((B), picture taken by Demel Teketay), and (C) flooded maize crop in March 2014. Pictures A and C taken by Keotshephile Kashe.

Okavango Delta and floods recede slowly from *molapo* fields resulting in late planting mostly in November. In Matsaudi, *molapo* fields are along the Thamalakane River and flood recession starts early giving farmers an opportunity to plant early in September.

Shorobe village is located in the lower part of the Okavango Delta. CSO, (2011) indicated that the population of Shorobe was 1,031. The local communities

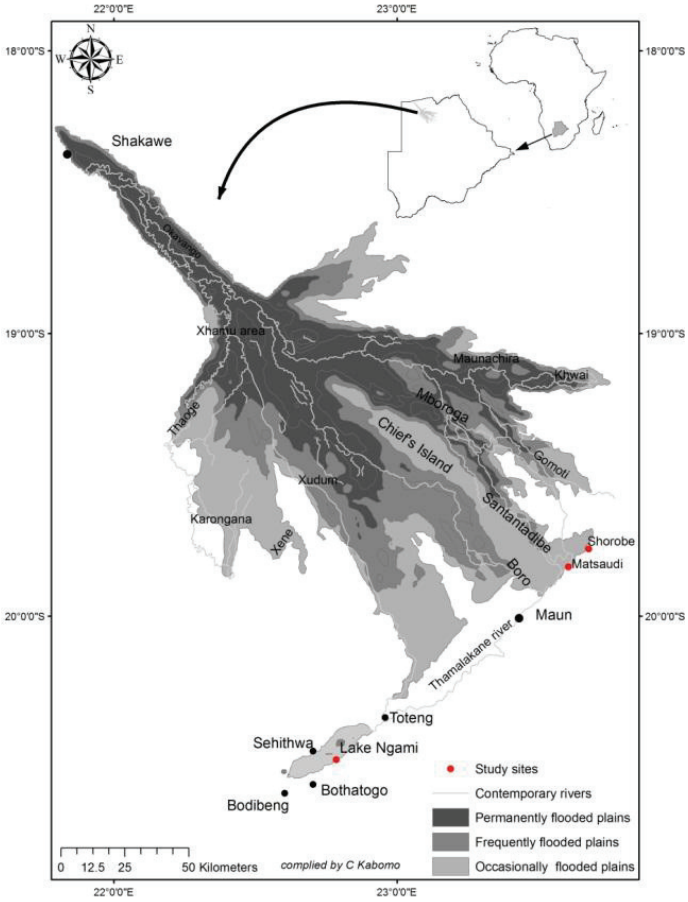

Figure 3. Map of Okavango Delta showing study sites.

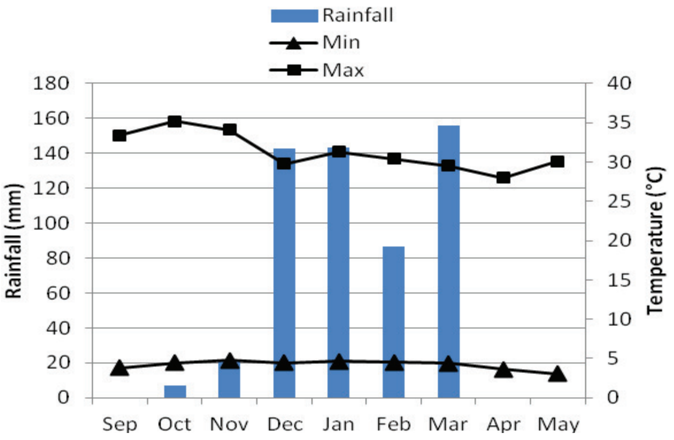

Figure 4. Monthly rainfall and mean monthly maximum and minimum temperature in Maun for 2013/14 crop growing season.

of this village sustained their living through basket-making, dry-land and flood recession (*molapo*) farming (Kgathi et al., 2007). Matsaudi is located on the eastern end of the Okavango Delta near Shorobe village. In 2011, its population was 345 (CSO, 2011). *Molapo* fields in Matsaudi are fed by the Santantadibe and Gomoti Rivers and backflow from the Thamalakane River. The main livelihood activities are *molapo* and dry-land farming, livestock rearing and fishing.

Lake Ngami occupies the south-west part of the Okavango Delta. It was originally fed by the Thaoge River, the western distributaries of the Delta. It last received inflow in 1989 and after a dry period has again since 2004, been receiving considerably inflow from Xudum distributary and is now considered its terminal portion (Wolski and Murray-Hudson, 2006). Lake Ngami is surrounded by three villages of Toteng, Bothathogo, Bodibeng and Sehithwa, with a population of 902, 555, 778 and 2 748, respectively (CSO, 2011). Livelihood activities for people in these villages include livestock rearing, *molapo* farming, dryland farming and fishing.

Climate

Maun and Sehithwa agro-meteorological weather stations were used as reference points for Matsaudi and Shorobe, and Lake Ngami respectively. Sehithwa station does not record maximum and minimum air temperature and uses Maun as its reference point. The hottest month during the crop growing season was October (35.4°C) and coolest was May (26.2°C) (Figure 4). The long-term (2004/2005 to 2013/2014) average seasonal rainfall was 341.39 and 471.63 mm, and the mean seasonal rainfall was 578.50 and 556.9 mm for Sehithwa and Maun, respectively. There was a dry spell in Matsaudi prior to sowing in September with no rainfall and only 7 mm for the month of October (Figure 4). However, in Sehithwa, 15.4 mm was recorded prior to sowing in November and 137.2 mm in December (Figure 5).

Hydrology of the Thamalakane River

Flooding of *molapo* fields along the Thamalakane River in 2013/2014 season began in mid-June when the annual floods reach Maun and the water level in the river rose from 1.605 to a peak of 2.515 in September and dropped to 1.658 m in December (Figure 6) as the floods started to recede. The maximum inundation was reached by the end August and floods started to recede by the beginning of September allowing farmers to start ploughing and planting crops.

MATERIALS AND METHODS

Field operations

Land preparation at *molapo* fields (Lake Ngami and Matsaudi) was done by donkey drawn mouldboard plough, whereas, in dryland (Shorobe) it was by tractor drawn mouldboard plough followed by discing to level the soil before planting. Soil samples were collected before ploughing and the main chemical properties of the soil from

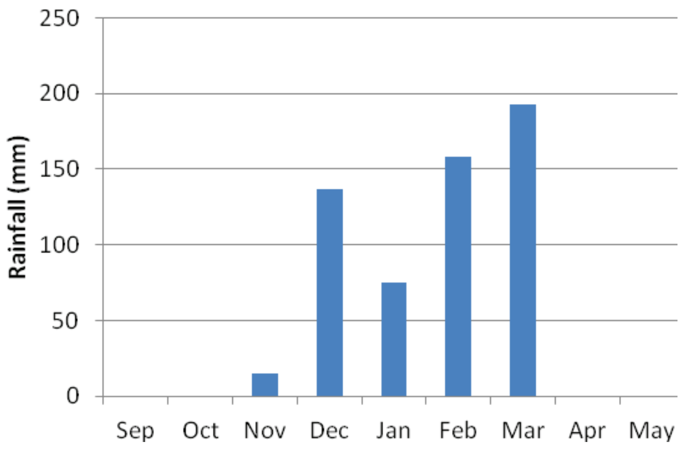

Figure 5. Monthly rainfall in Sehithwa for 2013/14 crop growing season.

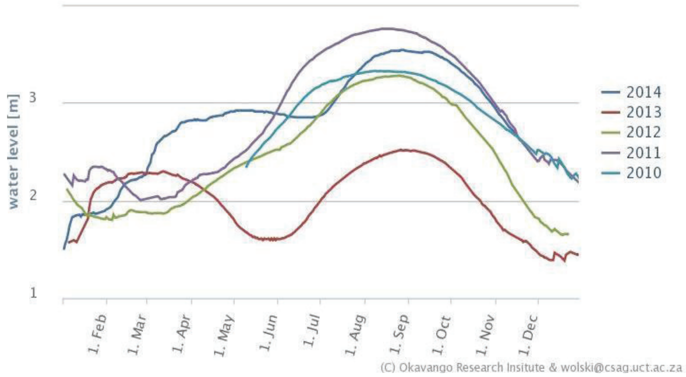

Figure 6. A graph showing water levels for the Thamalakane River for years 2010 to 2014.

the study sites were presented in Table 1. Maize hybrid (*Zea mays* cv. 'SC 403') was sown in 0.7 m rows at 60,000 plants ha^{-1} in a randomized complete block design with four replications on the 4th September, 15th November and 24th November 2013 at Matsaudi, Lake Ngami and Shorobe, respectively. No starter or post emergence fertilizer was applied. Weeding was done when necessary to maintain weed-free conditions until crops were harvested.

Data collection

Maize was harvested on the 5th January, 27th March and 4th April 2014 at Matsaudi, Lake Ngami and Shorobe, respectively. Measurements were taken at harvest. For plant height and grain yield, six consecutive plants from the centre row were randomly selected. Plant height was recorded in the field and was considered to be that of the highest leaf.

Statistical analysis

Data were analyzed using the statistical software R i386 3.0.1. Diagnostic plots were used to check the homogeneity of variance and normality of data for each response variable. Data for plant height and maize grain yield were compared using means and standard errors and represented as standard error bar plots.

RESULTS

Maize plant height and grain yield were significantly higher ($p < 0.05$) in *molapo* field at Lake Ngami compared to the other *molapo* field at Matsaudi and dryland field at Shorobe. Maize plants at Lake Ngami were taller (235 cm) than at Matsaudi (194 cm) and Shorobe (192 cm), which exhibited no significant difference (Figure 7). Similarly, grain yield was greater (3.40 t ha^{-1}) at Lake Ngami than at Matsaudi (2.4 t ha^{-1}) and Shorobe (2.58 t ha^{-1}) (Figure 8).

DISCUSSION

Overall, maize yields were significantly greater in *molapo* field at Lake Ngami than at the other *molapo* field at Matsaudi and dryland field at Shorobe. The variation in the yields between the three sites can be attributed to the difference in the temporal distribution of rainfall. Late planting at Lake Ngami (November) coincided with abundant rainfall resulting in even and unlimited moisture from planting to physiological maturity. The unlimited supply of soil moisture contributed to the growth and development of maize plants, which increased biomass and ultimately grain yield. Early planting at Matsaudi (September) with no rainfall and only 7 mm in October meant that the crop relied only on residual moisture in the floodplains.

Maize grain yield and plant height were significantly higher at Lake Ngami than at Matsaudi and Shorobe, with the latter two having no significant differences. The grain yield was 3.40, 2.41 and 2.58 t ha^{-1} at Lake Ngami, Matsaudi and Shorobe, respectively. These values are comparable to what Setimela et al. (2010) found for the same hybrid (SC403) under dry-land farming in Botswana. The grain yield in dry-land was, however, similar to *molapo* farms in Matsaudi, contrary to earlier findings by Molefe et al. (2013). The difference in the performance of maize can be associated with rainfall distribution in time. Lake Ngami and Shorobe received more rainfall (152 mm) from planting to flowering (November and December 2013), whereas, Matsaudi received nothing in September and only 7 mm in October 2013. The difference in the yields could be explained by this variation in the distribution of rainfall. Water availability is important during the maize's critical growth stages; flowering (55 to 65 days after planting) and grain filling (75 to 95 days after planting). Maize is very sensitive to moisture stress during these critical stages (Li-Ping, 2006). Maize at Matsaudi received a meagre 7 mm of rain during the critical growth stages. The period of time when maize experiences moisture stress may be more critical to grain yield than season-long deficits (Dalley et al., 2006). Considering that only 7

Table 1. Chemical properties of soil at the study sites.

Site	pH ($CaCl_2$)	P (ppm)	Ca cmol+/kg	Mg cmol+/kg	K cmol+/kg	Na cmol+/kg	CEC cmol+/kg
Matsaudi	5.9	11.9	1.14	1.05	0.18	0.01	2.37
Shorobe	6.3	11.5	1.11	1.31	0.25	0.01	2.67
Lake Ngami	5.6	62.9	7.16	8.82	1.42	0.06	17.40
Optimum levels	>6	>10	>1.00	>0.30	>0.10	<1.00	>2.50

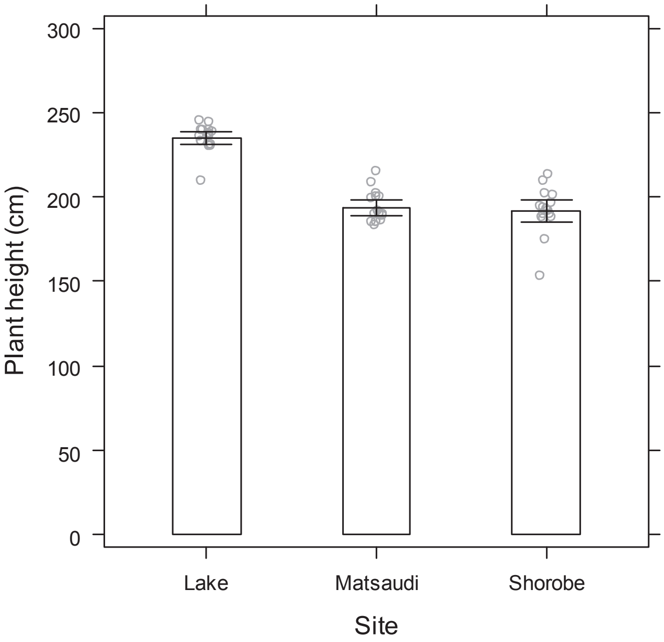

Figure 7. Maize plant height at Lake (Lake Ngami), Matsaudi and Shorobe. The columns show the mean. The circles represent the data points. The error bars show the standard error of the means.

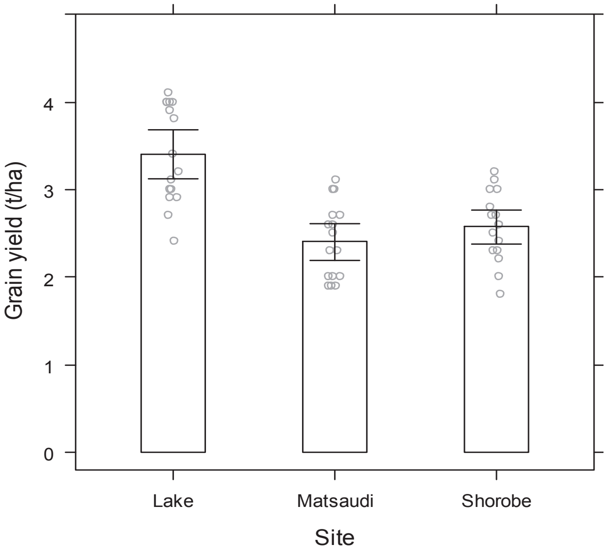

Figure 8. Maize grain yield at Lake (Lake Ngami), Matsaudi and Shorobe. The columns show the mean. The circles represent the data points. The error bars show the standard error of the means.

mm of rainfall was received in October 2013 during the period when maize was tasselling, this might have affected yield formation stages. Crop yield depend on the magnitude and timing of the total crop available water, which includes effective rain and available soil water at planting (Payero et al., 2009). Maize grown in arid and semi-arid is often limited by variation in the amount and frequency of rainfall (Pandey et al., 2000).

Water stress can negatively affect growth, development, and physiological processes of maize plants, which can reduce biomass and ultimately, grain yield (Payero et al., 2009), due to a reduction in leaf area (Pandey et al., 2000), shoot growth (Stone et al., 2001) and number of kernel per ear or the kernel weight (NeSmith and Richie, 1992; Traore et al., 2000).

Soil fertility is also important for crop production as much as water. Chemical soil analysis indicates that Lake Ngami was higher in all the nutrients analysed than Matsaudi and Shorobe. Better soil fertility at Lake Ngami contributed to greater grain yield and plant height. In most regions of North China, water scarcity and soil infertility were reported as the two critical factors limiting maize grain yield (Zou et al., 2008; Wang and Li, 2010).

While maize at Matsaudi and Shorobe performed less than at Lake Ngami, the grain yield observed (2.41 and 2.58 t ha^{-1}, respectively) is within the range of 1 to 5 t ha^{-1} reported by SeedCo Seeds (2014) for this hybrid. These values are also higher than yield values normally obtained by small-holder farmers in semi-arid zones in sub-Saharan Africa (SSA), where yields are often less than half of the potential yields (Barron and Okwach, 2005). The low yields in small-holder farming are generally associated with low and unreliable rain fall, and limited application of fertilisers. Starter fertilizer can stimulate early growth and improve maize yield (Vetsch and Randall, 2002; Niehues et al., 2004).

Conclusion

The results showed that maize plant height and grain yield were significantly superior in *molapo* field at Lake Ngami compared with the other *molapo* field at Matsaudi and dryland field in Shorobe. The superior performance in *molapo* field at Lake Ngami was generally associated with late planting supplemented by rainfall and better nutrients status. While maize grain yield was lower at Matsaudi and Shorobe, it was higher than yields normally obtained by small-holder farmers in semi-arid zones in sub-Saharan Africa, where yields are often less than half of the potential yields. Based on these results, we conclude that maize hybrid SC 403 when timely planted in *molapo* fields and supplemented by rainfall is capable of producing better yields in semi-arid regions where water is the most limited resource to crop production. Finally, the investigation of the effects of planting date on yield of crops in *molapo* fields is recommended.

Conflict of Interest

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

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This study was funded by the Okavango Research Institute, University of Botswana. We are grateful to Mr. Diane Kootsenye and Mr. Mmusi Mmusi for their help with field work. We are also grateful to *molapo* farmers who allowed us to use their fields for the study. Names of the crop varieties are solely provided as information to the reader and do not imply recommendation by the authors or their organisations.

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Full Length Research Paper

Integration crop-livestock: Is it efficient in suppressing troublesome weeds? A case study

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There is need to characterize the impact of the integration crop-livestock on weed infestation in production fields; higher infestation would result in lower system sustainability mainly due to the increased demand for agrochemicals, especially herbicides. Thus, we aimed with this study to assay weed dynamics in a farmer's managed, long-term crop-livestock system, through a case study adopting the phytosociological perspective. The monitored fields measured 282 ha at the municipality of Amambai-MS, Brazil. Each area was sub-divided into two sections ("1" and "2") for organization of quadrat distribution. A complete monitoring, which included both instantaneous infestation and soil seed bank studies, was conducted in both areas, which were managed under long-term crop-livestock integration, cycling every two years between soybean-corn succession and cattle raising (livestock). Phytosociological characterization of weed species was accomplished in 2011 based on the Ecological Approach. Estimations of relative density, frequency, dominance and Importance Value Index were obtained. Areas were also intra-characterized by the diversity coefficients of Simpson and modified Shannon-Weiner, and then grouped by cluster analysis. Crop-livestock integration proved to be efficient in suppressing some troublesome weed species, but others still prevail in integrated production fields; for Center-West region of Brazil, pigweed, beggartick and sourgrass tend to be preponderant weed species in crop-livestock areas; weed management should go beyond cultural practices, demanding the right herbicide to be applied at the right time aiming to control the weed species which were able to prevail even in the integrated production environment.

Key words: Integrated systems, phytosociological survey, soil seed bank, crop rotation.

INTRODUCTION

Weed infestation in soybeans can dramatically reduce yield if not properly managed. Losses in grain yield may reach 90% depending on the intensity of infestation, weed species present and moment of emergence (Sodangi et al., 2013). In the past, the use of an integrated management approach reduced demand for

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herbicides (Monquero, 2014); in the last decade, however, management programs almost totally abandoned the integrated approach heading to the abusive increase in herbicide application, with undesired consequences for economic, ecological and environmental aspects (Aktar et al., 2009; Bueno et al., 2011).

With the advent of transgenic soybeans resistant to the herbicide glyphosate (recommended for post-emergence weed control), which was supposed to hinder herbicide application in this crop, herbicide demand had in fact sharply increased due to the selection of troublesome weeds (Meyer and Cederberg, 2010). Chemical mismanagement with frequent application of herbicides with same mechanism of action, in absence of crop rotation, led to the selection of weed biotypes resistant to herbicides, being the main ones in Brazil three species of horseweed (*Conyza bonariensis*, *Conyza canadensis* and *Conyza sumatrensis*), sourgrass (*Digitaria insularis*), ryegrass (*Lolium multiflorum*) and goosegrass (*Eleusine indica*) (Vivian et al., 2013; Heap, 2014), which are all resistant to glyphosate. These species are widespread in soybean due to the misuse of Roundup Ready® technology, which bases weed control primarily on glyphosate.

Integrated crop-livestock systems have been adopted in several regions of Brazil. The benefits of integrated systems include increased soil fertility due to the accumulation of organic matter, improved nutrient cycling, increased fertilizer efficiency, better soil aggregation and also favor a more biologically active edaphic environment compared to other cropping systems (Salton et al., 2014). Rotation of crops with livestock can also help to break pest, disease, and weed cycles, thus reducing production costs and reducing the environmental risk posed by the proliferation of agrochemicals (Vilela et al., 2008).

Distinct cropping systems affect weed composition and its occurrence by changing the pool of management practices applied to the area, which will change the nature and amount of resources available for weeds, and help excluding from the system those weed species highly specialized in exploring a single or a few environmental resources, leaving room for less specialized and more flexible plant species (Gurevitch et al., 2009), which are usually not troublesome weeds.

Understanding not only the level of occurrence but also the composition of the weed community under each cropping system is important to achieve efficient control. Research data shows that management systems with low soil disturbance allow formation of a more diverse weed seed bank in soil. We hypothesize that long-term crop-livestock integration system promotes reduction in emergence of troublesome weed species while it increases the occurrence of less problematic plant species. Phytosociological studies allow assessing species composition of a given canopy and their estimation of density, frequency and dominance as well as the importance index for each species in the community, supporting inferences about a given group of plants (Gomes et al., 2010) and also about a given management.

There is need to characterize the impact of the integration crop-livestock on weed infestation in production fields; higher infestation would result in lower system sustainability mainly due to the increased demand for agrochemicals, especially herbicides. Thus, we aimed with this study to assay weed dynamics in a farmer's managed, long-term crop-livestock system, through a case study.

MATERIALS AND METHODS

Field location and brief on management

The monitored fields measured 282 ha, being the first one called "Esperança" with 172 ha (-23° 00' 11.5"; -55° 00'43") whose soil presented 17% clay, and the second one called Janaina, with 110 ha (-22° 58' 34.2"; -55° 00' 11.9") whose soil presented 30% clay, both located at the municipality of Amambai-MS, Brazil. Each area was sub-divided into two sections ("1" and "2") for organization of quadrat distribution. A complete monitoring, which included both instantaneous infestation and soil seed bank studies, was conducted in both areas, which were managed under long-term crop-livestock integration, cycling every two years between soybean-corn succession and cattle raising (livestock). The following crop sequence was used for more than seven years: (AGRICULTURE) Soybean in summer followed by corn intercropped with *Brachiaria ruziziensis* in the second crop; (LIVESTOCK) after two years of agriculture, cattle was raised over *Brachiaria* spp. All plantings were fully made under no-till system; soil was never prepared since the installation of crop-livestock.

When the field is under agriculture, soybean is planted in early October being harvested by late February, being corn planted in early March intercropped with *B. ruzizensis*. The forage (*B. ruziziensis*) is a C_4 carbon cycle species, which remains stagnated among corn plants due to shading, being able to establish after corn harvest. This species will serve as mulching until planting, if soybean is to be cropped on the next season, or will form the pasture in the area if it is shifting to the 2-year livestock cycle.

When areas were surveyed, they were entering the second year of agriculture. Soybean was planted in 27 and 29 September 2012, respectively for Esperança and Janaina, with variety Embrapa BRS 284, in rows spaced in 0.45 m with 14 seeds per meter of furrow. Fertilization was accomplished in the planting furrow according to the official recommendations (Embrapa, 2011).

Assessment 1 – Instantaneous infestation

Phytosociological characterization of weed species present in both areas was carried out on early October, 15 days after soybean emergence (DAE). For that, the Random Quadrats method (Barbour et al., 1998) was used and 20 quadrats with 0.50 m side were sampled in each area. All the emerged seedlings inside each quadrat were identified by species, collected and stored in paper bags, being dried in oven with continuous air circulation for posterior dry mass determination.

Estimations of relative density (based on number of individuals), relative frequency (based on the distribution of the species in the area) and relative dominance (based on the ability of each species to accumulate dry mass) were done for each species present. The Importance Value (I.V.), which ranks species in terms of importance within the studied area, was also determined Pandeya et al., 1968; Barbour et al., 1998), with the following equations:

$$rDe=\frac{I}{TI}*100 \qquad (1)$$

$$rFr=\frac{Q}{TQ}*100 \qquad (2)$$

$$rDo=\frac{DM}{TDM}*100 \qquad (3)$$

$$I.V.=\frac{rDe+rFr+rDo}{3} \qquad (4)$$

where *rDe* = relative density (%); *rFr* = relative frequency (%); *rDo* = relative dominance (%); *I.V.* = importance value; *I* = number of individuals of species *x* in the area *r*; *TI* = total number of individuals in the area *r*; *Q* = number of quadrats assessed in area *r* where species *x* is present; *TQ* = total number of quadrats assessed in area *r*; *DM* = dry mass of individuals from species *x* in the area *r*; *TDM* = total dry mass of weeds in the area *r*. Areas were also intra-characterized by the diversity coefficients of Simpson (D) and modified Shannon-Weiner (H') (Barbour et al., 1998), as follows:

$$D=1-\frac{\sum ni*(ni-1)}{N*(N-1)} \qquad (5)$$

$$H'=\sum\left(pi*\ln(pi)\right) \qquad (6)$$

where *D* = diversity coefficient of Simpson; *H'* = diversity coefficient of Shannon-Weiner (based on density); *ni* = number of individuals from species "*i*"; *N* = total number of individuals in the sample; *pi* = proportion of individuals in the sample from species "*i*".

After these analyses, areas were compared by Jaccard's presence-only similarity coefficient (Barbour et al., 2014) in a way to estimate the current degree of weeds similarity between areas. Based on Jaccard's binary coefficient, areas were grouped by cluster analysis considering the qualitative trait only (presence or absence of the species), according to the dissimilarities obtained from the inverse of Jaccard's similarity matrix, as follows:

$$J=\frac{c}{a+b-c} \qquad (7)$$

$$Di=1-J \qquad (8)$$

where *J* = Jaccard's similarity coefficient; *a* = number of plant species in area "*a*"; *b* = number of plant species in area "*b*"; *c* = number of plant species common to areas "*a*" and "*b*"; and *Di* = dissimilarity.

Hierarchical grouping was determined from the distance matrix (dissimilarities) by using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method (Sokal and Rohlf, 1962; Sneath and Sokal, 1973). Grouping validation was accomplished by the cophenetic correlation coefficient, using the Pearson linear correlation between the cophenetic matrix and the original matrix of distances.

All analyses were ran under the R Statistical Environment (R Core Team, 2014), using functions made available by the following additional packages: vegan, Hmisc, and ExpDes. All formulas and procedures, both at sampling and description of the areas, as well as at species clustering, followed the requirements suggested by Barbour et al. (1998) for synecological analyses.

Assessment 2 – Soil seed bank

For the soil seed bank study, a 2 kg soil sample from 0 - 5 cm depth of soil was also collected in each one of the locations sampled with quadrats in Assessment 1, so there would be a location correlation between studies. Soil was taken to greenhouse where it was revolved and clods dismounted, being put into 2 L plastic pots which were kept wet by daily irrigation at about 70% field capacity all throughout the assessment (Figure 1).

Every 20 days from 0 to 80 days after assembly, all plants emerged from soil seed bank were counted, collected, stored and processed in the same way used for Assessment 1. Soil was revolved again for a new emergence period of 20 days where a new evaluation would be done. The only difference between Assessments 1 and 2 is that plants present at Assessment 2 were stimulated to germinate from soil seed bank while plants considered at Assessment 1 were collected directly in the field.

RESULTS AND DISCUSSION

Analysis of areas for weed infestation, both in surface (Figure 2) and soil seed bank surveys (Figure 3) indicate average level of occurrence of weeds when compared with infestations pointed out by Van Acker et al. (1993) and Mohammadi and Amiri (2011). In absolute terms, however, there were differences between areas when measured "*in situ*" or through the soil seed bank. The surface analysis (Figure 2) indicated equivalent level of infestation between areas, except for Esperança 1; analysis of the seed bank, on the other hand, found Janaina 1 and 2 areas with the greatest potential of infestation (Figure 3), which may require more accurate management of weeds in this area due to the high skill of reinfestation from seed bank in the soil.

The survey of occurrence of weeds in the field (Figure 2) was decomposed by weed species, being the Importance Values for infestation (VI%) presented in Table 1. The VI% considers the offspring production potential of the species (species density), its relative spread in the area (frequency) and the ability of individuals from that species to accumulate dry mass and dominate plants from other species (dominance). Plants which perform better in these three items are the most troublesome weeds. Number of weeds (m^{-2})

In areas "Janaina" (1 and 2), the two most important weed species were pigweed (*Amaranthus retroflexus*) and sourgrass (*D. insularis*); in areas "Esperança" (1 and 2), however, pigweed was replaced by beggartick (*Bidens pilosa*) which together with sourgrass occupied a prominent position on the importance of infestation (Table 1). Beggartick was responsible for up to 49% of the infestation importance in Esperança 1 , which coupled

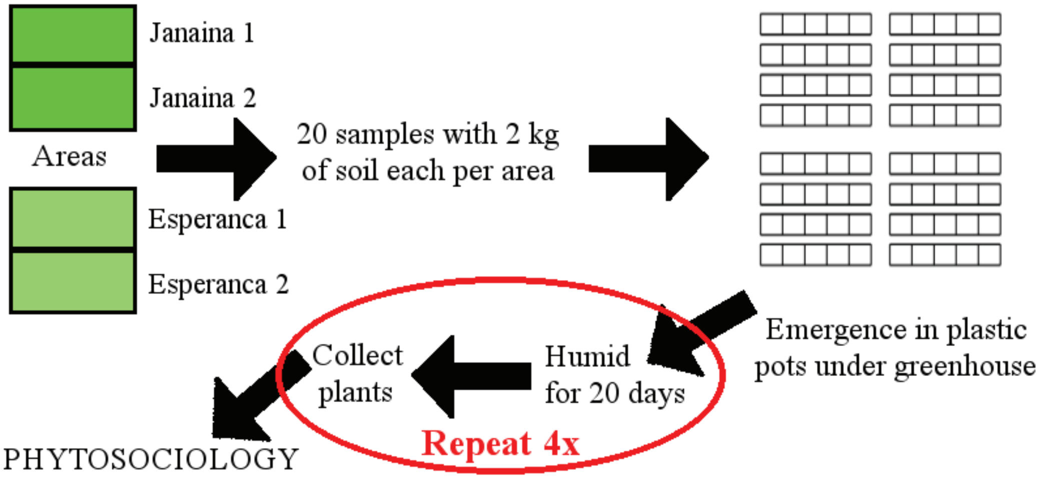

Figure 1. Schematics for assessment of weed species emerged from soil seed bank. Embrapa Western Agriculture, Dourados-MS, Brazil, 2014.

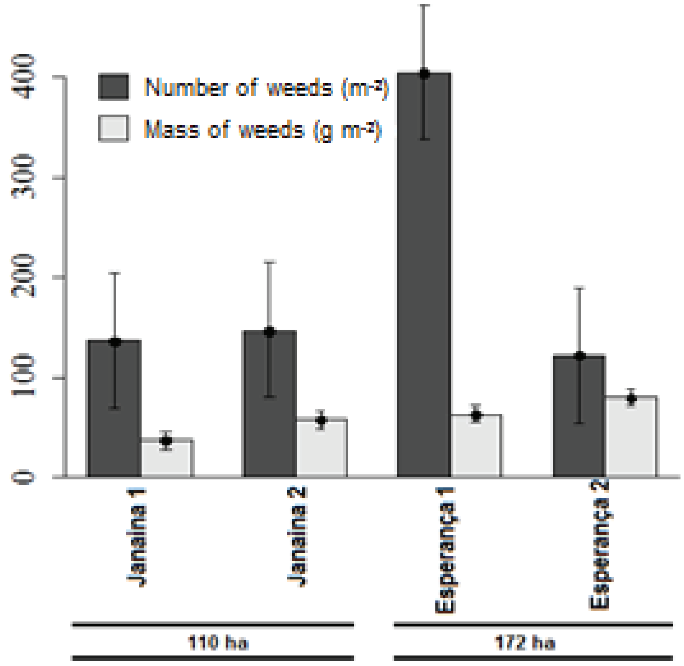

Figure 2. Number of individuals and dry mass of weeds as a function of area assessed, based on the field assessment in early post-emergence of no RR soybean. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012.

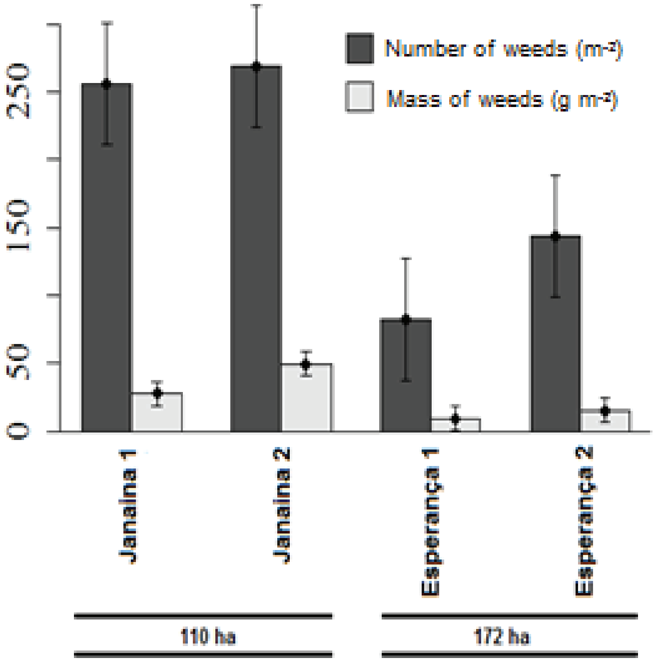

Figure 3. Number of individuals and dry mass of weeds as a function of area assessed, based on the soil seed bank study with soil collected in early post-emergence of no RR soybean. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012.

with the highest level of infestation in this area (Figure 2). This indicates a need for integration of control methods with herbicides to reduce beggartick occurrence.

The assessment of potential infestation through the soil seed bank, according to the method presented in Figure 1, indicated presence of 17 weed species in soil able to germinate and to infest the area supposing physical space is available (Table 2); in the surface assessment (Table 1), only 11 species were found.

Beggartick was the most important weed in all areas (Table 2), representing about 50% of potential infestation. This indicates that, supposing there is space available, this species is abundant in soil and could very easily become predominant in all fields. In Janaina 1, pigweed

Table 1. Value of Importance (V.I.) of weed species reported in the field survey held early post-emergence of soybean, in four areas located in the municipality of Amambai, MS, Brazil. Embrapa Western Agriculture, 2012.

Weed species	Common name	Janaina 1	Janaina 2	Esperança 1	Esperança 2
		Value of Importance (%)			
Amaranthus retroflexus	*Redroot pigweed*	30.8	26.23	2.13	1.74
Amaranthus viridis	*Slender amaranth*	0	1.56	0	0
Avena sativa	*Oat*	0	0	0	6.33
Bidens pilosa	*Hairy beggarticks*	9.58	24.15	49.57	34.16
Conyza bonariensis	*Horseweed*	0	0	1.7	17.56
Digitaria insularis	*Sourgrass*	31.85	30.25	35.23	33.35
Eleusine indica	*Goosegrass*	0	0	4.21	0
Euphorbia heterophylla	*Wild poinsettia*	5.11	8.52	4.85	0
Ipomoea spp.	*Morning glory*	19.06	3.54	0	0
Richardia brasiliensis	*Tropical Mexican clover*	0	0	2.31	6.86
Sida spp.	*Sida*	3.6	5.73	0	0

Marked cells (█) indicate the most important weed species in each area based on their V.I..

Table 2. Value of importance (V.I.) of weed species reported in the soil seed bank study carried out with soil collected post-emergence of soybean, in four areas located in the municipality of Amambai, MS, Brazil. Embrapa Western Agriculture, 2012.

Weed species		Janaina 1	Janaina 2	Esperança 1	Esperança 2
	Common name	Value of importance (%)			
Amaranthus hybridus	Smooth pigweed	6.97	5.76	0	0
Amaranthus retroflexus	Redroot pigweed	12.22	9.69	0	0
Avena sativa	Oat	0	0	0	1.06
Bidens pilosa	Hairy beggarticks	56.02	44.05	50.67	44.68
Cardiospermum halicacabum	Balloon vine	0	11.29	0	1.76
Commelina benghalensis	Benghal dayflower	0.66	15.12	0	0
Digitaria horizontalis	Jamaican crabgrass	1.38	1.95	6.09	3.74
Digitaria insularis	Sourgrass	4.87	3.41	36.61	20.86
Eleusine indica	Goosegrass	0	0	1.66	6.63
Euphorbia heterophylla	Wild poinsettia	0	0.65	0	1.03
Gnaphalium coarctatum	Cudweeds	3.96	5.05	1.52	1.03
Leonotis nepetifolia	Lionsear	0	0	3.45	0
Richardia brasiliensis	Tropical Mexican clover	8.38	0	0	13.54
Senna obtusifolia	Sicklepod	0.72	0	0	0
Sida spp.	Sida	4.26	1.48	0	1.03
Solanum sisymbrifolium	Sticky nightshade	0.56	1.56	0	0
Spermacoce latifolia	Oval leaf false buttonweed	0	0	0	4.64

Marked cells (█) indicate the most important weed species in each area based on their V.I..

figured as the second most important weed also in the study of seed bank, being replaced by spiderwort (*Commelina benghalensis*) at Janaina 2. In Esperança (1 and 2), sourgrass was the second most important weed (Table 2).

Rizzardi et al. (2003) studied the impact of beggartick on soybean yield as well as its threshold control level (TCL), concluding that the TCL varied from 0.4 to 33 plants m^{-2} depending on a series of factors; because of this, the authors highlighted that additional researches are demanded to improve the application of TCL and that it should be considered with caution since it does not consider the replenishing of the seed bank by plants left uncontrolled for not achieving the TCL. This, according to

Table 3. Weed species diversity as a function of field and study method. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012.

Area	Field study		Soil seed bank study	
	D[1]	H'[2]	D[1]	H'[2]
Janaina 1	0.57	1.12	0.71	1.55
Janaina 2	0.61	1.1	0.73	1.61
Esperança 1	0.26	0.56	0.57	1.01
Esperança 2	0.46	0.91	0.71	1.54

[1]D = diversity coefficient of Simpson; [2]H' = diversity coefficient of Shannon-Weiner.

Sattin et al. (1992) and Sartorato et al. (1996), would greatly shift the future occurrence of weeds on the following years often demanding additional management practices to be applied.

In the specific case of beggartick, Gomes et al. (2013) report effect of *Lupinus angustifolius* (narrowleaf lupin) extracts on beggartick in concentrations where it is not effective on crops like corn, being this an option to be grown in cooler environments where beggartick is widely proliferated and needs to be contained. Similarly, rapeseed reduces the germination ability of beggartick, being also an option for contributing to reductions in beggartick infestation in following years (Rigon et al., 2014).

Sourgrass (*D. insularis*) is other weed species which was present in this case study and concerns farmers and technicians. Some glyphosate-resistant sourgrass biotypes were found infesting annual and perennial crops in Brazil (Carvalho et al., 2013); thus, attention must be given to sourgrass management aiming to prevent plant survival and its increase in cropping systems. Being a perennial and hard-to-kill weed species post-emergence of crops, it should be efficiently controlled prior to crop planting and infestation in localized spots need to be eliminated to avoid seed dispersal mainly by wind (Gemelli et al., 2012; Carvalho et al., 2013).

Price and Kelton (2011) reported *Digitaria sanguinalis* among the most important weeds in conservation agriculture; according to the authors, both the cover crop and application of herbicides contributed for reduction of infestation in integrated cropping systems, being either of them alone barely efficient in suppressing weeds. Mondo et al. (2010) found that *D. insularis* in non-sensitive to light for germination, being able to establish even in areas under cover crops.

Being a positively photoblastic species (Yamashita and Guimarães, 2011), *Conyza* spp. demands light for its germination, which is less available in Integration Crop-Livestock systems due to a constant soil shading supplied by the different plant layers present in the field. In addition, animal traffic in the area may aggravate problems with weed species (Balbinot Jr. et al., 2008), demanding cover crops to be included in the cropping system. Thus, *Conyza* spp., the most important weed species in agriculture at Brazilian Center-West region, ws not important in the field survey and did not appear at all in the soil seed bank study (Tables 1 and 2).

Diversity is a concept which considers balanced plant communities in a given field as a consequence of good management (Pandeya et al., 1968). The diversity coefficient of Simpson (D) quantifies, in simple terms, the probability of two individuals randomly collected in the same area to be from the same species. The diversity coefficient of Shannon-Weiner (H'), on the other hand, derives from the Theory of the Information and sometimes confuses diversity with richness of species (Barbour et al., 1998). The diversity of species (Table 3), with no exception, was higher in the study of the soil seed bank, indicating that both areas present latent potential for infestation.

For both studies (field survey and soil seed bank), diversity was always lower for Esperança (1 and 2) compared to Janaina (Table 3) and differences were more remarkable at the field survey; in this situation, Esperança presented species diversity 39% inferior to the observed for Janaina indicating that pigweed, beggartick and sourgrass (Table 1) may be efficient competitors in suppressing the occurrence of other species present in the soil seed bank (Table 2). Thus, if the most important weeds (Table 1 and 2) are removed from the production system by species-aimed management, they would be sooner replaced by others with higher VI%.

Similarity analysis showed a match of 86% in weed composition for Janaina 1 and 2, while Esperança 1 and 2 were also pooled with 63% similarity. Janaina and Esperança, however, differed in similarity (Figure 4). According to Barbour et al. (1998), Jaccard similarity values above 25% is enough to indicate similarity between two given areas; in this sense, although not very similar, areas Janaina and Esperança are still similar (at 35% similarity) but the management applied to each area is starting to select differential weed species in each area because they are adapted to that management.

Figure 5 shows the similarity in composition of infestation in the same areas, based on the soil seed bank study. Janaina 1 and 2 still presented high correlation (68% similarity), whereas Esperança 1 and 2 differed not only from Janaina, but also between them.

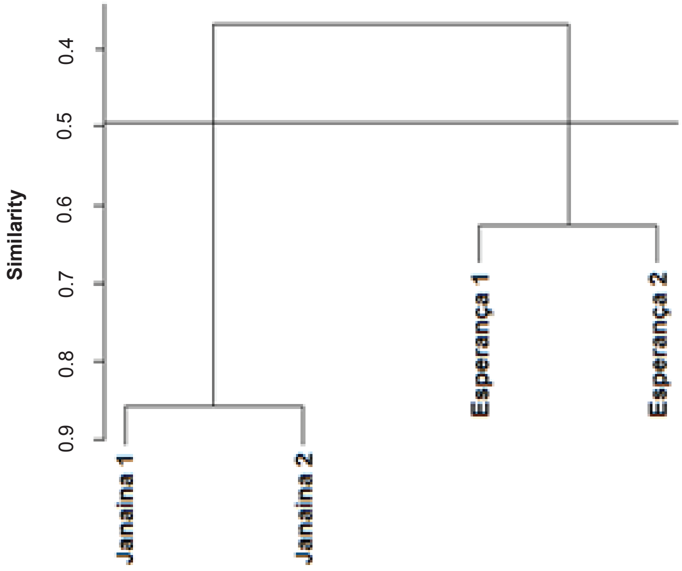

Figure 4. Multivariate cluster analysis of areas with field survey data of weeds occurrence, according to their similarity (coefficient of Jaccard), grouped by the UPGMA method. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012. Cofenetic correlation = 0.87. Threshold level = 0.49.

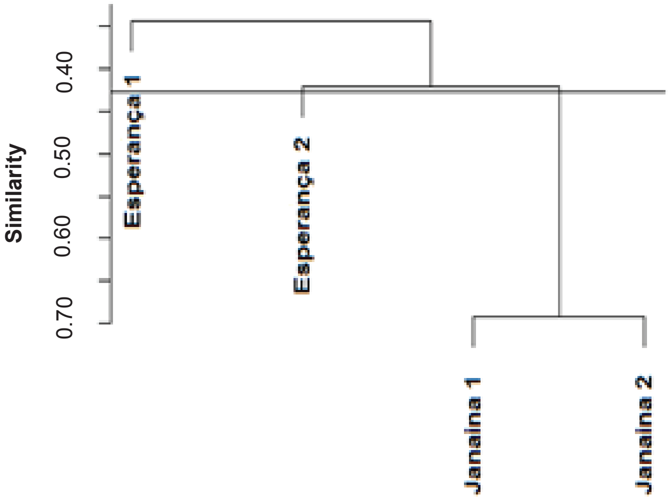

Figure 5. Multivariate cluster analysis of areas with soil seed bank data of weeds occurrence, according to their similarity (coefficient of Jaccard), grouped by the UPGMA method. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012. Cofenetic correlation = 0.93. Threshold level = 0.43.

This may indicate that the previous management applied to Esperança may have been differential between areas 1 and 2, or that the management adopted in recent years has been sufficiently diversified and sustainable to eliminate some of the weed species from the area (Figure 5). In fact, six weed species were found at Esperança 1 while 11 were found in Esperança 2 (Table 2). Integration crop-livestock helps smoothing problems with weed species in production systems. There are two mechanisms that can be related to the lower infestation and delayed emergence of seedlings in areas that have livestock. The first mechanism regards allelopathic issues. Aconitic acid is a substance that is commonly exudated by grasses such as *Brachiaria* species, which is responsible both for direct inhibition of plant growth (Putnan and DeFrank, 1983; Friebe et al., 1995) and for growth stimulus of endophytic fungus capable of attacking seeds in soil (Voll et al., 2004). According to Voll et al. (2010), aconitic acid affects the soil seed bank and its germination, which results in smaller competitive ability of the overall weedy community against the crop at the area.

The second mechanism regards the direct presence and action of livestock at the area – grazing (Popay and Field, 1996) and trampling (Marchezan et al., 2003), which could both reduce production of new seeds and vegetative propagules from weed species, and help forcing quiescent seeds to dormancy and later loss of their viability.

Although this case study highlighted a relatively more diverse environment in a farmer's managed crop-livestock integration, there are still some weed species which were capable of adapting themselves to the changing environment of a crop-livestock area with 2-year cycle. Although the currently most important most important weed species in Central Brazil cropping systems – horseweed – was almost absent from the fields, other important species prevailed.

Integration crop-livestock proved to be efficient in reducing *Conyza* spp. (horseweed) occurrence since seeds of this species are positively photoblastic (Vidal et al., 2007). These seeds not only require light to germinate but also the proper spectral composition, in particular the ratio of red: far-red wavelenghts (Chen et al., 2013). The presence of the forage every two years probably forced quiescent seeds to dormancy with posterior loss of viability due to the constant mulching on soil associated to the previous two commented factors.

Although horseweed is efficiently inhibited by crop-livestock integration, pigweed, sourgrass and beggartick prevailed. These species are recognized as important weeds and its presence in the long-term crop-livestock integration reports that some weeds are suppressed by the diversified management while others demand additional control practices to be applied.

Conclusions

Crop-livestock integration proved to be efficient in suppressing some troublesome weed species, but others still prevail in integrated production fields. For Center-West region of Brazil, pigweed, beggartick and sourgrass tend to be preponderant weed species in crop-livestock areas. Weed 0 management should go beyond cultural practices, demanding the right herbicide to be applied at the right time aiming to control the weed species which were able to prevail even in the integrated production environment.

Conflict of Interest

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

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Biostimulants, macro and micronutrient fertilizer influence on common bean crop in Vitória da Conquista- Ba, Brazil

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The use of plant biostimulants jointly or without macro or micro fertilization may be an alternative to change plant metabolism and consequently, improve bean crop yield. Under this circumstance, we aim to evaluate the influence of biostimulants and its interaction with macro and micronutrient fertilizers on common bean var. Pérola yield in Bahia State (BA). The research started on 12 December, 2013 in the experimental farm of the State University of Southwestern Bahia (UESB), campus in Vitória da Conquista – BA, Brazil. The experimental design used was the total randomized block with three replications, arranged in a factorial scheme (2x2x4) under two macronutrient fertilization levels (present or absent) and four biostimulants (Control, Stimulate, Booster and Biozyme), in which doses followed manufacturer recommendation for common bean crop. The following traits were assessed: plant height, stem diameter, first pod height, pod number, pod length, grain per plant, 100-grain dry mass and yield. The data was submitted to variance analysis, and means were compared by "F" and Scott Knott tests at 5% probability. We found that biostimulants enhanced common bean yield with or without macro and/or micronutrient supply.

Key words: Plant regulators, nutrients, fertilization, yield and *Phaseolus vulgaris* L.

INTRODUCTION

Common bean (*Phaesolus vulgaris* L.) is one of the most important domestic crops because of its high nutritional value and use as basic food in Brazil. The average consumption per capita, according to MAPA (2014), reaches 19 kg per year and seven out of ten Brazilians consume it daily. Common bean average yield in Bahia State (Brazil) is 509 Kg ha^{-1}, below the Brazilian State yield, which is 1,032 Kg ha^{-1} (IBGE, 2014). However, when it is used in a higher technological level, bean yield may exceed 3,000 Kg ha^{-1} (Vieira et al., 2006). In Bahia, there are three main periods to cultivate beans: "rainy season" that is between November to December, "dry season" being in February and March and "winter beans" sown from July to September (Ferreira et al., 2002).

This State produces the eighth worse yield from Brazil. Producing 509 Kg ha^{-1}, the State is only above seven

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others from Northeastern region. This value is 50.67% under national yield, which is 1,032 Kg ha^{-1} (IBGE, 2014).

In Vitória da Conquista – BA, Northeastern Brazil, most of the common bean producers are located at Mata de Cipó. The greatest part is small farmers that grow beans intercropped with other plants such as corn, cassava and coffee (Ganem, 2013). Crop yield in this region for 2011 was 398 Kg ha^{-1}, which is 21.80% under state average yield and 61.43% under national yield (IBGE, 2014). Decreased yield of crops is mainly related to low rainfall during the year and low technology level applied by most of the farmers.

There are some factors that may promote crop yield and performance losses in the field, e.g. minimal use of certified seed, resistance to technical innovations, improper irrigation management etc. After all, in recent years, great farmers have been increasing interest for common bean cropping, due to worth prices of the last harvests, mainly the carioca beans that is the most consumed in the country, which corresponds to 62.8 % of national bean production (CONAB, 2014).

Production and yield of several crops are related to genetic performance and selection of new varieties with traits of interest. Nonetheless, despite advances in plant breeding programs, the long term to obtain new cultivars increases the use of alternative tools to enhance crop yield and efficiency in available resource use. In such context, plant regulators are considered as alternative to change plant metabolism and, consequently, crop yield and product quality (Almeida, 2011). As reported by Avila et al. (2010), yield might be improved by means of effective use of new and consolidated technologies for beans, especially fertilizer and irrigation management and biostimulant use. New biotechniques' use such as bioregulators add to bean qualitative and quantitative traits (Alleoni et al., 2000), thereby availing the stress of overcoming diseases related to genetic (Bertolin et al., 2009) and environmental (Avila et al., 2010) factors.

Biostimulant narrow knowledge basis for beans combined with varied fertilization types support studies on this. As mentioned by Castro and Vieira (2011), plant biostimulants are defined as mixture of bioregulators with same or different chemical character (amino acids, vitamins, minerals etc.). Biostimulant use in agriculture to enhance commercial crop yield have been increasing within the last decades (Bourscheidt, 2011).

Researches on growth regulator usage associated or not with fertilizations have been increasingly common (Lana et al., 2009). Positive outcomes on biostimulant use were verified by several researches on Soybean (Bertolin et al., 2010), Grapes (Leão et al., 2005), Sugarcane (Miguel et al., 2009), Watermelon (Costa et al., 2008) and Caupi beans (Oliveira et al., 2013).

On the other hand, some surveys found no significant differences on Cotton (Baldo et al., 2006; Lima et al., 2006), Passion fruit (Ataíde et al., 2006) and Corn (Ferreira et al., 2008; Silva et al., 2008). Even though no significant difference was found for Beans, Alleoni et al. (2000) stated that biostimulants contribute to improve crop yield and other agronomical traits. Abrantes et al. (2011) observed that growth regulator application at appearance of the first flower bud increased grains per plant and grain yield for Carioca Precoce and IAC Apuã cultivars. Similarly, Cobucci et al. (2005) noticed Stimulate application at appearance of the first flower bud and appearance of the first pod promoted meaningful increment on bean yield. Just as in many other crops, results involving biostimulant usage have not always been significant for agronomical traits as reported by Bernardes et al. (2010) and Avila et al. (2010).

Accordingly, we aim to evaluate the influence of biostimulant use and its interaction with macro and micronutrient fertilizations on var. Pérola beans in Vitória da Conquista – BA, Brazil.

MATERIALS AND METHODS

The experiment was carried out in the Experimental Farm of the State University of Southwestern Bahia (UESB), in Vitória da Conquista County, located at 14° 51' 58" S latitude and 40° 50' 22" W longitude. The city lies at an average altitude of 940 m and according to Köppen classification, the climate is High Altitude Tropical (*Cwb*). Mean annual temperature is 21°C and mean annual rainfall of 730 mm concentrated between November to March.

The temperature, relative humidity and rainfall that occurred daily during the test driving period, are shown in Figure 1 Accumulated rainfall along experiment was 292-mm. Complementary irrigation was performed due to water requirement at each stage through spray irrigation. Local soil is classified as a Dystrophic Tb Haplic Cambisol (Inceptisol) (Vieira et al., 1998) medium-textured and flat topography. For soil analyses, single samples were collected from 0 to 20 cm layer and together sent to the Soil Analyses Laboratory of the Campinas Agricultural Institute (IAC). Table 1 shows the chemical analysis of soil from the experimental area.

The experimental design was randomized block with three replications arranged in a factorial scheme of 2 x 2 x 4. Wherein there were two macronutrient fertilization levels (level 1 – absence of fertilization and level 2 – fertilization with 400 Kg ha^{-1} 04-14-08 NPK at sowing and top dressing at opening of the first trifoliate leaf with 80 Kg ha^{-1} urea), two micronutrient fertilization levels (level 1 – absence of fertilization and level 2 – fertilization with 30 Kg ha^{-1} FTE - BR12 at sowing). In addition, four levels of biostimulant (Stimulate, Booster, Byozime TF, Control), totaling 48 plots was used.

The stimulate is manufactured by Stoller do Brasil, it is composed by 0.09 g L^{-1} cytokinin (kinetin) + 0.05 g L^{-1} indole-butyric acid + 0.05 g L^{-1} gibberellic acid (GA 3) and 4% molybdenum, and it is classified as slightly toxic and soluble concentrate solution (Stoller do Brasil, 1998). The Booster® - ZnMo is a liquid product with 2.3% molybdenum (Mo) and 3.5% zinc (Zn), 3.0% copper (Cu), auxin and cytokinin, manufactured by Agrichem. Arysta LifeScience (2013) manufactures the Biozyme TF, it is a liquid fertilizer for foliar application, containing in the formulation, macro and micronutrients associated with hydrolyzed vegetal extracts (2.43% Zn; 1.73 % N; 5% K_2O; 0.08% B; 0.49% Fe; 1% Mn; and 2.1% S). This later product is obtained from natural extracts and it has similar effects to the main plant growth-promoting hormones (cytokinins, auxins and gibberellins), micronutrients and other biologically active molecules.

Dosages, number and phenological stages of applications were followed according manufacturers:

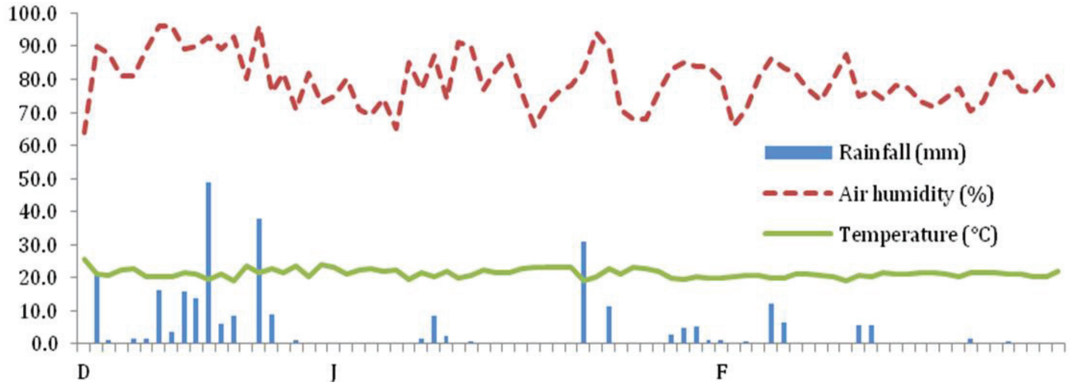

Figure 1. Shows the daily temperature, air humidity, and rainfall during experimental conduction.

Table 1. Chemical analysis of soil samples from 0-20 cm layer from the Experimental Farm of the State University of Southwestern Bahia (UESB), Vitória da Conquista – BA, Brazil - 2014.

Traits	Interpreted values
pH ($CaCl_2$)	4.4 VHA
P (mg dm^{-3})	43 VH
K (mmol$_c$.dm^{-3})	2.1 L
Al (mmol$_c$.dm^{-3})	0 L
Ca (mmol$_c$.dm^{-3})	15 M
Mg (mmol$_c$.dm^{-3})	3 L
H+Al (mmol$_c$.dm^{-3})	22 L
Cation exchange capacity (mmol$_c$.dm^{-3})	42.1 L
Percent base saturation (%)	48 M
B (mg dm^{-3})	0.49 M
Cu (mg dm^{-3})	1.4 L
Mn (mg dm^{-3})	15.5 H
Zn (mg dm^{-3})	1.10 M
Fe (mg dm^{-3})	79 H

Interpretation according to Commission of Soil Fertility from Minas Gerais State, Brazil. VHA = very high acidity; VH = very high content; H = high content; M = medium content; L = low content; VL = very low content.

1. Absence
2. Two applications of 200 ml ha^{-1} each, at opening of the third trifoliate leaf and appearance of the first flower bud using Stimulate.
3. Two applications of 100 mL ha^{-1} each, at opening of the third trifoliate leaf and appearance of the first flower bud using Booster
4. Three applications of 200 mL ha^{1} each, at opening of the third trifoliate leaf, appearance of the first flower bud and appearance of the first pod using Byozime TF.

The experiment commenced on December 12, 2013. Soil preparation was plowing and level harrowing, followed by furrow plough spaced by 50 cm using a 10 cm depth chisel plow. Seeds were manually sown into furrows, at 5 cm depth with 13 seeds per meter. Then, ten days after sow, thinning was performed leaving a density of eight plants per meter. Thus, a 160,000 plant/ hectare stand was obtained as suggested by Barbosa and Gonzaga (2012).

Crop handlings, such as pest control and irrigation were performed according to crop needs. Top dressing nitrogen fertilization for NPK treated plots was carried out at opening of the first trifoliate leaf stage. Stimulate and Booster were applied at 21 and 33 days after emergence (DAE) during opening of the third trifoliate leaf and appearance of the first flower bud stages, respectively. Moreover, Byozime TF was applied at 21, 33 and 60 DAE, at opening of the third trifoliate leaf, appearance of the first flower bud and appearance of the first pod respectively. Biostimulant application was made through spraying with a precision knapsack sprayer at CO_2 constant pressure of 2.0 kgf cm^{-2}, equipped with sprayer boom and flat fan jet nozzles (110 01) at 30 cm above plant canopy, spray outflow of 300 L ha^{-1} (Abrantes et al., 2011). Portable plastic curtains with 1.7-m height were set surrounding the plots at application time.

At 76 DAE, one day before harvesting, ten plants were collected by plot (third line within useful area), identified and taken to the laboratory. Then, evaluations were performed on production traits as number of pods per plant (NPP), number of grains per pod (NGP) and 100-grain weight (100GW). Plant height (PH), stem diameter (SD), first pod height (FPH) and pod length (PL) were also measured.

AT 77 DAE, we harvested the two planting lines (first and second line within useful area) of each plot; the plants were manually removed, sun-dried and weighed to obtain dry mass (kg.ha^{1}); then weight was corrected by assuming 13% moisture, to determine yield (Y). Data were submitted to normality test (Lilliefors) and

Table 2. Common bean stem diameter (cm) var. Pérola, with and without macronutrient application (NPK fertilizer), in Vitória da Conquista – BA, Brazil. UESB. 2014.

Parameter	NPK
Absence	5.09 b
Presence	5.38 a

Means followed by same lowercase letter in the column do not differ to each other by "F" test (P≤0.05).

Table 3. Common bean 100-grain weight var. Pérola with and without macronutrient application (NPK fertilizer), in Vitória da Conquista – BA, Brazil. UESB. 2014.

NPK	100-grain weight (grams)
Absence	24.09 b
Presence	25.55 a

Means followed by same lowercase letter in the column do not differ to each other by "F" test (P≤0.05).

variance homogeneity (Barlett). For that, the software SAEG 9.1 was used (Ribeiro Junior, 2001). Subsequently, variance analyses were carried out to determine macro, micronutrients and biostimulant effects. Means comparison was performed by "F" and Scott Knott tests at 5% probability through Sisvar 5.3 software (Ferreira, 2010).

RESULTS AND DISCUSSION

There were no effect of the factors at the level of the 5% of probability for the test F, for the variables: (H), (FPH), (NPP), (PL) and (NG). It was observed a significant effect for macronutrient on SD and means are shown in Table 2.

NPK use increased in 5.39% SD, which is an important trait for beans since the smaller the diameter, the greater are crop-lodging chances (Bezerra et al, 2012). In agreement with Leal and Prado (2008), NPK promotes SD thickening; these authors studied bean nutritional disorders by deficiency of macronutrients, bore, and zinc, they observed that lack of each nutrient (N, P, K) resulted in SD decreasing. Rodolfo Junior et al. (2008) found similar result for passion fruit, who observed an increase in SD when NPK was applied.

Rodrigues (2010) combined NPK doses with *Trichorderma* spp. in common beans and observed a quadratic effect of NPK rates, obtaining the larger diameter at 25% of the recommended dose. This author reported that dose from 25 to 75% decreased SD, and from 75 to 125% diameter growth was retaken.

We observed a significant effect of NPK application on 100GW. Table 3 presents means related to that variable. NPK fertilization promoted 6.06% increment. As stated by Ramalho and Abreu (2006), consumer market preferences are involving medium-size 'Carioca-like' grain, whose size correspond to 23 to 25 g per 100 grains, and both treatments had values close to those indicated by the authors. Despite being a qualitative heritage trait, 100-grain weight is little influenced by environment and controlled by some few genes (Zilio et al., 2011); our data confirm that NPK fertilizations may interfere positively with this parameter. Some researches under macronutrient availability, mainly nitrogen, interfere in 100GW, since N has great influence during grain filling stage, when large amount of nutrients are translocated into grains. By the time N availability is low, during that stage, old leaves might rapidly drop and photosynthesis rate also decreases, which interfere negatively in grain filling (Soratto et al., 2011; Teixeira et al., 2005).

Pereira Jr (2009), who studied Caupi beans, observed a significant effect on 100GW at 1% probability for N and P_2O_5 applied doses. The same authors checked a variation from 24.2 g (control) to 29.7 g (75 kg ha^{-1} N + 25 kg ha^{-1} P_2O_5).

Carvalho et al. (2010),studying beans intercropped with coffee, established that NPK use with irrigation enhanced linearly 100GW values of common beans; however, the NPK dose increase in non-irrigated plants promoted decrease of this variable.

Regarding seed densities, Souza et al. (2008) tested NPK levels and liming effects on beans under conventional cropping; they found no differences on 100-grain weight among NPK levels. Significant effect of NPK factor and triple interaction of NPK* Micronutrients *Biostimulants was noted. Table 4 present statistical breakdown means of biostimulants at each NPK and micronutrient levels. Biostimulant treatments in NPK and micronutrient absence produced more than Control, highlighting the Biozyme TF that promoted a yield of 1,523.7 Kg ha^{-1}, that is, 34.71 % superior to control yield. In treatments without NPK but with micronutrients,

Table 4. Common bean grain yield (kg ha^{-1}) var. Pérola on triple interaction breakdown of biostimulants at each NPK and micronutrient level, in Vitória da Conquista – BA, Brazil. UESB 2014.

Biostimulants	**NPK Absence**		**NPK Presence**	
	without micronutrients	**with micronutrients**	**without micronutrients**	**with micronutrients**
Control	1131.07 ^{b}	1536.98 ^{a}	1724.03 ^{a}	1433.72 ^{b}
Stimulate	1471.67 ^{a}	1296.60 ^{a}	1727.39 ^{a}	1819.55 ^{a}
Booster	1506.70 ^{a}	1511.54 ^{a}	1469.00 ^{a}	1749.62 ^{a}
Biozyme TF	1523.70 ^{a}	1529.58 ^{a}	1687.42 ^{a}	1785.14 ^{a}
Mean	1408.28	1468.69	1651.96	1697.00

Means followed by same lowercase letter in the column do not differ to each other by Scott-Knott test (P≤0.05).

Table 5. Common bean grain yield (kg ha^{-1}) var. Pérola on triple interaction breakdown of micronutrients at each NPK and biostimulant levels, in Vitória da Conquista – BA, Brazil. UESB 2014.

Biostimulants	**NPK Absence**		**NPK Presence**	
	without micronutrients	**with micronutrients**	**without micronutrients**	**with micronutrients**
Control	1131.07 ^{b}	1536.98 ^{a}	1724.03 ^{a}	1433.72 ^{a}
Stimulate	1471.67 ^{a}	1296.6 ^{a}	1727.39 ^{a}	1819.55 ^{a}
Booster	1506.70 ^{a}	1511.54 ^{a}	1469.00 ^{a}	1749.62 ^{a}
Biozyme TF	1523.70 ^{a}	1529.58 ^{a}	1687.42 ^{a}	1785.14 ^{a}
Mean	1408.28	1468.69	1651.96	1697.00

Means followed by same lowercase letter in the line (within NPK absence and presence) do not differ to each other by “F” test (P≤0.05).

biostimulants did not promote significant yield gain in relation to control. On the contrary, with NPK and without micronutrients, biostimulants demonstrated means higher than Control, highlighting Stimulate that reached a yield of 1,819.55 Kg ha^{-1}, that is, 26.91% higher than Control.

In general, biostimulants had greater yields with NPK and micronutrients, even if it was not statistically compared, and Biozyme TF detached when micronutrients were used. Plant hormones and growth regulators play an important role in several vegetal metabolism processes, including cell division, morphogenesis, elongation, compound biosynthesis and senescence (Taiz and Zeiger, 2009; Albrecht et al., 2011). Plant growth and development are controlled by a set of plant hormones, whose biosynthesis and degradation are responses of a complex interaction among physiological, metabolic and environmental factors (Dario et al., 2005). Releasing of analog growth-promoting hormones influence, condition, stimulate and maximize the performance of many crops such as common beans (Albrecht et al., 2011).

Therefore, beans under application of macro (NPK) and micronutrients with biostimulants demonstrated superior yield at 26.91% (Stimulate), 22.03 % (Booster) and 24.51% (Biozyme TF). Abrantes et al. (2011) found similar result testing Stimulate doses (0, 0.5, 1.0, 1.5 and 2.0 L ha^{-1}) in common beans. The authors verified that the crop had an increment of 40.1% yield at 2.0 L ha^{-1} with application during appearance of the first flower bud. Furthermore, these authors used NPK doses near those used in our study.

Lana et al. (2009) studied two biostimulants applied at various doses and manners and concluded that their use increase yield index compared to control (no plant regulators). In contrast, Almeida et al. (2014) did not observe increases in bean yield. Avila et al. (2010) also found no yield increment when testing two biostimulant and foliar fertilizer on beans with and without irrigation. Triple interaction breakdown means of micronutrients at each NPK and biostimulant levels are shown in Table 5.

It was verified that without NPK and with micronutrient application, control had a 36.06% yield increment. This result corroborates with Martins et al. (2013), who studied N doses with and without micronutrient application in Caupi beans. These authors noted that the highest yield (784.0 kg ha^{-1}) was obtained in micronutrient presence without N application, which was compared without micronutrient application (687.0 kg ha^{-1}), therefore, having a 12.4% yield increase.

It is important to note that micronutrient level within the area where the experiment was conducted are medium to high (Table 1), except for Cu, whose level was considered low.

Even with or without NPK, biostimulant treated plants did not have yield increase with FTE-BR12 application, probably due to adequate amount of micronutrient found in the soil. Venegas et al. (2010), assessing single and combined application of biostimulant with micronutrient

Table 6. Common bean grain yield (kg ha^{-1}) var. Pérola on triple interaction breakdown of macronutrients (NPK) at each micronutrient and biostimulant levels, in Vitória da Conquista – BA, Brazil. UESB 2014.

Biostimulants	Micronutrient absence		Micronutrient presence	
	without NPK	with NPK	without NPK	with NPK
Control	1131.07 ^{b}	1724.03 ^{a}	1536.98 ^{a}	1433.72 ^{a}
Stimulate	1471.67 ^{a}	1727.39 ^{a}	1296.66 ^{b}	1819.55 ^{a}
Booster	1506.70 ^{a}	1469.00 ^{a}	1511.54 ^{a}	1749.62 ^{a}
Biozyme TF	1523.70 ^{a}	1687.42 ^{a}	1529.58 ^{a}	1785.14 ^{a}
Mean	1408.28	1651.96	1468.69	1697.00

Means followed by same lowercase letter in the line (within micronutrient absence and presence) do not differ to each other by "F" test ($P \leq 0.05$).

and *Trichorderma* spp. in the initial growth of cotton, found no differences between both types for the evaluated traits.

Lana et al. (2008), searching micronutrients in no-tillage bean cultivation, evaluated the effects of them applying isolated (zinc) or associated (cobalt and molybdenum) and the worst means were found in control and the treatment with all micronutrients (micronutrient cocktail); thus, there was no significant difference between them. With this, we may point out that it is important to balance micronutrients, once unbalanced application could act against plant development.

Table 6 shows triple interaction breakdown means of macronutrients (NPK) at each micronutrient and biostimulant levels for yield variable.

Studying the breakdown, we verified that micronutrient absence with NPK application in control increased yield in 52.42%. This outgrowth can be partly explained by soil P amount. It is possible to affirm that NPK supply, especially N and K, raised nutrient availability and absorption, allowing grain growth and mass increment, because K content attained in the soil analysis was considered low.

Surprisingly, Control had yield upper to national average, which is 1,032 kg ha^{-1} (IBGE, 2014), and greater than National Supply Company (CONAB) estimates for 2013/ 2014 that was 1,045. Probably, it was due to the certified seed use and proper crop handling during experiment (CONAB, 2014).

Souza et al. (2008), who studied NPK levels and liming on beans, observed linear and positive effects, and the highest NPK dose (50% above recommended dose) got 88% yield increase.

By contrast, studying NPK effect on Caupi beans, Rodrigues et al. (2004) found that control treatment generated losses, NPK application at 250 kg.ha^{-1} and 500 kg.ha^{-1} rates promoted 35 and 32% profit on invested capital. Moreover, when micronutrients were used, NPK application increased plant yield at 40.32% together with Stimulate; what may infer that for this biostimulant best performance, it is necessary on adequate plant nutrition. Nevertheless, NPK presence did not raise significantly yield of plants treated with Booster and Biozyme TF in micronutrient presence or absence.

Conflict of Interest

The authors have not declared any conflict of interest.

CONCLUSIONS

NPK promoted wider stem diameters and heavier grains. Biostimulants enhanced common bean yield with or without macro and micronutrients.

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Full Length Research Paper

Impact of drying methods on the seed quality of sorghum (*Sorghum bicolor* (L.) Moench)

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Seed storage is being affected by factors *viz.* seed moisture content, temperature and relative humidity. The effects of four drying methods using silica gel, saturated salt solution of lithium chloride, concentrated sulphuric acid and dryer drying on different physiological and biochemical characteristics of genotypes CSH 16 and CSV 18 of sorghum (*Sorghum bicolor* (L.) Moench) were investigated. Faster drying rate was observed in acid and silica gel while dryer and saturated salt solution of lithium chloride exhibited slow drying rate. Acid drying was efficient in drying, but detrimental to the seed quality. Results obtained by silica gel and lithium chloride salt solution drying were comparable with those obtained by seed dryer. Among the various parameters investigated, germination, vigour, total protein content, dehydrogenase, amylase, superoxide dismutase (SOD) and peroxidase activity were found to show a decreasing trend, whereas electrical conductivity (EC) increased during storage irrespective of drying methods. Seed quality was preserved in conventional drying method (drying chamber at 15°C and 15% R^H), which was comparable to the quality of seeds dried using lithium chloride; though drying rate was slow. Silica gel resulted in faster rate of drying to maintain moisture content and seed quality.

Key words: Sorghum, silica gel, acid, dryer, lithium chloride, drying methods, seed quality.

INTRODUCTION

The drought tolerant crop, Sorghum (*Sorghum bicolor* (L.) Moench) predominantly cultivated in arid and a semi-arid region is gaining importance due to climate change. In India it is grown in 6.32 million hectares to yield 6.03 million tonnes of grain (DES, 2011). Sorghum is grown for food, feed and fodder in drought prone area and is expected to play an important role in dry land economy in the changing environmental conditions. Low seed moisture content is a pre-requisite for long-term storage and is the most important factor affecting longevity. A combination of 3 to 7% seed moisture content (mc) and a storage temperature below 0°C was reported to be suitable for long-term preservation of orthodox seeds (FAO/IPGRI, 1994). Seeds lose viability and vigour during processing. The process of drying decreases the seed weight and volume.

Diverse methods of seed drying, such as shade and sun drying, vacuum drying, freeze drying and refrigeration drying with low R^H are available (Ellis and Roberts, 1991) along with recommended methods for

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safe drying of seeds such as seed drying chambers, seed dryers and controlled conditions (Ellis et al., 1985). In developing countries, such drying facilities for germplasm storage are not available. With an objective of developing efficient, alternative and energy efficient drying methods to reduce seed moisture content without compromising seed health and quality, the present investigation was executed to elucidate the effects of silica gel, saturated salt solution of lithium chloride, concentrated sulphuric acid and dryer drying on the different physiological and biochemical seed characteristics of sorghum genotypes CSH 16 and CSV 18.

MATERIALS AND METHODS

Sorghum cultivars CSH 16 and CSV 18 procured from Directorate of Sorghum Research, Hyderabad with an initial seed moisture content of 11± 0.2%. Four drying methods were used to obtain two different drying rates. Rapid drying (RD) was achieved by placing seeds in glass desiccators containing silica gel and concentrated sulphuric acid. For slow drying seeds were placed in glass desiccators containing saturated salt solution of lithium chloride and seed dryer maintained at 15% R^H and temperature at 15°C.

Samples of both the genotypes were weighed to 42 g each and packed in muslin cloth bags for drying. Silica gel drying was carried out as described earlier by (Fischler, 1993). Lithium chloride saturated salt solution (12 to 13% R^H) was placed at the bottom of a desiccator for seed drying. For sulphuric acid drying, acid was directly placed in the bottom of a desiccator. After 24 h the samples were kept in muslin cloth bags and placed over the desiccator plate. Drying chamber was maintained at 15°C temperature and 15% R^H; samples were placed in the drying trays for drying in drying chamber.

Enough time was allowed to reach the seed moisture at the desired level of 6±0.1% from the initial 11±0.2% level. When the desired moisture content was achieved, one sample of each genotype was taken out for assessing various quality parameters under replicated trials. The remaining seed sample was packed in aluminium foils with a vacuum proof seal. The remaining second sample of each genotype was kept as such to assess drying trend.

Drying time was predicted by weighing after every four-day interval and based on weight loss using following formula

Final seed weight = Initial weight of seeds × [(100 - Initial moisture content) / (100 - Target moisture content)]

Final moisture content was confirmed by high constant temperature method as per high constant temperature oven method (ISTA, 2011) and then samples were stored for 6 months. Various quality parameters were recorded from control, initial storage after drying, three months after storage and six months after storage.

Standard seed germination was assessed using between paper method with three replicates of 50 seeds each (ISTA, 2011). Vigour Index (VI) and seed leachate conductivity were calculated using the formulae

Vigour Index I= Germination % × Seedling length (cm)

Vigour Index II= Germination % × Seedling dry weight (g)

$$\text{Conductivity}\ (\mu s/cm/g) = \frac{\text{solution conductivity} - \text{control conductivity}}{\text{weight of replicate (g)}}$$

Dehydrogenase (Kittock and Law, 1968), amylase (Murata et al., 1968), superoxide dismutase (Dhindsa et al., 1981) and Peroxidase activity (Castillo et al., 1994) were estimated.

RESULTS

Assessment of drying rate

The initial moisture content was 11 ± 0.2% for all seed lots. Time taken to reduce the moisture content to 6±0.1% was about 7 to 11 days in rapid drying methods while it is about 19 to 24 days in slow drying methods. On continuous drying of the remaining second sample up to 36 days, it is evident that in both the genotypes drying rate was found to be highest in acid drying methods followed by silica gel. The impact of drying methods on seedling shoot length and root length were also analysed (Figures 1 and 2).

Seed viability

Decline of about 11 and 9% in acid drying followed by 8 and 7% in control was observed in CSH 16 and CSV 18 genotypes, respectively. All other drying methods showed only 2 to 6% decline from the initial value after 6 months of storage.

Vigour index

In the present study, vigour index showed a steady decline over the storage period. The total reduction in vigour was more pronounced in acid drying (40 to 45%) and control which were found to be on par in both the genotypes of sorghum. Silica gel and seed dryer method showed maximum vigour index of 3068 and 3026 in CSH 16 and CSV 18 genotypes of sorghum respectively, after six months of storage. In CSV 18 lithium chloride showed significantly higher vigour index value of 2968 followed by seed dryer drying and silica gel drying. Vigour index II also showed similar trend of decline by acid drying followed control. Only 10 to 15% decline was observed in other drying methods.

Electrical conductivity

The EC of leachates observed under different drying methods increased significantly with loss in seed viability. Maximum value was observed in control and acid dried seeds of sorghum (42 to 50%) while minimum was observed in the seed lot dried with seed dryer followed by lithium chloride (Table 1).

Amylase activity

As the storage duration progressed, decline in amylase

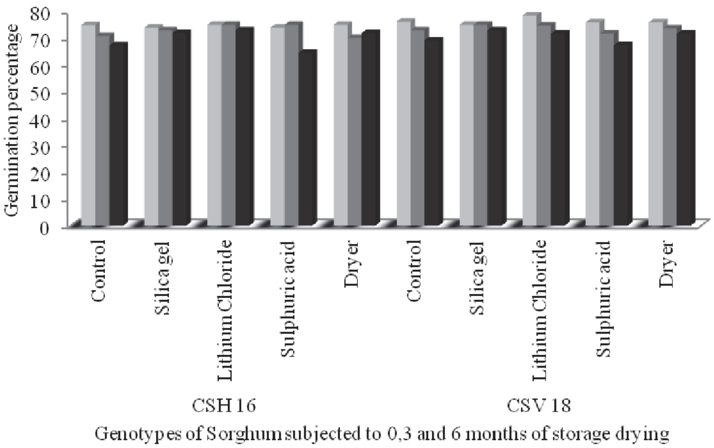

Figure 1. Effects of different drying methods on seed germination of sorghum.

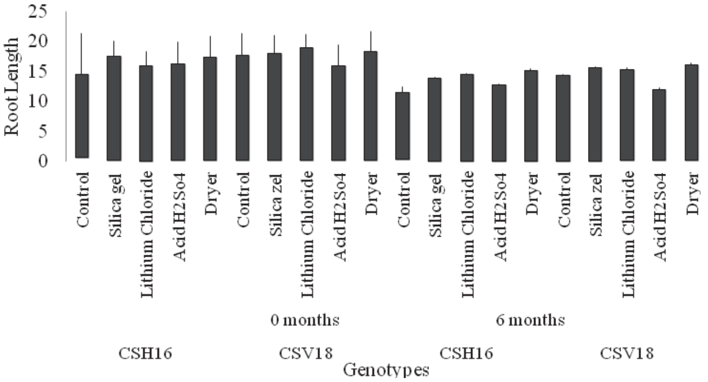

Figure 2. Effects of different drying methods and drying rate on root length of sorghum.

activity was observed; however maximum reduction in enzyme activity was observed in control and acid drying method. Other drying methods also exhibited significant difference in the amylase activity. About 40 to 50% decline in amylase activity was observed after 6 months of storage in control and acid dried seed samples. The maximum decline in amylase activity value was observed in control from 53.79 mg maltose/g of seed to 28.97 mg maltose/g of seed after six months of storage in CSH 16 (Table 2). Seeds dried with lithium chloride, silica gel and dryer showed a decline of about 26 to 34% in CSH-16 as well as CSV-18 genotypes.

Dehydrogenase

Seeds dried using lithium chloride and drying chamber had dehydrogenase activity 0.223 (OD value) and 0.221 (OD value) in sorghum genotype CSH 16 (Table 1). The significant reduction in the dehydrogenase activity was noticed after six months in acid dried seeds and control. In CSV 18, maximum decline was observed in control (43%) while other drying methods showed lower value of 27 to 29%.

Peroxidase activity

Peroxidase activity was high in fresh seeds and decreased gradually with increase in storage period (Table 2). Sorghum genotype CSV 18 showed maximum decline (52%) in peroxidise activity from 139.18 µmolar/min/g of fresh seed to 66.86 µmolar/min/g of fresh seed in seeds dried by acid. Similar trend was observed in CSH 16 which recorded 38% decline from the initial value after six months of storage. All other drying methods showed an activity decline ranging within 26 to 31%.

Table 1. Effects of different drying methods and rate of drying on seed quality of sorghum.

Genotype	Drying methods	Vigour index I			Vigour index II			EC (µ siemens/cm/g seed)			Dehydrogenase activity (OD at 480 nm/ 25 seed)		
		Storage duration (month)			Storage duration (month)			Storage duration (month)			Storage duration (month)		
		0	3	6	0	3	6	0	3	6	0	3	6
CSH 16	Control	3764	2730	2166	16.0	14.1	11.6	121.47	150.32	189.69	0.205	0.144	0.113
	Silica gel	3785	3288	2647	16.4	15.0	13.7	120.35	143.52	165.59	0.213	0.178	0.158
	Lithium Chloride	3639	3313	2968	16.5	15.4	15.0	113.04	132.89	154.79	0.223	0.186	0.15
	Acid (Conc H_2SO_4)	3490	2739	1913	14.6	12.4	10.1	137.74	158.15	187.98	0.192	0.141	0.107
	Dryer	3891	3296	2764	18.4	16.5	16.3	114.47	127.82	159.24	0.221	0.178	0.154
CSV 18	Control	3923	3005	2324	19.5	15.5	13.0	130.74	152.74	182.79	0.317	0.264	0.18
	Silica gel	4292	3508	3069	18.1	16.8	15.0	122.96	136.12	175.89	0.338	0.295	0.23
	Lithium Chloride	3965	3377	2801	19.7	17.6	14.3	119.82	108.78	155.1	0.339	0.283	0.244
	Acid (Conc H_2SO_4)	3554	2810	2077	15.6	11.9	10.1	138.27	158.2	185.49	0.299	0.253	0.216
	Dryer	4380	3343	3026	18.3	16.2	15.5	109.38	122.78	149.51	0.339	0.278	0.24
Source			CD at 5%			CD at 5%			CD at 5%			CD at 5%	
Genotype (G)			17.9			0.085			0.89			0.001	
Drying method (M)			28.31			0.134			1.4			0.002	
Storage Duration (D)			21.93			0.104			1.08			0.001	
G X M			40.03			0.19			1.98			0.003	
G X D			31.01			0.14			1.54			0.002	
M X D			49.03			0.232			2.43			0.003	
G X M X D			69.34			0.328			3.44			0.005	

Superoxide dismutase (SOD)

Activities of different genotypes of sorghum showed a gradual decrease during the storage period. The amount of SOD measuring 3.42 units/g of seed/min and 3.45 units/g of seed/min was observed in CSH 16 genotype of sorghum seed lots dried by silica gel and seed dryer methods respectively, which declined to 2.69 units/g of seed/min and 2.82 units/g of seed/min after six months of storage. In general, maximum decline was observed in control samples followed by acid drying methods. Minimum reduction in SOD activity of 19% was observed in the seed lots which were dried by seed dryer in the genotype of CSV 18.

DISCUSSION

The parameters of the seed quality including seed viability and seed vigour play a key role during long term storage. Seedling vigour is ultimately the most important expression of the seed quality (Heydecker, 1972). In the present study the genotypes showed significant difference for methods of drying. Maximum value of root, shoot, seedling length and vigour index were observed in the seed lots dried by using seed dryer followed by silica gel. However, lithium chloride was also on par with silica gel. Acid drying was harmful as it drastically reduced moisture content causing sudden and abrupt physical and physiological changes in seed which ultimately leads to poor germination and production of more number of abnormal seedlings with low vigour index. Similar

Table 2. Effects of different drying methods and rate of drying on seed quality of sorghum.

Genotype	Drying methods	Protein content (mg/g seed)			Peroxidase enzyme activity (µmolar/min/g fwt)			Super Oxide Dismutase enzyme activity (units/g seed/min)			Amylase enzyme activity (mg maltose/g seed fwt/5 min)		
		Storage duration (month)			Storage duration (month)			Storage duration (month)			Storage duration (month)		
		0	3	6	0	3	6	0	3	6	0	3	6
CSH 16	Control	92.14	83.16	72.07	147.87	116.08	87.36	3.21	2.48	1.58	53.79	40.42	28.97
	Silica gel	95.81	84.74	80.85	150.24	136.58	100.16	3.42	3.10	2.69	57.93	49.56	37.78
	Lithium Chloride	92.6	86.93	80.77	177.33	161.21	118.21	2.96	2.54	1.79	53.82	43.98	39.61
	Acid (Conc H_2SO_4)	95.24	82.26	68.66	145.31	132.1	89.06	2.85	2.32	1.70	49.73	40.82	29.12
	Dryer	94.2	86.97	82.35	162.55	147.77	108.37	3.45	3.13	2.82	59.41	50.88	40.84
CSV 18	Control	97.85	86.05	78.64	126.27	107.34	78.56	2.23	1.71	1.38	51.08	36.6	21.73
	Silica gel	96.89	87.8	80.78	146.81	120.69	107.92	3.33	3.02	2.29	53.03	47.35	33.85
	Lithium Chloride	96.41	85.06	78.66	160.42	145.84	115.86	2.36	2.16	1.90	51.3	44.83	35.62
	Acid (Conc H_2SO_4)	93.34	80.33	75.46	139.89	106.47	66.86	2.28	2.08	1.61	46.99	36.06	27.76
	Dryer	95.03	90.25	84.08	184.08	166.45	126.02	2.78	2.53	2.36	51.95	44.78	37.94
Source		CD at 5%			CD at 5%			CD at 5%			CD at 5%		
Genotype (G)		0.491			0.72			0.015			0.25		
Drying method (M)		0.776			1.15			0.023			0.395		
Storage Duration (D)		0.601			0.89			0.018			0.306		
G X M		1.098			1.62			0.033			0.558		
G X D		N.S.			1.26			0.025			0.433		
M X D		1.34			1.99			0.04			0.684		
G X M X D		1.9			2.82			0.057			0.967		

results were also reported by acid drying in different vegetable crops (Nutile, 1963) where decline in germination and reduced seedling length was conspicuously observed. Membrane degradation enhances solute leakage from imbibed seed, resulting in loss of viability and seed vigour (Matthews and Bradnock, 1968). In the present study, increase in electrolyte leakage was observed in the acid dried seeds. However the change in relative electric conductivity of acid dried seeds after six months in ambient conditions was lower than control (10 to 11%), while minimum EC value was found in seeds dried in dryer followed by silica gel and lithium chloride drying.

Dehydrogenase plays the leading role in the metabolism and is influenced by aging. Dehydrogenase activity and the seed viability are positively correlated (Ellis et al., 1985). In the present study, dehydrogenase activity of sorghum showed significantly lower values in acid drying as compared to control, which meant that dehydrogenase activity of acid dried seeds were more prone to desiccation and found to be inefficient in maintaining the seed viability.

In the present study, there was significant difference in amylase activity of seeds dried with different methods. Seed lots dried with silica gel and lithium chloride resulted in maximum amylase value. Similar results was also reported in *Melilotus suaveolens* (Liu et al., 2011).

However, there was significant reduction in amylase activity of acid dried seeds, both in case of sorghum and pearl millet genotypes suggesting that acid drying was detrimental to the seed quality, irrespective of crop species and respective genotypes.

Peroxidase enzyme is involved in dehydrogenation of large number of organic compounds such as aromatic amines and free radicals. The decrease in the level of this enzyme could lead to the accumulation of toxic substances in the seeds. Such accumulation of toxic free radicals accompanied by the decreased activity of antioxidant enzyme has been reported (Hendry, 1993). A decrease in the level of soluble protein is an expression of the loss of activities of the membrane associated superoxide dismutase (Weisiger and Fridovich, 1973). In the present study, peroxidase and SOD activities in sorghum and pearl millet showed a significant decline in the seed lots dried by acid whereas, the minimum value for peroxidase and SOD activity was observed in seed dryer method. However, comparable results were noticed in silica gel and lithium chloride drying.

The results obtained under this study have shown that all the drying methods improved the seed quality parameters except acid drying. Observations showed that drying with acid is most effective in lowering seed moisture content in both the crops at a faster rate, but the seed quality was adversely affected by acid drying. Hence, acid drying is not recommended for seed drying purposes. Silica gel gave the next highest drying rate and the quality of seeds was maintained as in case of drying using drying chamber. Hence, silica gel drying can be suggested as an alternative drying method for less quantity of seed for conservation of germplasm. Lithium chloride drying also showed comparable results with seeds dried using silica gel and dryer methods in terms of quality parameters. However, drying rate was found to be relatively slow. Although silica gel is a very effective desiccant for drying seeds to very low moisture contents, many authors have argued that the cost and labour involved in the daily regeneration of silica gel makes it a less practical method, as compared with oven drying or freeze drying (Hong and Ellis, 1996). However, in situations where the supply of electricity is a problem, silica gel may be a viable option. From the germplasm conservation perspective, further studies are needed to determine the impact of these drying methods on the long term seed storability in seed gene bank.

Conflict of Interest

The authors have not declared any conflict of interest.

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Estimation of heterosis and combining ability for earliness and yield characters in pumpkin (*Cucurbita moschata* Duch. Ex. Poir)

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Heterosis breeding is a potential tool to achieve improvement in quantity, quality, and productivity of pumpkin. A line x tester mating design was used to study standard heterosis for earliness and yield characters in pumpkin. An investigation was carried out during 2009 to 2010 with twelve lines and three testers at Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore to study the heterosis and combining ability for earliness and yield characters. Evaluation of parents based on *per se* and general combining ability (*gca*) effects revealed that the parents Kasi Harit, Vadhalagundu Local and CO 2 were identified as the best genotypes for improvement of earliness and yield characters. The hybrids *viz*., Kasi Harit × Avinashi Local and Vadhalagundu Local × CO 2 had registered favourable values of mean, significant sca and standard heterosis for earliness and yield characters. Considering the *per se* performance, specific combining ability (sca) and the standard heterosis, the aforementioned hybrids had registered favourable values for the most important characters like earliness, number of fruits and yield of fruits. Further, these top performing F_1 hybrids can be tested in different seasons over different locations for assessing their stability for high yield.

Key words: Pumpkin, *Per se* performance, general combining ability (*gca*), specific combining ability (sca) standard heterosis.

INTRODUCTION

Pumpkin *(Cucurbita moschata* Duch ex.Poir*)* originated from Central Mexico is cultivated in tropical and subtropical region all over the world and an important cucurbitaceous vegetable crop of India and principal ingredient of several Indian dishes (Mohanty and Mohanty, 1998). In India, it occupies an area of 11,060

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*Corresponding author. E-mail: tamilaaru@gmail.com ha with an annual production of 2, 77,560 tonnes accounting to an average productivity of 25.10 t/ha (Anon, 2012). Pumpkin is consumed as culinary vegetable at immature and mature fruit stage. It provides a valuable source of carotenoid and ascorbic acids that have a major role in nutrition in the form of pro-vitamin A and vitamin C as antioxidants (Jha et al., 2009). Its big size seeds contain appreciable quantities of protein and oil. It may serve as good substitute for edible oil, similar to that of oil of summer squash (*Cucurbita pepo).* Therefore, pumpkin as vegetable is becoming important ingredient in daily diet, but relatively little attention has been paid towards development of hybrids/varieties rich in carotenoids with high yielding capacity.

Though a wide range of variability is encountered in this crop, very little attention has been paid to exploit it in breeding programmes. A thorough knowledge about the genetic behaviour of a character is important in formulating appropriate breeding technique in a crop. The monoecious character, conspicuous and solitary flowers, large seed number per fruit and wide variability for yield, size and shape of fruit make this crop congenial for commercial breeding. During the last two decades many workers utilized heterosis breeding as a tool for improvement of yield in pumpkin (Sirohi and Ghorui, 1993). However, the genetic potential of this crop needs further exploitation to its nearest perfection. Hence the present investigation was undertaken to determine the magnitude of heterosis for earliness and yield parameters in pumpkin.

Choice of parents considered as an important aspect in any breeding programme aimed to improve the yield and its related attributes. The success of hybridization programme is generally depends upon the breeder to select suitable parents to obtain high proportion of desirable recombination. One of the possible approaches for achieving the targeted production is to identify and develop suitable hybrids with high yield and good quality. The exploitation of heterosis is much easier in cross pollinated crops and pumpkin being monoecious crop, provides ample scope for the utilization of hybrid vigour on commercial scale.

Further, the diversified parents from different locations with high yield and quality would also pave way for the development and release of hybrids through heterosis breeding. The hybrid vigour is substantially increased on crossing genetically diverse inbreds and thus heterosis mostly obtained from genetic diversity among the parents involved (Sharma, 1994).

Line x tester analysis helps in the selection of desirable parents and also appropriate breeding procedure by measuring general combining ability (*gca*), specific combining ability (sca) variances and their effects and the genetic components of variance (Singh and Narayanan, 1993).The concept of combining ability helps the breeder to determine the nature of gene action involved in the expression of quantitative traits of economic importance.

MATERIALS AND METHODS

The experimental material comprised fifteen diverse genotypes including twelve lines viz*.,* Pusa Vishwas (L_1), Punjab Samrat (L_2), Narendra Abhushan (L_3), Narendra Uphar (L_4), Ambili(L_5), Virudhachalam Local (L_6), Chakor (L_7), Ashoka Farm Aids (L_8), Vadhalagundu Local (L_9), Karamadai Local (L_{10}), Karwar Local (L_{11}) and Kasi Harit (L_{12}) and three testers *viz*., Arka Suryamukhi (T_1), Avinashi Local (T_2), CO 2 (T_3) and they were crossed in line x tester mating design to obtain thirty six hybrids. The fifteen parents and thirty six F_1 hybrids were evaluated along with the standard check "hybrid MPH-1" (Mahyco Hybrid Seeds Private Limited) in randomized block design (RBD) with three replications at Department of Vegetable Crops, Tamil Nadu Agriculture University, Coimbatore - 641103 during 2009-10.The seeds of the experimental material was planted in an inter row spacing of 2.5 m and intra row spacing of 2.5 m apart. There were five plants per plot per replication with a total of 780 plants maintained. Observations were recorded on traits *viz*. days to first female flower appearance, node number to first female flower appearance, sex ratio (Female flowers / Male flowers), days to first harvest, fruit number per vine, fruit weight, flesh thickness (FT) and fruit yield per vine quality traits *viz*.,Total carbohydrate content, total carotenoids content and crude fibre content. Total carbohydrate content of fruit was estimated at harvestable maturity with the anthrone method of Hedge and Hofreiter (1962). Total carotenoid content of fruit flesh was estimated using the method of Roy (1973) and crude fibre estimation by the method suggested by Chopra and Kanwar (1976) and expressed as per cent.

The mean values were utilized for statistical analysis. Heterosis in F_1 hybrids was estimated for each trait based on all the criteria using three mean values (Gowen, 1952). Estimation of general and specific combining ability analysis was done using the line x tester method described by Kempthrone (1957).

Estimation of combining ability effects

Both the *gca* and *sca* effects of an ijkth observation was derived by using the mathematical model given below

$$X_{ijk} = \mu + \hat{g}_i + \hat{g}_j + \hat{s}_{ij} + \hat{l}_{ijk}$$

The general combining ability effect of parents and specific combining ability effect of hybrid combinations were estimated as follows.

$\mu = x_{..} / rlt$

***gca* effects of lines**

$$gca \text{ effect of lines } (g_i) = \frac{X_{i..}}{rt} - \frac{X_{...}}{rlt}$$

***gca* effects of testers**

$$gca \text{ effect of testers } (g_j) = \frac{X_{.j.}}{rl} - \frac{X_{...}}{rlt}$$

***sca* effect of hybrids**

sca effects of hybrids(s_{ij}) = $\frac{X_{ij}\cdot}{r} - \frac{X_i\cdot\cdot}{rt} - \frac{X\cdot_j\cdot}{rl} + \frac{X\ldots}{rlt}$

Where,
x … = Total of hybrids over 'r' number of replication
x_i.. = Total of i^{th} line over 't' testers and 'r' replications
x.$_j$. = Total of j^{th} tester over 'l' lines and 'r' replications
sx_{ij}. = Total of the hybrids between i^{th} line and j^{th} tester over 'r' replications.

RESULTS AND DISCUSSION

In any crop breeding programme, it is essential to eliminate the undesirable types, which can be achieved by studying the *per se* performance of parents and hybrids. The choice of parents become easy when a trait is unidirectionally controlled by a set of alleles and additive effects are prominent, since they can be chosen on the basis of *per se* performance. The *per se* performance and *gca* effects of the parents are presented in Table 1. Among the twelve lines and three testers evaluated, Vadhalagundu Local (L_9) was the best as it expressed good performance for yield, seven yield contributing characters *viz.,* days to first female flower appearance, sex ratio, days to first harvest, fruit number per vine and total carbohydrate content and total carotenoids content. It was followed by the line Kasi Harit (L_{12}) which possessed good performance for yield, yield contributing traits *viz.,* days to first female flower appearance, node number for first female flower appearance, sex ratio, days to first harvest, and fruit number per vine, quality trait *viz.,*Total carbohydrate content and total carotenoid content (Table 1).

Among the testers, CO 2 (T_3) ranked first as it registered superior *per se* performance for days to first female flower appearance, sex ratio, days to first harvest, fruit number per vine, fruit weight and fruit yield per vine and quality characters like total carbohydrate content and crude fibre content. This was followed by the tester Avinashi Local (T_2) exhibiting superiority for node number for first female flower appearance, fruit weight, FT, total carbohydrate content and total carotenoids content. However, selection of parents based on *per se* performance alone might not hold promise in producing superior hybrids.

In majority of the cases, parents with high mean performance were found to show significant *gca* effect and this was in conformity to the report of Lawande and Patil (1990) and Sundaram (2006) in bitter gourd. In the present investigation, the combining ability for each character was analysed (Table 1). The line Vadhalagundu Local (L_9) recorded significant *gca* effects for twelve traits *viz.,* days to first female flower appearance, node number for first female flower appearance, sex ratio, days to first harvest, fruit number per vine, total carbohydrate content, total carotenoid content and yield. This was followed by the line Kasi Harit (L_{12}) which was the best combiner for days to first female flower appearance, node number for first female flower appearance , sex ratio, days to first harvest, fruit number per vine , total carbohydrate content, total carotenoid content, and yield per vine. Among testers, CO 2 (T_3) had significantly high *gca* effect for days to first female flower appearance, node number for first female flower appearance, fruit number per vine, total carotenoid content and yield per vine. The tester Avinashi Local (T_2) could also be used to develop hybrids with total carbohydrate content , total carotenoid content and fruit yield per vine as by its significant higher *gca* value (Table 1).

As evaluation based on *per se* performance and combining ability effects separately did not show parallelism, it is therefore necessary to consider both *per se* and combining ability effects together for further isolation of desirable parental genotypes and hybrids. The *per se* performance and *gca* effects were related to each other in parents. According to Sharma and Chauhan (1985), the *per se* performance and *gca* effect of the parents were directly related to each other, will result in the selection of parents with good reservoir of superior genes. Majumder and Bhowal (1988) also reported the parallelism between *per se* performance and *gca* effect. Combining *gca* and *per se,* Kasi Harit (L_{12}) was the best parent for days to first female flower appearance, node number for first female flower appearance, sex ratio, days to first harvest, total carotenoid content, total carbohydrate content, crude fibre content and yield. The parent Vadhalagundu Local (L_9) had desirable performance for days to first female flower appearance, days to first harvest, sex ratio, fruit number per vine, total carbohydrate content and total carotenoid content and fruit yield per vine. Hence crosses involving Kasi Harit (L_{12}) and Vadhalagundu Local (L_9) would help in improvement of yield (Table 1).

The *sca* effect of hybrid is the deviation from the performance predicted based on the *gca* of the parents (Allard, 1960). The *sca* effect is due to dominance, epistasis and environmental influence. Under certain favourable conditions, all the non additive gene functions may get triggered and result in high *sca* effect and mean value of a responding hybrid. Thus evaluation of a hybrid for high *per se* and *sca* effect is also an important criterion. The *per se, sca* effect and standard heterosis values of 36 hybrids were given in Table 2.

Hybrids with high *per se* and *sca* effect were evaluated for selection of best hybrids. Evaluation of hybrids for *per se* and *sca* revealed that the cross Kasi Harit × Avinashi Local (L_{12} × T_2) was adjudged as the best hybrid, since it recorded the highest mean and *sca* effect for more number of traits of study *viz.,* earliness in terms of early female flowering, early node of female flower appearance, sex ratio fruit number per vine, FT, total carotenoid content and total yield per vine. The next

Table 1. *Per se* performance and *gca* of parents for earliness, yield and quality traits in pumpkin.

Parents	Days to first female appearance	Node no. for first female flower appearance	Sex ratio	Days to first harvest	Fruit number per vine	Fruit weight	FT	Total carbohydrate content	Total carotenoid content	Crude fibre content	Fruit yield per vine
Lines											
L_1	**53.62**	**19.12**	**18.33**	**125.70**	**1.62**	**5.28**	**3.07**	**0.77**	**0.56**	**1.38**	**5.82**
	*3.35***	*-3.60***	*-1.89***	*10.21***	*-1.38***	*0.61***	*-0.28***	*-0.88***	*-0.59***	*0.03 ns*	*-2.20 ***
L_2	**51.00**	**23.62**	**18.65**	**126.50**	**3.87**	**3.89**	**2.77**	**1.70**	**0.96**	**0.51**	**7.98**
	-0.53^{ns}	*0.02*^{ns}	*-2.07***	*16.63***	*0.62***	*0.01*	*-0.12*^{ns}	*-0.38***	*-0.49***	*-0.11 ***	*0.97 ***
L_3	**49.12**	**22.87**	**27.07**	**106.75**	**2.37**	**4.22**	**3.56**	**1.84**	**0.75**	**0.91**	**9.47**
	*-2.28***	*-1.52***	*6.38***	*-8.54***	*-0.80***	*-0.30***	*-0.02*^{ns}	*-0.45***	*-0.50***	*0.06 ***	*-1.70 ***
L_4	**50.37**	**24.62**	**19.68**	**101.50**	**4.12**	**3.35**	**2.32**	**1.78**	**0.54**	**0.79**	**7.92**
	-0.40^{ns}	*0.32*^{ns}	*-1.30***	*-6.88***	*-0.72***	*0.23***	*-0.35***	*-0.20***	*-0.42***	*0.00 ns*	*0.22 ***
L_5	**50.87**	**25.62**	**24.37**	**128.50**	**2.87**	**5.08**	**2.80**	**0.73**	**0.33**	**1.04**	**11.11**
	0.18^{ns}	*-0.43*^{ns}	*3.00***	*-1.33*^{ns}	*-0.92***	*0.73***	*0.11*^{ns}	*-0.60***	*-0.65***	*-0.01 ns*	*0.37 ***
L_6	**63.12**	**26.62**	**27.98**	**143.75**	**1.12**	**6.84**	**3.27**	**1.99**	**1.015**	**1.26**	**7.54**
	*4.22***	*2.61***	*6.89***	*18.17***	*-1.76***	*0.94***	*0.37***	*-0.23***	*-0.44***	*0.00 ns*	*-2.41 ***
L_7	**52.87**	**24.87**	**19.33**	**146.75**	**3.12**	**2.83**	**3.28**	**1.14**	**0.75**	**0.86**	**8.40**
	*3.56***	*1.40***	*-1.05***	*-1.63*^{ns}	*0.49***	*0.61***	*0.39***	*-0.09***	*-0.33***	*-0.00 ns*	*3.13 ***
L_8	**54.12**	**26.25**	**19.70**	**148.37**	**4.25**	**3.62**	**2.83**	**1.73**	**0.67**	**1.15**	**9.50**
	0.43^{ns}	*2.82***	*-1.17***	*-3.88***	*-0.05*^{ns}	*0.35***	*0.50***	*-0.26***	*-0.40***	*0.04 **	*-0.37 ***
L_9	**48.12**	**25.87**	**17.36**	**108.75**	**4.00**	**1.95**	**3.07**	**2.77**	**2.25**	**0.92**	**10.11**
	*-3.44***	*-2.43***	*-3.12***	*-11.04***	*2.03***	*-1.12***	*-0.44***	*0.38***	*1.23***	*-0.17 ***	*1.68 ***
L_{10}	**49.50**	**17.62**	**18.21**	**128.50**	**3.37**	**2.39**	**2.36**	**1.93**	**1.065**	**1.11**	**8.47**
	*-2.61***	*0.69**	*-1.51***	*-2.67**	*1.41***	*-0.55***	*0.10*^{ns}	*0.52***	*0.18***	*0.04 **	*0.55 ***
L_{11}	**48.87**	**25.12**	**19.81**	**113.50**	**1.75**	**4.34**	**2.72**	**1.30**	**0.96**	**0.78**	**6.70**
	*2.14***	*2.23***	*-0.12*^{ns}	*0.08*^{ns}	*-0.34**	*-0.28***	*-0.36***	*1.01***	*1.08***	*0.06 ***	*-1.99 ***
L_{12}	**44.75**	**16.50**	**14.88**	**107.37**	**3.75**	**2.35**	**3.48**	**2.34**	**2.045**	**1.33**	**8.23**
	*-4.61***	*-2.10***	*-4.02***	*-9.13***	*1.41***	*-1.22***	*0.10*^{ns}	*1.17***	*1.34***	*0.05 **	*1.74 ***
Testers											
T_1	**42.37**	**14.50**	**19.44**	**108.37**	**1.62**	**1.93**	**1.87**	**1.05**	**0.99**	**0.68**	**3.61**
	0.06^{ns}	*0.11*^{ns}	*0.09*^{ns}	*-1.30**	*-0.28***	*0.02*	*-0.04*^{ns}	*-0.26***	*-0.31***	*0.04 ***	*-0.89 ***
T_2	52.12	**16.87**	**23.64**	**146.12**	**3.25**	**3.01**	**3.02**	**2.95**	**3.00**	**0.75**	**7.80**
	0.72**	**0.48****	**0.24ns**	**-0.22ns**	**0.05ns**	**-0.07***	**0.06ns**	**0.36****	**0.23****	**-0.06 ****	**0.34 ****
T_3	**44.62**	**21.12**	**18.96**	**125.62**	**4.75**	**3.35**	**3.12**	**2.31**	**1.97**	**1.01**	**8.56**
	*-0.78***	*-0.59***	*-0.33**	*-1.08*^{ns}	*0.23***	*0.05*	*-0.02*^{ns}	*-0.10***	*0.08***	*0.02 ns*	*0.55 ***

per se values are in bold and *gca* values are in italics. *, ** Significantly superior at 5 and 1% levels respectively.

Table 2. *Per se* performance, *sca* and standard heterosis of pumpkin hybrids for earliness, yield and quality traits.

Hybrids	Days to first female appearance	Node no. for first female flower appearance	Sex ratio	Days to first harvest	Fruit number per vine	Fruit weight	FT	Total carbohydrate content	Total carotenoid content	Crude fibre content	Fruit yield per vine
Pusa Vishwas × Arka Suryamukhi	**52.87**	**16.12**	**18.50**	**120.75**	**2.62**	**3.60**	**2.43**	**0.53**	**0.98**	**1.26**	**9.33**
	_0.69_	_-1.82**_	_-0.71_	_-5.55*_	_1.15**_	_-0.49**_	_1.00*_	_0.02_	_0.41**_	_0.24**_	_3.40**_
	3.17	-28.73**	-7.68*	-11.81**	-51.16**	19.76**	2.09	-70.56**	-69.89**	-4.55	1.81
Pusa Vishwas × Avinashi Local	**52.62**	**17.75**	**19.65**	**127.62**	**1.37**	**4.45**	**2.08**	**1.03**	**0.88**	**0.64**	**5.83**
	_-0.22_	_-0.57_	_0.29_	_3.22_	_-0.42_	_0.45**_	_-0.33_	_-0.10**_	_-0.23**_	_-0.28**_	_-1.33**_
	2.68	-21.55**	-1.95	-6.50**	-74.42**	47.86**	-12.57	-42.50**	-72.96**	-51.52**	-36.42**
Pusa Vishwas × CO 2	**50.87**	**19.62**	**19.21**	**125.87**	**1.25**	**4.16**	**2.62**	**0.76**	**0.77**	**1.02**	**5.29**
	_-0.47_	_2.38**_	_0.42_	_2.33_	_-0.73*_	_0.05_	_-0.67_	_0.08*_	_-0.18**_	_0.03_	_-2.07**_
	-0.73	-13.26**	-4.14	-7.78**	-76.74**	38.44**	9.74	-57.78**	-76.34**	-22.35**	-42.23**
Punjab Samrat × Arka Suryamukhi	**48.12**	**19.87**	**17.85**	**126.50**	**3.62**	**3.57**	**2.72**	**1.03**	**0.92**	**0.85**	**10.10**
	_-0.18_	_-1.69**_	_-1.17*_	_-5.84**_	_0.15_	_0.08_	_-1.83**_	_0.01_	_0.25**_	_-0.03_	_1.00**_
	-6.10**	-12.15**	-10.93**	-7.33**	-32.56**	18.60**	14.14	-42.78**	-71.74**	-35.61**	10.14**
Punjab Samrat × Avinashi Local	**49.50**	**22.75**	**19.35**	**132.37**	**4.25**	**3.76**	**2.98**	**1.73**	**1.31**	**0.89**	**13.44**
	_0.53_	_0.81_	_0.18_	_1.55_	_0.45_	_0.37**_	_0.96*_	_0.09**_	_0.10_	_0.11**_	_3.11**_
	-3.41	0.55	-3.44	-3.02	-20.93**	24.95**	25.13*	-3.89	-59.75**	-32.58**	46.63**
Punjab Samrat × CO 2	**47.12**	**21.75**	**19.60**	**134.25**	**3.37**	**3.06**	**1.91**	**1.08**	**0.71**	**0.79**	**6.43**
	_-0.35_	_0.88_	_1.00_	_4.29*_	_-0.61*_	_-0.45**_	_0.87_	_-0.10**_	_-0.35**_	_-0.07*_	_-4.11**_
	-8.05**	-3.87	-2.20	-1.65	-37.21**	1.91	-19.74*	-40.00**	-78.19**	-40.15**	-29.85**
Narendra Abhushan × Arka Suryamukhi	**45.87**	**20.62**	**26.38**	**107.50**	**2.50**	**2.57**	**2.22**	**1.17**	**0.98**	**0.98**	**6.42**
	_-0.68_	_-0.15_	_-1.09*_	_0.32_	_0.44_	_-0.61**_	_-2.83**_	_0.23**_	_0.32**_	_-0.07*_	_0.00_
	-10.49**	-12.15**	31.64**	-21.25**	-53.49**	-14.49*	-6.81	-34.72**	-69.89**	-25.76**	-29.89**
Narendra Abhushan × Avinashi Local	**47.00**	**22.87**	**29.90**	**104.37**	**1.62**	**2.78**	**2.65**	**1.25**	**1.02**	**0.88**	**4.49**
	_-0.22_	_2.48**_	_2.27**_	_-1.28_	_-0.75*_	_-0.30*_	_2.09**_	_-0.32**_	_-0.18**_	_-0.07*_	_-3.16**_
	-8.29**	1.10	49.20**	-23.53**	-69.77**	-7.51	10.99	-30.56**	-68.66**	-33.33**	-50.98**
Narendra Abhushan × CO 2	**46.62**	**17.00**	**25.88**	**105.75**	**2.87**	**4.11**	**3.05**	**1.20**	**0.90**	**1.17**	**11.02**
	_0.90_	_-2.33**_	_-1.18*_	_0.96_	_0.31_	_0.91**_	_0.74_	_0.09**_	_-0.14**_	_0.14**_	_3.16**_
	-9.02**	-24.86**	29.14**	-22.53**	-46.51**	36.57**	27.75**	-33.33**	-72.35**	-11.36**	20.20**
Narendra Uphar × Arka Suryamukhi	**49.75**	**21.25**	**19.83**	**107.87**	**1.37**	**3.27**	**2.18**	**1.11**	**0.82**	**0.99**	**4.70**
	_1.32_	_-1.23*_	_0.04_	_-0.97_	_-0.76*_	_-0.44**_	_6.17**_	_-0.08*_	_0.08_	_-0.00_	_-3.64**_
	-2.93	-8.84*	-1.05	-20.97**	-74.42**	8.76	-8.38	-38.06**	-74.81**	-25.00**	-48.69**
Narendra Uphar × Avinashi Local	**47.37**	**23.50**	**19.97**	**107.12**	**2.50**	**3.71**	**2.66**	**2.11**	**1.37**	**0.68**	**9.26**
	_-1.72*_	_1.27*_	_0.03_	_1.05_	_0.04_	_0.09_	_-2.91**_	_0.30**_	_0.09_	_-0.21**_	_-0.31**_
	-7.56**	3.87	-0.35	-20.60**	-53.49**	23.29**	11.52	17.50**	-57.91**	-48.48**	1.04

Table 2. Contd.

Narendra Uphar **×** CO 2	**48.00**	**21.12**	**19.31**	**106.37**	**3.37**	**4.08**	**2.10**	**1.14**	**0.96**	**1.19**	**13.74**
	0.40	*-0.03*	*-0.06*	*-0.08*	*0.73**	*0.35***	*-3.26***	*-0.22***	*-0.17***	*0.22***	*3.96***
	-6.34**	-6.63	-3.64	-22.07**	-37.21**	35.70**	-12.04	-36.67**	-70.51**	-9.85**	49.92**
Ambili **×** Arka Suryamukhi	**49.87**	**20.00**	**24.97**	**110.62**	**2.25**	**4.74**	**3.07**	**1.13**	**0.84**	**1.00**	**10.61**
	0.74	*-1.11*	*0.88*	*-2.89*	*0.32*	*0.53***	*1.92***	*0.34***	*0.33***	*0.02*	*2.11***
	-2.93	-11.60**	24.60**	-18.32**	-58.14**	57.49**	28.80**	-36.94**	-74.19**	-24.24**	15.77**
Ambili × Avinashi Local	**51.00**	**21.87**	**23.95**	**112.00**	**2.00**	**3.76**	**2.57**	**1.52**	**1.17**	**1.03**	**7.54**
	1.32	*0.39*	*-0.30*	*-0.86*	*-0.25*	*-0.36***	*-3.29***	*0.10***	*0.12**	*0.15***	*-2.19***
	-0.49	-3.31	19.51**	-17.95**	-62.79**	24.95**	7.75	-15.56**	-64.06**	-21.97**	-17.71**
Ambili × CO 2	**46.12**	**21.37**	**23.10**	**115.75**	**2.37**	**4.07**	**2.67**	**0.51**	**0.44**	**0.79**	**10.01**
	*-2.60***	*0.72*	*-0.58*	*3.75*	*-0.07*	*-0.17*	*1.37***	*-0.45***	*-0.45***	*-0.17***	*0.07*
	-10.00**	-6.63	15.27**	-15.20**	-55.81**	35.33**	12.04	-71.67**	-86.48**	-40.15**	9.23**
Virudhachalam Local × Arka Suryamukhi	**50.00**	**24.62**	**28.45**	**128.75**	**1.37**	**4.51**	**3.08**	**1.44**	**0.95**	**1.01**	**6.92**
	-3.06**	0.48	0.47	-2.64	0.28	0.09	0.42	0.27**	0.23**	0.02	1.21**
	-2.44	8.84*	41.97**	-3.85	-74.42**	50.06**	29.32**	-20.00**	-70.81**	-23.48**	-24.47**
Virudhachalam Local × Avinashi Local	**56.37**	**23.87**	**28.85**	**134.25**	**1.12**	**4.59**	**3.01**	**1.66**	**1.30**	**0.95**	**6.16**
	*2.65***	*0.65*	*0.72*	*3.39*	*-0.30*	*0.26**	*3.21***	*-0.13***	*0.03*	*0.06*	*-0.79***
	10.00**	5.52	43.96**	-0.55	-79.07**	52.55**	26.18**	-7.78**	-60.06**	-27.65**	-32.82**
Virudhachalam Local × CO 2	52.62	23.62	26.38	130.87	1.62	4.09	2.98	1.19	0.85	0.89	6.74
	0.40	0.17	-1.18*	-0.75	0.02	-0.36**	-3.63**	-0.14**	-0.26**	-0.08*	-0.42**
	2.68	4.42	31.64**	-4.21*	-69.77**	35.95**	25.13*	-33.89**	-73.89**	-32.58**	-26.49**
Chakor × Arka Suryamukhi	**5.51**	**55.75**	**22.75**	**19.80**	**119.87**	**3.37**	**3.60**	**3.40**	**1.15**	**1.01**	**10.24**
	3.36	*-0.19*	*-0.24*	*5.78***	*0.03*	*-0.49***	*-0.67*	*-0.15***	*0.18***	*0.05*	*-1.01***
	8.78**	0.55	-1.20	-12.18**	-37.21**	19.55**	42.41**	-36.11**	-68.97**	-21.21**	11.67**
Chakor **×** Avinashi Local	**4.24**	**52.75**	**24.87**	**20.21**	**105.87**	**3.12**	**4.41**	**2.92**	**1.98**	**1.27**	**0.87**
	-0.31	*1.56***	*0.02*	*-6.70***	*-0.55*	*0.42***	*-1.68***	*0.06*	*-0.11**	*-0.02*	*-0.30***
	2.93	9.94**	0.85	-22.44**	-41.86**	46.74**	22.51*	10.28**	-60.98**	-34.09**	32.88**
Chakor **×** CO 2	**4.25**	**48.50**	**20.87**	**19.85**	**112.62**	**4.37**	**4.18**	**2.83**	**1.55**	**1.15**	**0.93**
	*-0.36***	*-1.37**	*0.23*	*0.92*	*0.52*	*0.07*	*2.35***	*0.09**	*-0.07*	*-0.03*	*1.31***
	-5.37**	-7.73*	-0.95	-17.49**	-18.60*	39.06**	18.85	-13.89**	-64.67**	-29.17**	52.75**
Ashoka Farm Aids × Arka Suryamukhi	**3.71**	**46.75**	**25.62**	**20.15**	**122.75**	**2.87**	**4.35**	**3.42**	**1.36**	**0.91**	**0.72**
	*-2.51***	*1.27**	*0.23*	*10.91***	*0.07*	*0.52***	*0.04*	*0.23***	*0.15***	*-0.31***	*0.95***
	-8.78**	13.26**	0.55	-10.07**	-46.51**	44.67**	43.46**	-24.44**	-72.04**	-45.45**	-5.07**
Ashoka Farm Aids **×** Avinashi Local	**7.25**	**48.87**	**23.62**	**19.35**	**104.75**	**3.50**	**3.35**	**3.52**	**1.79**	**1.40**	**1.30**
	-1.06	*-1.11*	*-0.73*	*-5.57***	*0.37*	*-0.39***	*1.21**	*0.03*	*0.10**	*0.37***	*1.32***
	-8.00**	4.42	-3.44	-23.26**	-34.88**	11.25*	47.64**	-0.56	-56.99**	-1.52	12.38**
Ashoka Farm Aids × CO 2	**8.55**	**52.00**	**23.50**	**20.01**	**104.12**	**2.87**	**3.73**	**2.53**	**1.03**	**0.89**	**0.96**
	*3.57***	*-0.16*	*0.50*	*-5.33***	*-0.44*	*-0.13*	*-1.26**	*-0.26***	*-0.25***	*-0.05*	*-2.27***
	1.46	3.87	-0.15	-23.72**	-46.51**	23.95**	6.28	-42.50**	-72.66**	-27.27**	-24.47**

Table 2. Contd.

Vadhalagundu Local × Arka Suryamukhi	**3.31**	**45.50**	**20.75**	**18.12**	**103.87**	**4.25**	**2.50**	**1.71**	**1.47**	**1.22**	**0.87**
	_0.11_	_1.64**_	_0.15_	_-0.80_	_-0.64*_	_0.14_	_1.25*_	_-0.30**_	_-1.17**_	_0.05_	_-1.46**_
	-11.22**	-8.29*	-9.58**	-23.90**	-20.93**	-16.69**	-28.27**	-18.33**	-62.52**	-34.09**	-8.87**
Vadhalagundu Local × Avinashi Local	**2.89**	**46.75**	**20.87**	**19.23**	**105.62**	**3.87**	**2.58**	**1.73**	**2.08**	**1.78**	**0.82**
	_0.69_	_1.39*_	_1.11*_	_2.47_	_-1.34**_	_0.31*_	_-2.33**_	_-0.32**_	_-1.15**_	_0.11**_	_-4.81**_
	-8.78**	-7.73*	-4.04	-22.62**	-27.91**	-14.28*	-27.23**	15.56**	-45.31**	-37.50**	-32.03**
Vadhalagundu Local × CO 2	**4.36**	**43.75**	**15.37**	**16.30**	**100.62**	**8.50**	**1.94**	**3.22**	**2.56**	**5.10**	**0.64**
	_-0.81_	_-3.03**_	_-1.25*_	_-1.67_	_1.98**_	_-0.44**_	_1.08*_	_0.62**_	_2.32**_	_-0.16**_	_6.26**_
	-14.63**	-32.04**	-18.66**	-26.28**	37.21**	-35.28**	35.08**	42.22**	56.68**	-51.52**	90.99**
Karamadai Local × Arka Suryamukhi	**4.17**	**46.62**	**22.87**	**19.23**	**107.12**	**4.25**	**3.32**	**2.80**	**1.95**	**1.53**	**0.75**
	_0.40_	_0.64_	_-0.35_	_-5.93**_	_-0.01_	_0.39**_	_-0.79_	_0.04_	_0.19**_	_-0.28**_	_0.78**_
	-9.02**	1.10	-4.04	-21.52**	-20.93**	10.42	17.28	8.61**	-53.00**	-43.18**	3.16**
Karamadai Local × Avinashi Local	**6.27**	**45.25**	**22.37**	**19.45**	**117.12**	**5.50**	**2.39**	**2.48**	**2.93**	**2.11**	**0.92**
	_-1.64*_	_-0.23_	_-0.28_	_5.59**_	_0.91**_	_-0.45**_	_-0.99*_	_0.39**_	_0.23**_	_-0.01_	_0.13_
	-11.71**	-1.10	-2.94	-14.19**	2.33	-20.51**	4.19	62.78**	-35.18**	-30.30**	9.47**
Karamadai Local × CO 2	**3.77**	**46.75**	**21.12**	**19.80**	**111.00**	**3.87**	**3.02**	**3.00**	**1.65**	**1.30**	**1.31**
	_1.24_	_-0.41_	_0.64_	_0.33_	_-0.90**_	_0.06_	_1.79**_	_-0.43**_	_-0.42**_	_0.30**_	_-0.90**_
	-9.02**	-6.63	-1.20	-18.68**	-27.91**	0.46	25.65*	-8.33**	-59.91**	-0.76	0.53
Karwar Local × Arka Suryamukhi	**3.50**	**50.37**	**23.25**	**20.95**	**120.87**	**2.62**	**3.66**	**1.93**	**1.83**	**1.60**	**1.25**
	_-0.60_	_-0.52_	_-0.02_	_5.07*_	_0.11_	_0.46**_	_0.29_	_-0.58**_	_-0.64**_	_0.20**_	_0.53**_
	-1.71	2.76	4.54	-11.45**	-51.16**	21.63**	-18.85	1.67	-50.84**	-5.30	-27.21**
Karwar Local × Avinashi Local	**5.31**	**54.50**	**24.75**	**21.75**	**114.75**	**2.87**	**2.66**	**2.50**	**3.05**	**3.24**	**0.93**
	_2.86**_	_0.60_	_0.63_	_0.47_	_0.04_	_-0.45**_	_-2.04**_	_0.02_	_0.46**_	_-0.02_	_1.40**_
	6.34**	9.39*	8.53*	-15.93**	-46.51**	-11.58*	4.71	69.44**	-0.46	-29.55**	-4.33**
Karwar Local × CO 2	**5.53**	**47.87**	**23.00**	**19.95**	**107.87**	**2.87**	**3.21**	**2.47**	**3.13**	**2.80**	**0.86**
	_-2.26**_	_-0.08_	_-0.60_	_-5.54**_	_-0.15_	_-0.01_	_1.74**_	_0.56**_	_0.18**_	_-0.17**_	_-1.93**_
	-6.59**	1.66	-0.45	-20.97**	-46.51**	6.68	3.66	74.17**	-13.98**	-34.85**	-38.36**
Kasi Harit × Arka Suryamukhi	**3.79**	**44.62**	**22.12**	**18.91**	**109.12**	**3.12**	**2.09**	**2.46**	**2.54**	**2.16**	**1.17**
	_0.40_	_2.68**_	_1.83**_	_2.53_	_-1.14**_	_-0.17_	_-4.96**_	_-0.02_	_-0.34**_	_0.13**_	_-3.86**_
	-12.93**	-2.21	-5.64	-20.05**	-41.86**	-30.47**	3.14	41.39**	-33.64**	-11.36**	-34.54**
Kasi Harit × Avinashi Local	**5.81**	**42.00**	**13.87**	**13.31**	**101.75**	**7.37**	**2.22**	**3.55**	**3.07**	**3.57**	**0.77**
	_-2.89**_	_-5.94**_	_-3.92**_	_-3.32_	_1.79**_	_0.05_	_6.09**_	_-0.12**_	_0.54**_	_-0.17**_	_6.92**_
	-18.05**	-38.67**	-33.58**	-25.46**	18.60*	-26.28**	48.69**	70.56**	9.83**	-41.67**	96.44**
Kasi Harit × CO 2	**4.97**	**45.87**	**22.00**	**18.75**	**105.00**	**4.12**	**2.40**	**2.28**	**2.88**	**2.68**	**1.05**
	_2.49**_	_3.26**_	_2.09**_	_0.79_	_-0.65*_	_0.12_	_-1.13*_	_0.15**_	_-0.20**_	_0.04_	_-3.05**_
	-10.49**	-2.76	-6.44	-23.08**	-23.26**	-20.22**	-4.19	60.00**	-17.67**	-20.45**	-10.01**

Per se values are in bold, *sca* values are in italics and standard heterosis values are in normal font.

Table 3. Analysis of variance for combining ability of different traits of pumpkin genotypes.

Source	df	Mean sum of squares										
		Days to first female flower appearance	Node no. for first female flower appearance	Sex ratio	Days to first harvest	Fruit number per vine	Fruit weight	FT	Total carbohydrate content	Total carotenoid content	Crude fiber content	Fruit yield per vine
Hybrids	35	22.56	14.71	26.09	215.97	3.86	1.24	0.47	1.05	1.81	0.06	21.65
Lines	11	50.20	26.20	74.92	579.59	8.64	3.02	0.60	2.44	3.48	0.03	18.91
Testers	2	13.55	7.11	2.08	35.00	1.59	0.09	0.07	2.50	1.86	0.06	14.50
Line x Testers	22	9.56	9.66	3.85	50.61	1.68	0.45	0.44	0.23	0.97	0.08	23.66
Error	35	0.93	0.66	0.50	8.41	0.16	0.02	0.05	0.002	0.004	0.002	0.009

best hybrid, Vadhalagundu Local × CO 2 (L_9 × T_3) could also be justified as the better combination through less node number for first female flower appearance, fruit number per vine, sex ratio, FT, total carotenoid content and fruit yield per vine (Table 2). Jha et al. (2009) endorsed the same results in pumpkin.

Evaluation of hybrids based on the three criteria *viz.,* mean, *sca* and standard heterosis would lead to the identification of different sets of cross combinations for each of these criteria. However, the scope for exploitation of hybrid vigour in a heterosis breeding programme depends not only on the extent of heterosis for individual traits but also on the mean performance and *sca* effects of hybrids. Hence, it would be more appropriate to evaluate the hybrids based on all these criteria.

Such an evaluation had revealed that none of the hybrid was found to exhibit superiority for all the three criterions for all the characters under study. Evaluation based on *per se* performance, *sca* effects and standard heterosis had revealed that the hybrid Kasi Harit × Avinashi Local was adjudged as the best hybrid as it excelled in exhibiting its superiority on more number of traits *viz.,* earliness in terms of days for first female appearance, sex ratio, days to first harvest, fruit numbers per vine, FT, quality trait like total carotenoid content besides yield per vine. Next to this hybrid, Vadhalagundu Local × CO 2 was adjudged as the next best one as the hybrid surpassed in *per se*, *sca* effect and heterosis for traits *viz.*, earliness in terms of node number for first female flower appearance, sex ratio, fruit number per vine, FT, Total carotenoid content and fruit yield per vine (Table 2). Concomitant reports were also given by Vidya et al. (2002) in pumpkin.

Highly significant variances were observed for both general and specific combining ability for all the characters under study (Table 3). Findings indicated that parents and crosses differed significantly with regard to their general and specific combining ability, respectively. The ratio of *gca / sca* variance exhibited additive and non-additive gene action, for all traits (Table 4). The ratio of *gca*: sca variance indicated higher magnitude for sca variance than *gca* variance for the following characters viz., days to first female flower appearance, node number for first female flower appearance, sex ratio, days for first harvest, number of fruits per vine, fruit weight, total carotenoid content, total carbohydrate content, crude fibre content of the fruit and fruit yield per vine implying the preponderance of non-additive gene action (Table 5). This indicated the limited scope of population improvement for these characters and heterosis breeding could be adopted for exploiting the genetic variations. Similar results in respect of these characters were obtained by Srinivasan (2003) and Jha et al. (2009) in pumpkin.

The hybrids Kasi Harit × Avinashi Local and Vadhalagundu Local × CO 2 can be well exploited through heterosis breeding to obtain higher yield with quality fruits. Moreover, these hybrids could be better utilized for the improvement of the characters concerned and intermating among superior segregants resulting from these heterotic hybrids, is likely to throw desirable progenies in the subsequent later generations. On the basis of the above findings, it can be concluded that improvement in pumpkin for earliness and yield related characters would be brought out through hybridization (heterosis breeding).

Conflict of Interest

The authors have not declared any conflict of interest.

Table 4. Magnitude of genetic variance of yield and yield components of pumpkin parents and hybrids.

Character	*gca* variance	sca variance	Ratio *gca*: sca
Days to first female flower appearance	0.3070	4.3151	0.07114
Node number for first female flower appearance	0.1194	4.4988	0.02654
Sex ratio	0.5251	0.6767	0.7759
Days to first harvest	3.9052	21.1021	0.1850
Fruit number vine	0.0516	0.7582	0.06805
Fruit weight	0.0186	0.2136	0.0870
FT	0.0006	0.1972	0.003
Total carbohydrate content	0.0195	0.1145	0.17030
Total carotenoid content	0.0199	0.4837	0.04114
Crude fibre content	-0.0004	0.0400	-0.01
Fruit yield per vine	-0.047	11.830	0.0039

gca – General combining ability: sca – Specific combining ability.

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Analysis of risks in crop production due to climate change in the Central Rift Valley of Ethiopia

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This study was conducted to investigate historical climate dynamics and the resultant risks at four sites (Meki, Melkassa, Miesso and Ziway) in the Central Rift Valley of Ethiopia. It involved analysis of rainfall and temperature data in the study areas. The results showed the existence of high inter-annual rainfall variability within seasons and sites. The number of rainy days exhibited a declining trend at Meki in both *belg* (FMAM) and *kiremt* (JJAS) seasons and an increasing trend at Melkassa in the *belg* season; while an increasing trend was observed at Miesso and Ziway in the *kiremt* season, and no change in trends was observed in the *belg* season at both sites. The minimum and maximum temperature showed an increasing trend at Miesso and Ziway, whereas no change was observed at Melkassa. As opposed to the cessation of the rainfall, onset dates of rainfall were highly variable at all sites. The median length of the growing period was found to be 101, 88, 118 and 104 days at Meki, Melkassa, Miesso and Ziway, respectively. The obtained results will certainly help the farming community and the agricultural sector to make a decision for the best management scheme in the central rift valley of Ethiopia.

Key words: Climate change, risk, rainfall, temperature, crop production, Central Rift Valley, Belg, Kiremt.

INTRODUCTION

Increasing fossil fuel burning and land use changes emits large quantities of greenhouse gases into the atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). A rise in these gases is causing a rise in the amount of heat from the sun withheld in the Earth's atmosphere, heat that would normally be radiated back into space. This increase in heat load has led to the greenhouse effect resulting in climate change (UNFCCC, 2007).

The fourth assessment reports of the Inter-governmental Panel on Climate Change (IPCC, 2007) dispels many uncertainties about climate change. Warming of the climate system is now unequivocal. It is clear that global warming is mostly due to man-made emissions of greenhouse gases (mostly CO_2). Over the last century, atmospheric concentrations of carbon dioxide has increased from a pre-industrial value of 278 ppm to 379 ppm in 2005, and the average global temperature has risen by 0.74°C (IPCC, 2007). There is now strong evidence showing that the earth's climate is changing mainly as a result of the increasing concentration of greenhouse gases in the atmosphere emitted from various human activities (NAPA, 2007).

Agriculture is the source of livelihoods for the majority

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of the Ethiopian population and the base of the national economy. It employs more than 80% of the labor force and accounts for 45% of the GDP, as well as 85% of the export revenue (MoFED, 2006). However, Ethiopian agriculture is dominated by small-scale and subsistence farming systems and it is heavily dependent on rainfall, as irrigation is currently applied to only 3% of arable land. Thus, the dependency of farmers on rainfed agriculture has made the country's economy extremely vulnerable to the aberrations of weather and climate (Kidane et al., 2006).

A recent vulnerability and poverty mapping study of Africa (Orindi et al., 2006; Stige et al., 2006) put Ethiopia as one of the most vulnerable countries to climate change with the least capacity to respond. Rainfall variability and associated drought have been major causes for the country's food shortages. Nationally, the link between drought and crop production is widely recognized, but little is known about how climate change is affecting crop production and what strategies households are employing (Mahmud et al., 2008).

The Ethiopian Central Rift Valley (CRV) is one of the regions in the country which is affected by climate variability and change. It covers a variety of agro-ecologies characterized by extensive areas of low rainfall and limited areas receiving adequate rainfall. The rainfall pattern in the CRV is bi-modal in nature and largely influenced by the annual oscillation of the inter-tropical convergence zone, which results in warm, wet summers (with most of the rainfall occurring from June to September) and dry, cold and windy winters. The main rainy season accounts for 70 to 90% of the total annual rainfall. Minor rain events, originating from moist south-easterly winds, occur between March and May (Hengsdijk and Jansen, 2006).

Crop production in semi-arid regions is largely determined by climatic and soil factors. Among the climatic factors, the distribution and amount of rainfall affect the agricultural systems of the CRV. Therefore, rainfall is considered a limiting factor in these areas and many of the farm decisions are made based on the time of the onset of rainfall. The onset and distribution of rainfall governs crop yields and determines the choice of the crops to be grown (Stelio, 2004). The cultivated land in the CRV is mostly located on the valley floor and the major field crops grown include: teff, barley, maize, sorghum, lentils, chickpeas and field peas. The most important vegetables grown under irrigation include the common bean, tomato, onion, cabbage and broccoli (Moti, 2002).

In general, the inter-annual and inter-seasonal climate variability coupled with climate change are the main causes of fluctuating annual production with occasional drastic reduction of crop yields in the region. However, the dearth of information on the degree of climate variability and change; and information on climate risks on agricultural production, such as rainfall onset dates, end dates, duration and dry spell lengths, which together make up the overall rain feature for field crop management options in the study areas is extensive. Therefore, this study was undertaken to analyze risks of climate in crop production in the Central Rift Valley of Ethiopia, using long term rainfall and temperature data.

MATERIALS AND METHODS

The areas covered by this study were Meki (latitude 8° 15' N, longitudes 38° 82' E and altitude 1400 m.a.s.l), Melkassa (latitude 8° 4' N, longitude 39° 32' E and altitude 1550 m.a.s.l), Miesso (latitude 9° 23' N, longitude 40° 75' E and altitude 1400 m.a.s.l). Ziway (latitude 7° 93' N, longitudes 38° 72' E and altitude 1640 m.a.s.l), all located in the Central Rift Valley of Ethiopia. The choice of the districts was based on data availability, farming systems and representativeness of agro-ecological settings in the Central Rift Valley (Figure 1).

Climate change and variability analysis

Secondary data obtained from the National Meteorological Agency was used for climate change and variability analysis. The data base period for all the study sites is shown in Table 1.

Rainfall and temperature variability and change analysis

The annual and seasonal pattern of rainfall and temperature were examined for each district by processing daily rainfall and temperature data using the INSTAT version 3.36 (Stern et al., 2006). The rainfall and temperature variability at each site were determined by calculating mean, standard deviation and the coefficient of variation (CV). The CV was calculated as the ratio of the standard deviation to the mean rainfall in a given period. The standardized anomaly (Z) for rainfall and temperature was calculated as:

$$Z=\frac{x-\overline{X}}{S}$$

Where x = annual total rainfall or annual mean temperature

$\overline{X}$ = long term mean

S = standard deviation of the entire series

Onset and cessation of rain, probability of dry spells and length of growing season analysis

The onset of rain (a successful planting date) was defined as the first occasion after 1st March when the rainfall accumulates for three consecutive days and rainfall is at least 20 mm and no dry spell of more than seven days in the next 30 days (Sivakumar, 1988; Kindie and Walker, 2004). To analyze the onset of wet and dry spells, a first order Markov chain model was fitted to get more than 30 years of data for each site using the INSTAT version 3.36. The daily rainfall data was processed to give maximum dry spell lengths in the next 30-day periods, starting from the onset of rain for each site. Probabilities of the maximum dry spell lengths exceeding 5, 7, 10, 15 and 20 days over the next 30 days from planting, were calculated to get an overview of the drought at the study area for the whole year. The end of the rainy season (defined as the

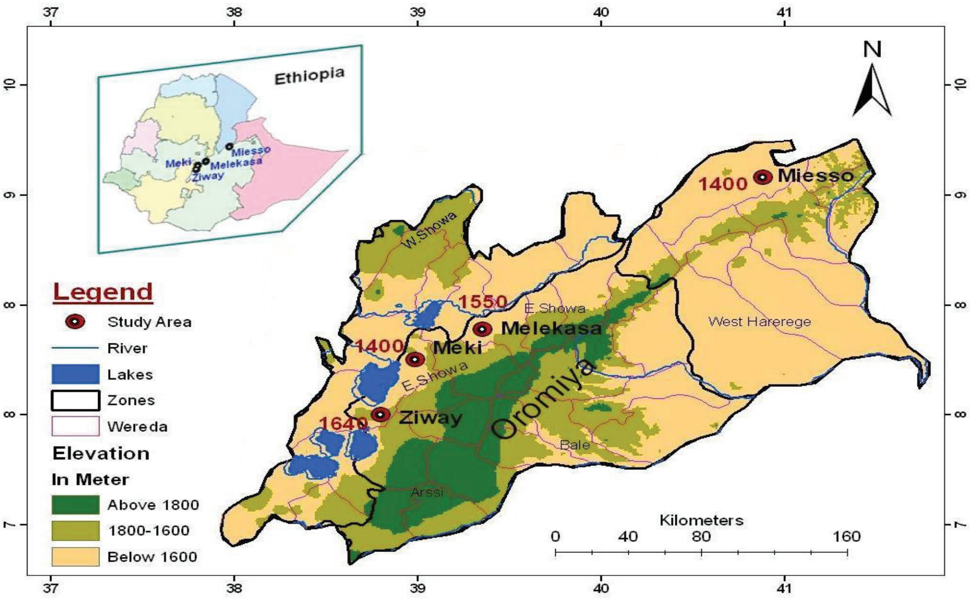

Figure 1. Location map of the study areas.

Table 1. Database period for rainfall and temperature.

District	Rainfall		Maximum and Minimum Temperatures	
	Database period	No. of years	Database period	No. of years
Meki	1966-2009	41	NA	NA
Melkassa	1977-2009	33	1977-2009	33
Mieso	1974-2009	36	1990-2009	20
Ziway	1970-2009	40	1970-2009	40

NA: Data not available. Source: National Meteorological Agency.

occurrence of a day after first September when the soil water drops to 10 mm m^{-1}) was determined by using the water balance dialogue in the INSTAT climatic guide (Stern et al., 2006). Subsequently, the length of the growing period in the study areas was determined as the difference between the onset date and end date (Stern et al., 2006; Kindie and Walker, 2004).

RESULTS AND DISCUSSION

Climate variability and change analysis

Rainfall variability and change

The long-term rainfall data for the four sites are presented in Table 2. The mean annual rainfall of the study areas ranged from 719 mm (Miesso) to 791 mm (Melkassa) and varied slightly from district to district with a standard deviation ranging from 167 (Melkasa) to 191mm (Miesso) and CV ranging from 21(Melkassa) to 27 % (Miesso). This indicates that the rainfall at Miesso is more variable than the other sites.

A time series bar chart indicates high inter-annual rainfall variability among the districts (Figure 2). The annual total rainfall ranged from 281 to 1131 mm at Meki, 425-1234 mm at Melkassa, 271 to 1111 mm at Miesso and 314 to 1042 mm at Ziway (Figure 2). These annual rainfall figures indicate that Melkassa has a greater total annual rainfall than the rest of the sites studied. The highest and lowest total annual rainfall years were 1983 and 1995 at Meki, 2007 and 1989 at Melkassa, 1996 and 1986 at Miesso and 2008 and 1970 at Ziway, respectively (Figure 2).

The standardized rainfall anomaly gives a clear picture of average (normal), above average (wet) and below average (dry) years (Figure 3). As can be seen from Figure 3, the four stations experienced both dry and wet years over the last 33 (Melkassa) and 41 years (Meki). For instance, Meki experienced dry conditions in 1991, 1995 and 2009, whereas it enjoyed wet conditions in 1983. The years that gave above average rainfall at Melkassa were 1977 and 2007 as opposed to 1989 when dry conditions prevailed. Miesso experienced dry

Table 2. Long-term annual rainfall statistics of four meteorological stations in the Central Rift Valley of Ethiopia.

Characteristics	Weather Station			
	Meki	Melkassa	Miesso	Ziway
Mean (mm)	729	791	719	742
Standard deviation (mm)	179	167	191	168
CV (%)	25	21	27	23

CV = coefficient of variability.

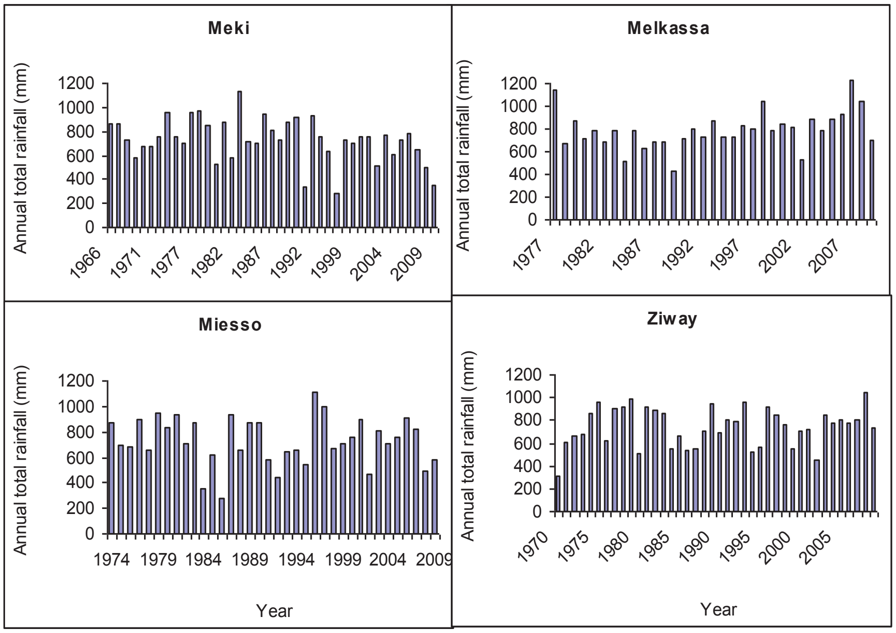

Figure 2. Long-term inter-annual variability of rainfall at four sites in the Central Rift Valley of Ethiopia.

conditions in 1984 and 1986 and wet conditions in 1996. The years that dry and wet conditions prevailed in Ziway were 1970 and 2008, respectively (Figure 3). Moreover, the linear trend line for Meki clearly demonstrates a general decline in rainfall since 1966, whereas an increasing trend was observed for Melkassa. On the other hand, there was little or no change in the rainfall trend at Miesso and Ziway (Figure 3).

The bimodal pattern of rainfall at the study sites is presented in Table 3. The first rainy season (*Belg*) extends from the end of February to May (FMAM), while the second (*Kiremt*) runs from June to September (JJAS). The long-term minimum FMAM season rainfall total ranges from 0 mm (Miesso) to 75.1 mm (Ziway), while the long-term maximum rainfall ranges from 323 mm (Melkassa) to 531 mm (Miesso). In 1 out of 4 years, the FMAM season rainfall ranges from 115.1 mm (Melkassa) to 163.2 mm (Miesso) with an upper quartile value of 260.5 mm (Melkassa) to 306.4 mm (Miesso). The median and average seasonal rainfall for *belg* season ranges from 187.5 mm (Meki) to 245.7 mm (Ziway) and 185.1 mm (Melkassa) to 248.6 mm (Miesso), respectively.

The *belg* (FMAM) exhibited higher rainfall variability (41 to 47%), compared to the *kiremt* rainfall variability (21 to 29%) at the four sites (Table 3). The analysis also shows that the *belg* rainfall was more variable at Miesso, while it was much less variable at Ziway. Miesso had the most variable *kiremt* rainfall, while Melkassa varied the least for the same season. Even though the study areas are located in close proximity, they differed in the amount of seasonal rainfall distribution and the degree of variability of seasonal rainfall. On the other hand, the dry season (*Bega)* in the study area extends from October to December (OND). The long term minimum seasonal rainfall total is 0 mm in all sites and the maximum seasonal rainfall total ranges from 262 mm (Meki) to 435mm (Miesso). The *Bega* rainfall exhibits the highest rainfall variability (105 to 130%) at the four sites, compared to *Belg* and *Kiremt* seasons, even if the season was dry under normal conditions (Table 3).

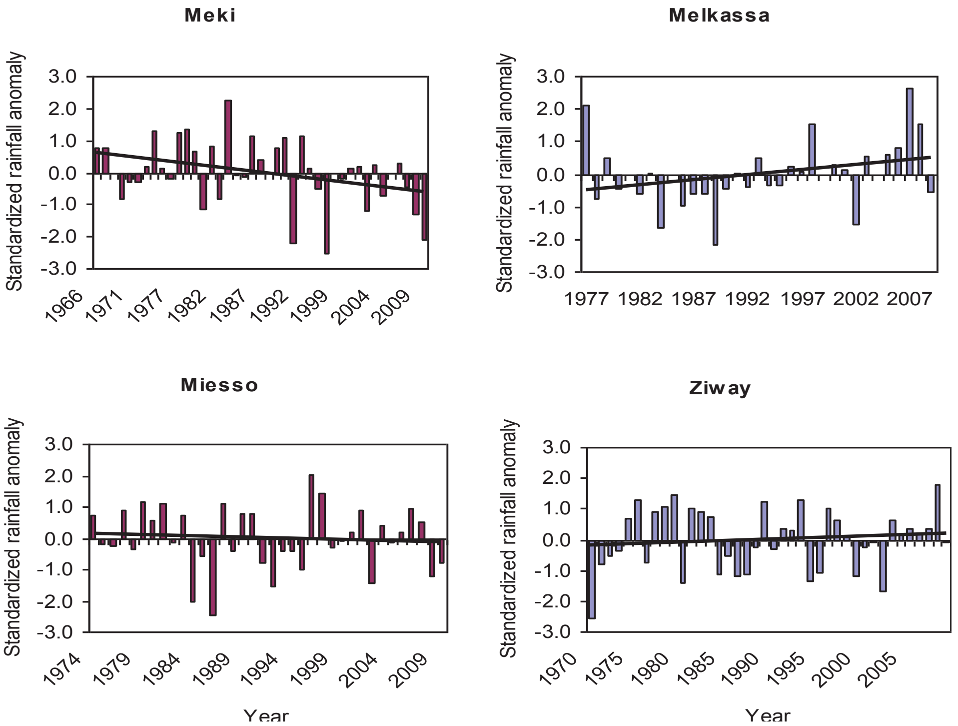

Figure 3. Rainfall variability and trend as expressed by standardized rainfall anomaly at four sites in the Central Rift Valley of Ethiopia.

Table 3. Seasonal rainfall distribution and its statistical attributes at four sites in the Central Rift Valley of Ethiopia

Site	Rainfall statistics								
			%ile					SD	CV
	Season	Minimum	25	50	75	Maximum	Mean	(±)	(%)
	FMAM	71.2	150.7	187.5	266.4	510.4	213.9	95.2	44.5
Meki	JJAS	90.6	409.3	464.9	551.3	658.8	468.2	119.4	25.5
	OND	0.0	6.6	22.7	58.7	262.6	42.9	55.7	129.7
	FMAM	23.0	115.1	197.6	260.5	323.6	185.1	83.2	45.0
Melkassa	JJAS	289.2	435.3	526.1	584.1	704.3	515.8	107.3	20.8
	OND	0.6	13.0	45.1	135.1	314.2	71.0	74.4	104.9
	FMAM	0.0	163.2	237.7	306.4	530.8	248.6	115.8	46.6
Miesso	JJAS	184.5	288.5	396.4	479.8	648.1	395.3	116.3	29.4
	OND	0.0	18.8	42.1	112.4	435.1	70.46	85.1	120.8
	FMAM	75.1	162.9	245.7	302.8	394.9	232.7	96.3	41.4
Ziway	JJAS	112.3	390.4	445.9	502.7	788.6	443.5	122.0	27.5
	OND	0.0	5.9	23.4	71.1	289.2	47.5	60.1	126.6

The seasonal rainfall analysis on the number of rainy days is presented in Figure 4. Number of rainy days shows a declining trend in both the *belg* and *kiremt* seasons at Meki, followed by the *belg* season at Melkassa. On the other hand, the number of rainy days showed an increasing trend in the *kiremt* season at Melkassa, Miesso and Ziway.

Onset and cessation of rainfall, length of growing season and dry spell risk analysis

The analysis of rainfall for agricultural purposes mustinclude information on the trends or changes in precipitation; the start, end and length of the rainy season; and the distribution of rainfall amounts through

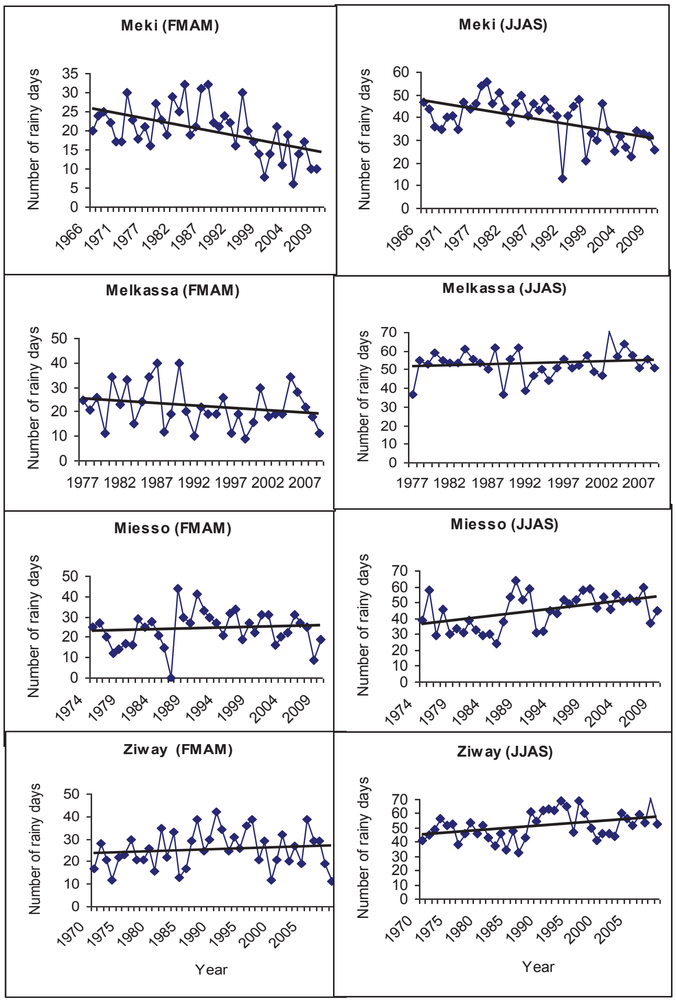

Figure 4. Variability and Trend of number of rainy days in *belg* (FMAM) and *kiremt* (JJAS) seasons at four sites in the Central Rift Valley of Ethiopia.

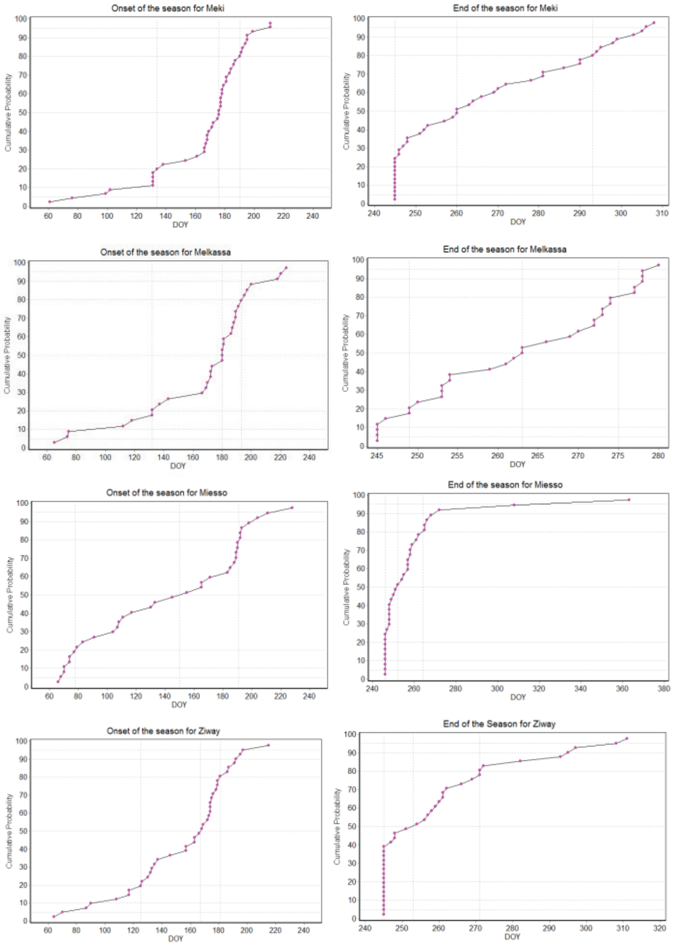

Figure 5. Cumulative probability of onset and end of rainy season at four sites in the Central Rift Valley of Ethiopia.

the year, and the risk of dry spells (Stelio, 2004). The cumulative probabilities of onset and end dates and length of the growing period in the study areas are presented in Figures 5 and 6 respectively. The variability of onset dates for the four districts was higher, compared to end dates and lengths of the growing period. At Meki, the rain started before May 10 (131 DOY) in 20% of the time, before June 21 (173 DOY) 50% of the time and before July 6 (188 DOY) 80% of the time. In the case of Melkassa, the rain started earlier than May 11 (132 DOY) in one out of five years, earlier than June 25 (177 DOY) 50% of the time and 80% of the time in four out of five years as it started before July 9 (191 DOY).

On the other hand, at Miesso, the rain started earlier than March 18 (78 DOY) 20% of the time, indicating that planting earlier than 18 March is possible only once in every five years. The chance of planting before June 3 (155 DOY) and July 10 (192 DOY) at Miesso is 50 and 80%, respectively. The chances of effective planting before April 19 (110 DOY), June 14 (166 DOY) and June 24 (176 DOY) at Ziway were 20, 50 and 80%, respectively (Figure 5). A further note that could also be made from the data in Figure 5 is that rainfall duration is dependent mainly on the onset date. For 50 to 80% of the time, the rain ended in all districts in the month of September, except Meki where it extended up to the month of October 80% of the time. The median (50%) length of the growing period was found to be 101, 88, 118 and 104 days at Meki, Melkassa, Miesso and Ziway respectively. For 80% of the years studied, the length of the growing period did not exceed 138, 121, 175 and 141 days at Meki, Melkassa, Miesso and Ziway, respectively (Figure 6).

Overall, except for the rainfall onset dates of seasons, the four stations bear similar patterns for the end dates and lengths of growing periods. Culturally, the first planting time for the study area is in the month of March in Miesso, but the probability of having rainfall onset in the beginning of this month is less than 10 % in all the other three sites.

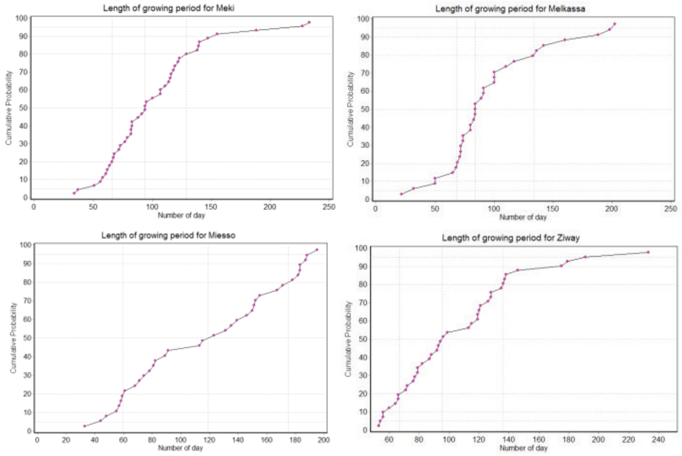

Figure 6. Cumulative probability of length of growing season at four sites in the Central Rift Valley of Ethiopia.

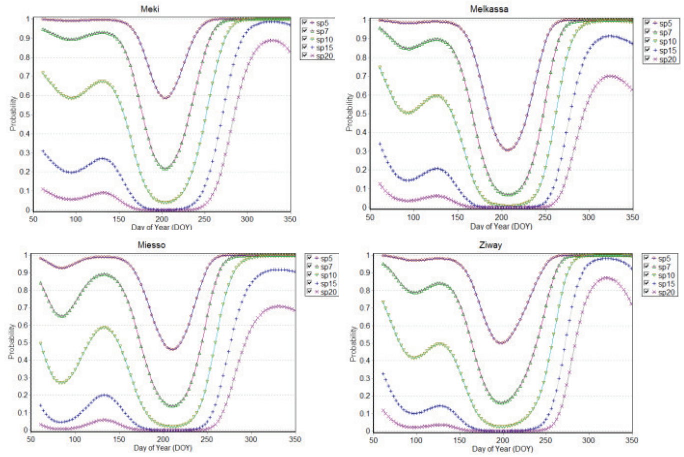

Figure 7. Probability of dry spells longer than 5, 7, 10, 15 and 20 days at four sites in the Central Rift Valley of Ethiopia.

The ‘parabolic-type’ curves explain that the probability of dry spells longer than 20 days from March to September is less than 10% in all districts, whereas they show a certain degree of an upward slope in April and May and descend to zero from the middle of June to the middle of July. The probability of dry spells more than 15 days is less than 10% for Miesso, and less than 20% for the rest of the districts in March. The dry spell graphs show a variation across sites in the probability of dry spells longer than 10 days (Figure 7). Moreover, the probability of five day dry spells stays at 100 % during the earlier and later months in the growing season. All the dry spell length probability curves converge to their minimum only during the peak rainy period (July and August) for all districts and turn upward again around September, indicating the end of the growing season (Figure 7).

Temperature variability and change

The mean annual maximum temperature at the three sites (Melkassa, Miesso and Ziway) ranged from 26.8 to 30.6°C, while the mean minimum temperature ranged from 13.7 to 15.0°C (Table 4). The minimum temperature shows a higher variability than the mean maximum temperature at all the sites (Table 4). The maximum temperature indicates a clear increasing trend at Miesso and Ziway but it remained static at Melkassa. On the other hand, the minimum temperature shows a slight increasing trend at Miesso and Ziway, but a clear decreasing trend at Melkassa (Figures 8 and 9).

The increasing trend of both mean maximum and minimum temperatures particularly at Miesso and Ziway and increase in maximum temperature at Melkassa indicate a clear warming of the atmosphere in the regions. An increase in maximum and minimum temperatures is taken as a good indicator of global warming in a given area (IPCC, 2001).

Conclusion

There was high inter-annual rainfall variability within the four districts. All districts experienced both very dry and very wet years in their meteorological record history. The trend line analysis exhibits a decreasing tendency of rainfall at Meki and an increasing tendency at Melkassa. There was no change in annual rainfall trends at Miesso and Ziway. The *belg* (FMAM) season had higher rainfall variability than the *kiremt* season (JJAS) at the four study sites. Meki exhibited a dramatic decline in the trend of number of rainy days in both seasons, while a slight declining trend was observed in the *belg* season at Melkassa. On the other hand, a reasonable increment was observed at Miesso and Ziway in the *kiremt* season, while there were no changes in the trend of rainy days in the *belg* season at both these sites.

Onset, cessation, dry spells and length of growing season analyses have shown that except for the onset date of the rainfall season, the districts have similar patterns for end dates and lengths of the growing period. In 50 to 80% of the time, the rains ended in September in the study sites except for Meki where it ended in the month of October. For 50% of the time, the length of the growing period is 3 to 4 months. Given that 1st March is a potential planting date, the probability of getting dry spells longer than 20 days from March to September is less than 10% at all sites, while the probability of getting dry spells longer than five days is above 50% for all sites, except Melkasaa. The long-term temperature analysis shows an alarming increase in both maximum and minimum temperatures at Miesso followed by Ziway. However, no change in minimum temperature was observed at Melkassa, although the maximum temperature exhibits an upward trend.

Table 4. Mean maximum and minimum temperatures at three sites in the Central Rift Valley of Ethiopia

Temperature	Sites		
	Melkassa	Miesso	Ziway
Maximum temperature			
Mean (°C)	28.6	30.6	26.8
Standard deviation (°C)	0.5	0.6	1.2
CV (%)	1.8	1.9	4.5
Minimum temperature			
Mean (°C)	14.1	15.0	13.7
Standard deviation (°C)	1.5	0.6	1.4
CV (%)	10.6	3.7	10.1

CV = coefficient of variability.

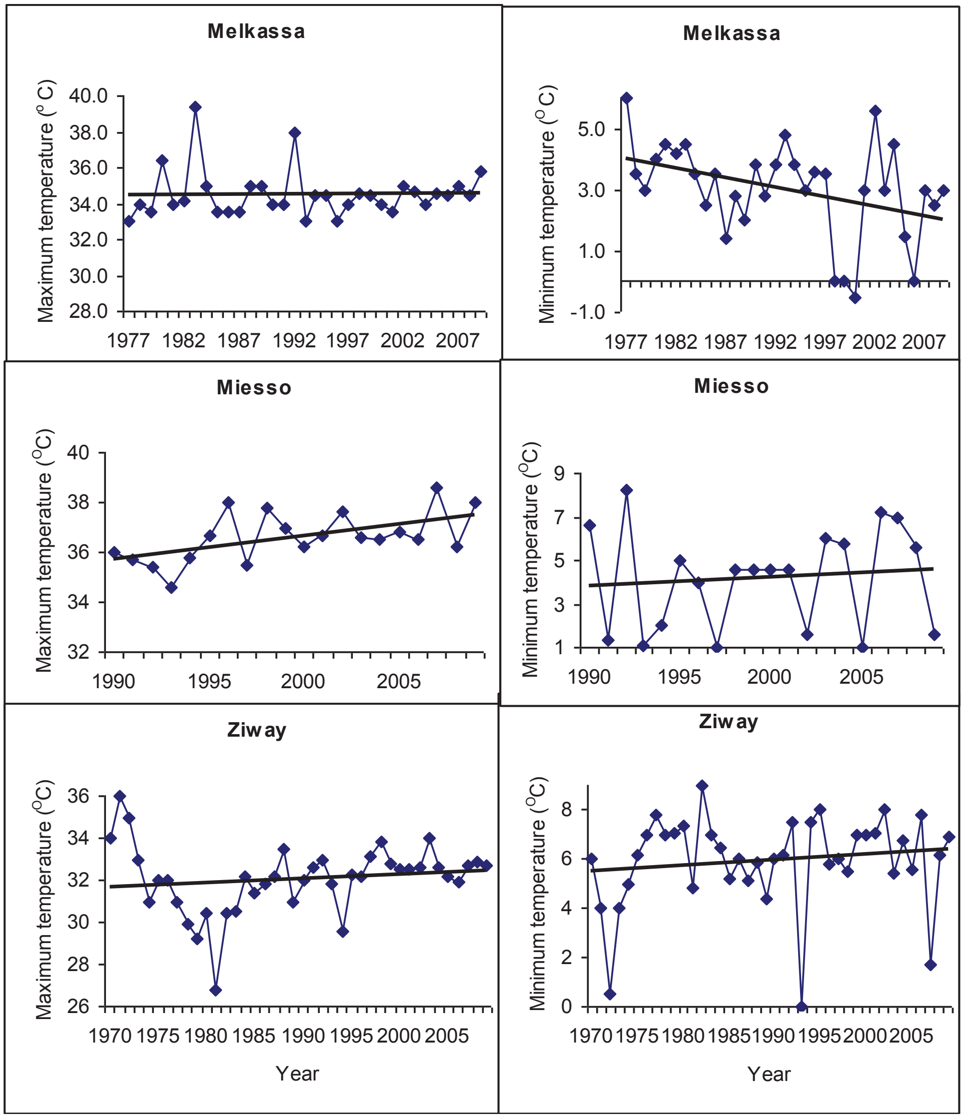

Figure 8. Annual maximum and minimum temperature variability and trend at three sites in the Central Rift Valley of Ethiopia.

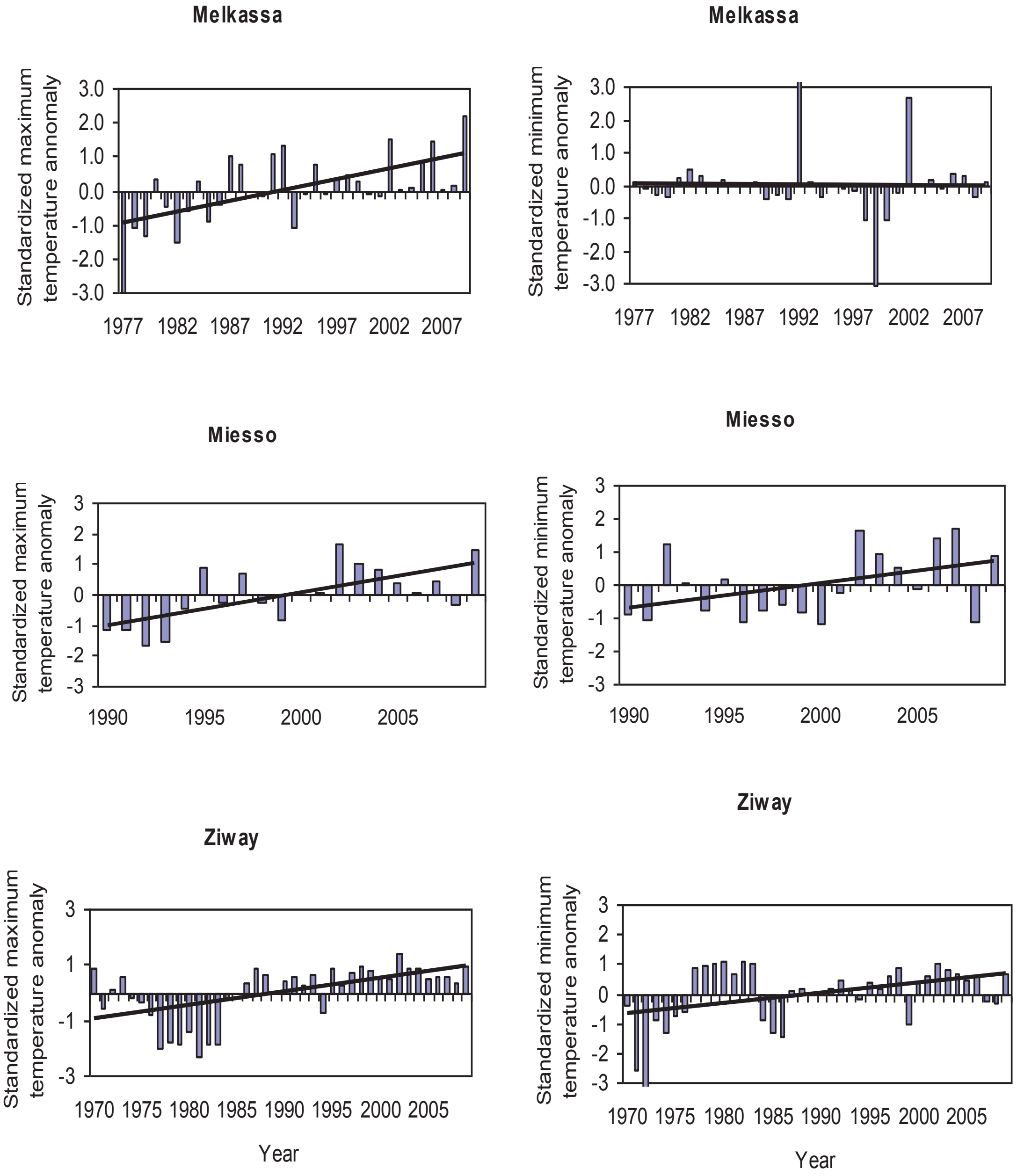

Figure 9. Annual mean maximum and minimum temperature variability and trend at three sites in the Central Rift Valley of Ethiopia.

The result of this study will help the farming community in their day-to-day agricultural activities and the agricultural sector will also benefit for the best agricultural management scheme and decision making in the central rift valley of Ethiopia. The current study clearly indicates a high inter-annual rainfall variability in the study areas and associated climate risks. This calls for consideration of climate information utilization by the farmers. Therefore, research in the utilization of climate information by farmers in the study area is suggested for further study.

Conflict of Interest

The authors have not declared any conflict of interest.

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