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Mitigating mid-season drought effect in soybean (*Glycine max* L. Merril) in Western Kenya

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ABSTRACT

Irregular rainfall distribution has increased incidences of mid-season drought in Western Kenya despite high amount of annual rainfall. This experiment's aim was to determine soil moisture content under soybean and grain yield during mid-season drought. The objective was evaluated at two agro-ecological zones using sowing dates as main-plots, conventional and no tillage as sub-plots and Nyala, SB19 and SB20, soybean varieties, as sub-sub-plots. Soil moisture content between tillage methods at R2 and R4 in long and short rains were similar in Kanduyi and Alupe. However, it was different between sowing dates, among varieties and among interactions. Soybean grain yield was high on sowing at two weeks after the onset of long and short rains in Kanduyi whereas in Alupe it was the contrary. Increases of 5.9% and 12.8% in soil moisture in long rains and short rains respectively at R2 led to grain yield gain of 47.8% and 27.2% respectively at Kanduyi. Therefore, sowing at the onset of rains in Alupe and at two weeks after the onset of rains in Kanduyi increases soil moisture at R2 and R4 and consequently mitigates mid-season drought.

Key words: Full bloom, Full pod, No till, Soil moisture content, Till.

INTRODUCTION

In Western Kenya, amount of rainfall within a season is presumed adequate for growth and maturity of most crops. However, a trend has been emerging in the last decade where farmers experience rainfall shortage in the middle of the season (Awuor, 2009). It mostly sets in at full bloom (R2) and full pod (R4) stages (Ahmed and Suliman, 2010) thus, reducing soybean yields. Mid-season drought leads to reduction in soil moisture at critical stages of soybean growth such as full bloom and full pod (Brevedan and Egli, 2003). A regular farmer practice like sowing date is based on soil moisture availability (Akmal *et al.*, 2011; Mhizha *et al.*, 2014) even though, it varies per region due to differences in climatic factors and crop. The time of sowing will either enable the crop to escape mid-season drought or allow moisture accumulation in the soil from previous rain before mid-season drought set in (Unger *et al.*, 2006). Western Kenya has two seasons of long rains and short rains (Mugalavai *et al*., 2008) although, farmers have variable sowing dates within a given season; some sow on the onset of rains while others sow two or three weeks later (Kipkorir *et al.*, 2007). This is a major determinant on the influence of mid-season drought on soil moisture availability and as such, the need to discern sowing dates that would lead to increased biological nitrogen fixation and soybean grain yield in an imminent mid-season drought. In addition to timely sowing dates, technologies such as, cover cropping, mulching (Rockstrom *et al.*, 2009), minimum tillage and vegetative barriers (Guto *et al.*, 2011; Guto *et al.*, 2012) and supplemental irrigation (Fox and Rockstrom, 2000; Fox *et al.*, 2005) have proved to improve soil moisture.

Over the past decades, numerous solutions have been presented to curb early, mid or late season drought (Gicheru *et al.*, 2004; Kulecho and Weatherhead, 2006; Ferna´ndez *et al.*, 2009), most of which are viable in different scenarios. Furthermore, some of these solutions are not affordable to most resource-poor farmers in certain regions (Andersson and Gabrielsson, 2012; Pannell *et al*., 2014). It is therefore mandatory to exploit solutions that can be managed by farmers for example, proper timing of sowing and appropriate tillage method among others in order to curb mid-season drought.

This study evaluated the influence of sowing date under no tillage and conventional tillage on soil moisture content and grain yield of early, medium and late maturing

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soybean varieties during mid-season drought at different agro-ecological zones of Western Kenya. In addition, it assessed the effect of soil moisture content on the amount of nitrogen fixed by three soybean varieties at two agro-ecological zones.

MATERIALS AND METHODS

The experiment was conducted at two agro-ecological zones of Western Kenya in the season of long rains of March to August, 2011 (LR2011) and short rains season of September to December, 2011 (SR2011). The first site was Kanduyi in Bungoma county (0^o 35´ N, 34^o 35´ E) in agro-ecological LM 1 – Lower midland sugarcane zone. This area receives annual rainfall of 1600 to 1800 mm, average temperature of 21 to 22^{o}C and the soils are well drained, deep to very deep, red to dark brown and friable sandy clay (classified as Ferralo – orthic acrisols). The second site was Alupe (0^o 28´ N, 34^o 07´ E) in Busia County. The area receives 1100 to 1450 mm rainfall annually and average temperature of 22 to 23^{o}C. The soils are well drained, deep and of low fertility (classified as Ferralo – orthic acrisols). It lies on agro-ecological zone LM 3 - Lower midland marginal cotton zone (Jaetzold *et al.,* 2005).

Experimental design, establishment and management: At each site the experiment was laid out in a randomized complete block design in a split-split-plot arrangement in three replicates. Sowing date (sowing at the onset of rains and two weeks later) were the main plot, tillage methods (no tillage and conventional tillage) were the sub-plot, and soybean varieties (Nyala, SB19 and SB20) were the sub-sub-plots.

Soybean varieties for the experiment were: Nyala - a local early maturing (60 days) variety nodulating with specific rhizobial strains and two International Institute for Tropical Agriculture (IITA) bred dual purpose, promiscuous soybean varieties: TGx1740-2F (locally known in Kenya as SB 19) and TGx1448-2E (locally known in Kenya as SB 20). SB 19 is medium maturing (80 days) whereas SB 20 is late maturing (120 days). In order to assess sowing date effect and consequently mid-season drought on the soybean varieties, the trial was planted at two sowing dates. The first sowing done at the onset of rains and the second sowing done two weeks after the onset of rains.

Each main experimental plots measured 28 m by 22 m, sub-plots measured 13 m by 11 m while the sub-sub-plots measured 4m by 3m. Sub-sub-plots were planted with three soybean varieties (Nyala, SB19 and SB20) spaced at 50 cm between rows and 5 cm within the rows, resulting in plant population of 400,000 plants per hectare. During the long rains (LR2011), sowing was done in Kanduyi on 24th March (first sowing date) and 7th April (second sowing date) and in Alupe first sowing was done 18th March and second sowing on 1st April. During the short rains (SR2011); first sowing date in Kanduyi was on 2nd September and the second sowing date on 17th September. In Alupe, first sowing date was on 29th August and second sowing date was on 13th September during the short rains (SR2011). Prior to sowing, all plots received a basal application of 30 kg P ha^{-1} supplied as Triple Super Phosphate (TSP) and 30 kg K ha^{-1} supplied as Muriate of Potash (MOP). The fertilizers were applied in furrows of 5 cm depth and 5 cm away from the planting lines and covered with soil immediately after application. To enhance biological nitrogen fixation, soybean seeds were inoculated with BIOFIX inoculant containing rhizobium strain USDA 110 by a two-step method (Somasegaran and Hoben, 1994). The inoculants were applied at a rate of 10 g kg^{-1} of seeds and the inoculated seeds were sown immediately after inoculation to ensure maximum survival of introduced rhizobial cells. The plots were kept weed free at interval of two weeks.

Determination of soil moisture content: Soils for moisture determination were collected using standard corings (diameter of 5cm and height of 5cm) at depths 10, 20 and 30 cm by hammering the coring into the soil using a compaction hammer. Soil moisture measurement in the plots was taken at full bloom (R2) on the fifth day after the beginning of this stage and at full pod (R4) also on the fifth day after the beginning of this stage (Liu *et al.,* 2003). In the field, the sampled soils were kept in a cool-box and transported to the lab where fresh weights were taken before they were transferred into brown paper bags (size 2) of known weights for drying in the oven at 105 ºC for 48 hours and finally dry weights taken. Soil moisture content was then calculated using a gravimetric method then converted to volumetric water content (Hillel, 1980).

Rainfall data: Rainfall data were collected in Kanduyi and Alupe during the period of experiment. In addition, data for ten years were obtained from meteorological stations within the experimental sites.

Determination of N_2-fixation: Plants for N fixation determination were randomly sampled in an area of 0.1m^2 within the net plot at 50% flowering stage (Unkovich *et al.,* 2008). At this stage, weeds from weedy fallow strips were sampled in triplicates and brought to the lab for drying. In the laboratory the plant samples were oven dried at 65 ºC to a constant weight for 48 hours. The dry plant samples (including the weeds) were ground in an electric grinder (model – Retsch SM 100 comfort) to pass through 1 mm sieve prior to laboratory analysis.

The ground plants samples were used to determine the amount of nitrogen fixed using ^{15}N natural abundance method (Unkovich *et al.*, 2008). Non N_2 fixing reference plants were three weed plants sampled from the fallow plots. The weeds were: *Brassica napus*, *Sorghum sudanense* and *Oxalis corniculata*. Determination of N fixed using ^{15}N abundance was conducted at Wageningen University, Netherlands.

Grain yield and data analysis: Grain yield data were collected at physiological maturity within a net plot of 7.8 m^2 after drying the seeds at 65 ºC for 48 hours in the oven. Data collected were subjected to analysis of variance (ANOVA) at 5% level of significance and means were separated using LSD in SAS software version 9.00 (SAS, 2002).

RESULTS AND DISCUSSION

Rainfall: Fig. 1, compares average rainfall in ten years with the year in which the experiment was conducted (2011) in Kanduyi. It illustrates that in the first season (March to August), the average rainfall peak was April while that of 2011 was March, the peak in March rapidly declined towards April forming a plateau between April and May before ascending to create a second peak in June. The second season of September to December had no similar pattern although, rainfall amount was lower than the average; the peak for the average was September whereas in 2011 it was October.

The average rainfall in ten years had two distinctive peaks in April and September in Alupe. However, rainfall distribution in 2011 did not echo this pattern; it was uneven in both season one and season two. In season one, rainfall peaks were in March and May and a formed depression in April, which was the middle of the season, likewise, in season two rainfall was higher in September and November and decreased in the middle of the season (October) (Fig. 2).

Soil moisture content: Sowing two weeks after the onset of long rains in Kanduyi increased soil moisture content at full bloom stage whereas, the converse occurred at full pod during SR2011. Additionally, second sowing date was moister at R2 during short rains (Fig. 3a). The Alupe soils were wetter at full bloom stage when soybean was planted two weeks after the onset of short rains, this was in contrast to R4 stage during SR2011 (Fig. 3b).

Fig. 4 illustrated the significant differences in soil moisture content among soybean varieties though, at R4 in Kanduyi and at R2 and R4 in Alupe during LR2011 soil moisture content was similar among the varieties. During the long rains, plots planted with SB19 and SB20 were wetter than plots of Nyala at R2 while, during the short rains SB19

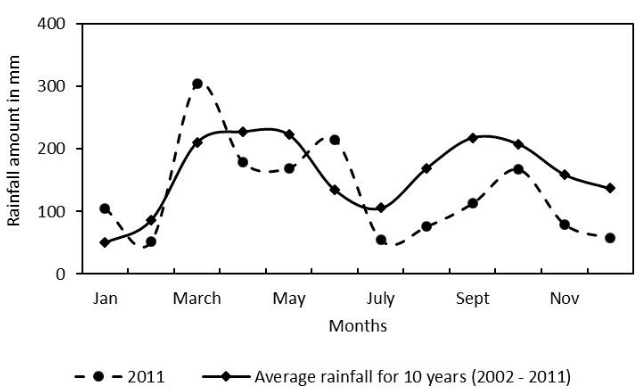


FIG 1: Rainfall amount in Kanduyi during the year of experiment (2011) and average for 10 years.

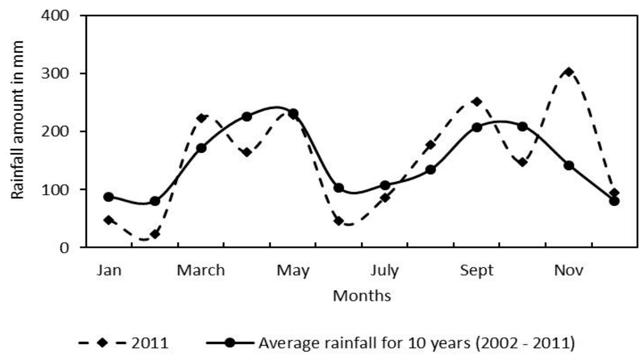


FIG 2: Rainfall amount in Alupe during the year of experiment (2011) and average for 10 years.

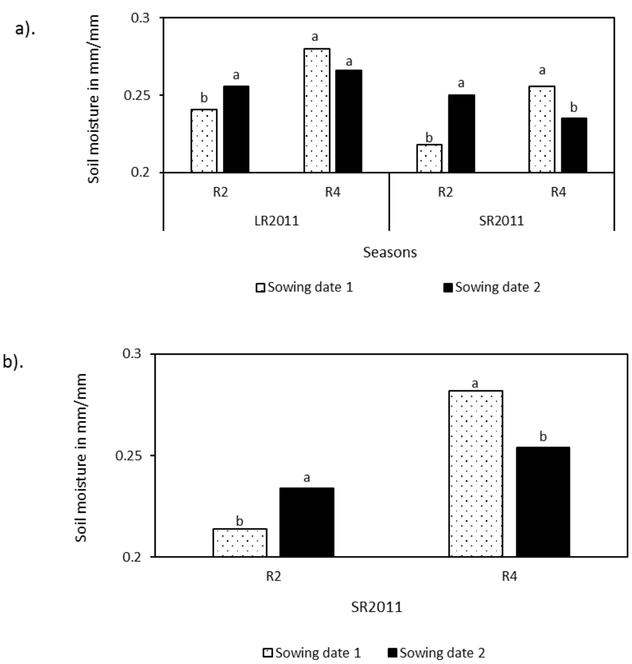


FIG 3: Effect of sowing dates on soil moisture content: a) in Kanduyi during LR 2011 and SR 2011 and b) in Alupe during SR 2011. Means with different letters are significantly different at p<0.05 within a soybean growth stage. R2 - Soybean full bloom stage; R4 - Soybean full pod stage. 'LR' and 'SR', 'long rainy season' and 'short rainy season' respectively.

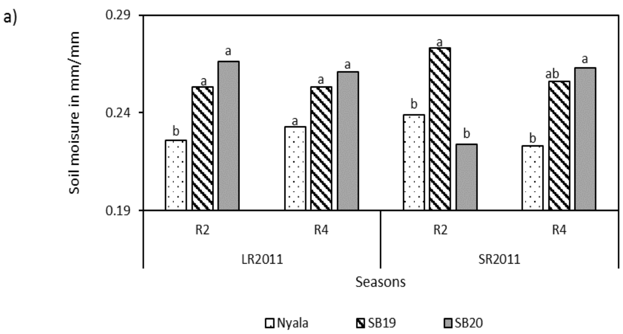
and SB20 plots were moister at full bloom at full pod in Kanduyi respectively (Fig. 4a). Soil under SB20 during the short rains was moist at both growth stages albeit there was no significance among the varieties at R4 (Fig. 4b). Regardless of this non significance, soil under SB20 was 4.9% wetter.

The interaction of sowing date and variety had significantly different soil moisture content in the two sites except during the short rains at R4 stage in Kanduyi and during the long rains at R2 stage in Alupe. In Kanduyi, sowing at the onset of short rains and two weeks after the onset of rains interacting with SB19 increased soil moisture content at R2 stage. In the same agro-ecological zone, soil where SB20 was sown two weeks after onset of rains was moister during long rains at the two growth stages and at full pod on sowing at the onset of short rains. In Alupe, soils where Nyala was sown at the onset of short rains were drier compared to those of SB20 (Table 1).

Amount of nitrogen fixed: Sowing of SB20 at the onset of rains enhanced the amount of nitrogen it fixed in Kanduyi and Alupe. SB19 also fixed significant amount of nitrogen when planted at the onset of rains in Alupe. However, it was noted that Nyala fixed high amount of nitrogen in Alupe even though, there was no significant difference between the sowing dates (Fig. 5).

Soybean grain yield: Grain yield was significantly different between the sowing dates and among the varieties (Fig. 6). Sowing two weeks after the onset of short and long rains in Kanduyi and at the onset of rains in Alupe increased grain yield. Grain yield of SB19 during short rains in the two sites surpassed both Nyala and SB20. Conversely, grain yield of SB20 and Nyala during the long rains were the highest at Kanduyi and Alupe respectively (Fig. 6).

The interaction of soybean variety and date of sowing was significant; SB19 and SB20 sown two weeks



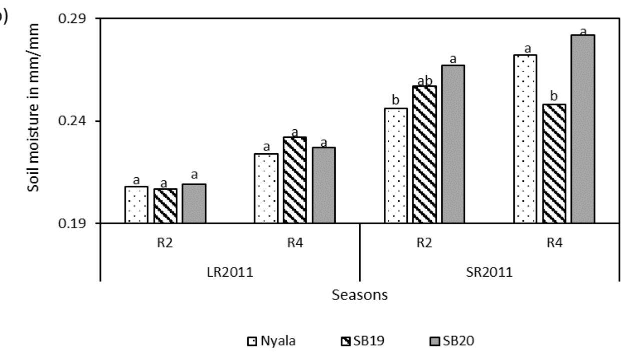


FIG 4: Effect of soybean varieties on soil moisture content: a) in Kanduyi and b) in Alupe during LR 2011 and SR2011 under two growth stages. Means with different letters are significantly different at p<0.05 within a soybean growth stage. R2 – Soybean full bloom stage; R4 – Soybean pod full pod stage. 'LR' and 'SR', 'long rainy season' and 'short rainy season' respectively.

TABLE 1: Interactive effect of sowing date and variety on soil moisture content at Kanduyi and Alupe

Sowing date	Variety	Soil moisture content at R2 (mm/mm)		Soil moisture content at R4 (mm/mm)	
		LR2011	SR2011	LR2011	SR2011
Kanduyi					
1	Nyala	0.212d	0.186c	0.271ab	0.231bc
	SB19	0.244b	0.263a	0.287ab	0.261ab
	SB20	0.238c	0.226b	0.262b	0.276a
2	Nyala	0.259bc	0.251ab	0.258b	0.214c
	SB19	0.262bc	0.272a	0.261b	0.251ab
	SB20	0.294a	0.179c	0.292a	0.250ab
Alupe					
1	Nyala	0.208a	0.217b	0.195b	0.255c
	SB19	0.207a	0.259a	0.260a	0.288ab
	SB20	0.199a	0.269a	0.245a	0.307a
2	Nyala	0.205a	0.276a	0.254a	0.289c
	SB19	0.207a	0.255a	0.203b	0.206d
	SB20	0.219a	0.266a	0.209b	0.267bc

[1]Means with different letters are significantly different at p<0.05 within a column in an agro-ecological zone. Words in bold are sites. 'LR' and 'SR', 'long rainy season' and 'short rainy season' respectively.
(Footnotes)

after the onset of short and long rains in Kanduyi were respectively superior in grain yield. In Alupe, Nyala sown at the onset of short and long rains performed highly (Table 2).

The erratic nature of rainfall distribution could not be captured by averaging ten years, although in 2011 it was visible. This fluctuation in rainfall distribution could have led to reduction in soil moisture content in the middle of the season causing mid-season drought.

Incidences of mid-season drought at critical soybean growth stages especially at reproductive stages produce low grain yields. This was validated by planting soybean at two weeks after the onset of rains in Kanduyi. At this sowing date, soil water content at R2 and R4 growth stages increased thus improving soybean grain yields. Moreover, the reduction of soybean grain yield caused by water deficit at R2 and R4 to R5 was also reported by other authors (Sweeney and Granade, 2002; Dogan *et al.,* 2007). Reasons cited for reduction in grain yield at low soil water content include: flower abortions, decreased seed enlargement, and pod filling (Desclaux and Roumet, 1996, Liu *et al.,* 2003). To further emphasize the impact of water deficit at critical growth stages of soybean, low grain yield was obtained in Kanduyi on sowing at the onset of long and short rains. Contrary, in Alupe sowing at the onset of long rains was beneficial, probably due to high amount of rain between March and September. This improved soil moisture content at critical soybean growth stages.

The benefit of early sowing or sowing at the onset of rains was proved to increase soybean grain yields (Ilkaee *et al.,* 2012; Barati *et al.,* 2013; Yagoub and Hamed, 2013). Nonetheless, this was only observed in Alupe. This notwithstanding, the results from Kanduyi suggested that it is not only early sowing that improves grain yield but discerning the time at which soil moisture content deficit influence on critical growth period is less injurious. This stands true in spite of other benefits of early sowing such as:

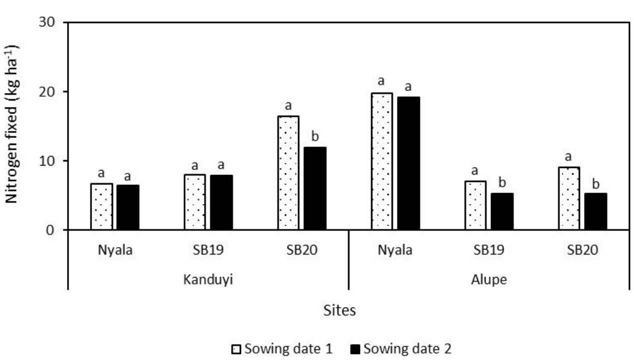


FIG 5: Effect of sowing dates on amount of nitrogen fixed by different soybean varieties in different sites. Means with different letters are significantly different at p<0.05 within a variety.

reduction in pest damages (Sastawa, 2004) and Brevedan and Egli, (2003) observation of increased flower and pod abortion, decreased vegetative growth and duration of the seed filling stage, lower seed number, and seed size in late sowing. These previous observations consequently confirm the high grain

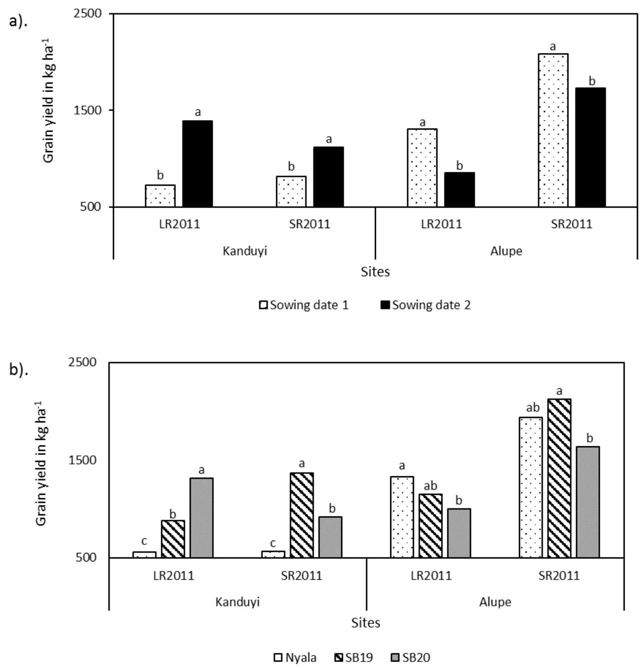


FIG 6: Effect of: a) sowing dates and b) varieties on grain yield of soybean in Kanduyi and Alupe during LR 2011 and SR2011. Means with different letters are significantly different at p<0.05 within a rainy season. 'LR' and 'SR', 'long rainy season' and 'short rainy season' respectively.

TABLE 2: Interactive effect of sowing date and variety on grain yield at Kanduyi and Alupe

Sowing date	Variety	Grain yield (kg ha^{-1})	
		LR2011	**SR2011**
Kanduyi			
1	Nyala	544b	592bc
	SB19	866b	671bc
	SB20	773b	1067b
	Nyala	684b	426c
	SB19	915b	1873a
	SB20	1855a	769bc
Alupe			
1	Nyala	1299a	2365a
	SB19	1404a	2243ab
	SB20	1197a	1542c
2	Nyala	1154a	1367c
	SB19	894a	2001abc
	SB20	805a	1716bc

[1]Means with different letters are significantly different at p<0.05 within a column in an agro-ecological zone. Words in bold are sites. 'LR' and 'SR', 'long rainy season' and 'short rainy season' respectively.
(Footnotes)

yield realized when mid-season drought effect was reduced during critical growth stages.

Variety SB20 outperformed other varieties during the long rains in Kanduyi probably due to sufficient soil moisture at the critical growth stages, for example, 4.9% and 3.1% soil moisture increase at R2 and R4 respectively in SB20 plots against SB19 led to 33.3% yield increase whereas, against Nyala, 15.0% and 10.7% soil moisture increase led to 57.9% grain yield increase. In addition, SB20 is a long maturing variety and produces highly in regions which receive high amount of rainfall. This was the scenario in Kanduyi during the long rains. Tefera, (2011) also observed that this variety produces high yields in areas receiving high amount of rainfall. Furthermore, this high grain yield could have been due to enhanced amount of nitrogen fixed. Increased amount of nitrogen could have led to massive vegetative growth and increased photosynthesis and consequently increased translocation of photosynthates to the grains (Tardieu *et al.*, 2011). SB19 had the highest grain yield in Kanduyi and Alupe during short rains perhaps due to moderate rainfall amount that could support growth and maturity of a medium maturing soybean variety such as SB19. Nyala grain yield was outstanding in Alupe in the long rains. This was probably caused by the genetic characteristic of Nyala of being an early maturing variety (Dankit and Wafula, 2002) and hence, it could have utilized available soil moisture effectively before soil moisture deficit set in, since Alupe receives minimal amount of rainfall. Besides, this superior grain yield of Nyala could be attributed to enhanced amount of nitrogen fixed. This corresponds to Sinclair *et al.*, (2007) study, which observed that improved symbiotic N_2 fixation increased yield of soybean.

CONCLUSION

Enhancing soil moisture content at critical growth stages of soybean lead to increased grain yield. This can be achieved by correct sowing date, for example in Kanduyi sowing two weeks after the onset of rains and in Alupe sowing at the onset of rains. However, this has to be coordinated with the weather forecast of that season. Soybean varieties adapted to different agro-ecological zones are highly dependent on soil moisture content, therefore soybean SB20 should be grown in areas having high soil moisture content, SB19 and Nyala in moderate and low soil moisture content respectively. It is also important to note that whenever soils are wetter amount of nitrogen fixed increased as observed in SB20 and Nyala in Kanduyi and Alupe respectively. Soil moisture content should be linked to the sowing date to discern variety-season specific approach for high grain yield.

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