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EFFECT OF RIDGING AND INTERCROPPING ON SORGHUM PRODUCTIVITY IN ARID AND SEMI-ARID LANDS OF EASTERN KENYA

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ABSTRACT

Soil moisture deficit is a key constraint to sorghum (*Sorghum bicolor*) productivity in arid and semi-arid lands globally. The objective of this study was to determine the effect of ridging and sorghum-bean intercropping (additive system) on soil moisture conservation and sorghum productivity. Sorghum (*gadam*) was grown either as a sole crop or intercropped with two bean (*Phaseolus vulgaris* L.) varieties (*KATx56* and *KAT B1*), under two types of ridging (open ridges and tied ridges), and a control without ridges for two years. The study was set up in split plot arrangement, in a randomised complete block design, at the Kenya Agricultural and Livestock Research Organization, Kiboko, in 2019 and 2020. There was no significant interaction between ridging and intercropping. Soil moisture content increased by 11-26% due to ridging; and decreased by -11 and -7% due to sorghum-*KAT B1* and Sorghum-*KAT X56* intercropping, respectively. Higher moisture content due to ridging was attributed to formation of basin-like structures, which increased water harvesting and infiltration compared to the no ridges where surface run-off was predominant. The highest moisture content was attained on sole bean, followed by sole sorghum and then sorghum/bean intercropping. The decrease in moisture content in intercrops of sorghum/bean relative to their specific sole crops was attributed to higher crop density, which reduced crop spacing, thus triggering competition for available soil moisture. The highest sorghum grain and equivalent yields were obtained in the ridged plots. Intercropping resulted into decrease in sorghum grain yield, but led to increase in sorghum equivalent yield (SEY) and Land Equivalent Ratio (LER). The results show that both ridging and intercropping are suitable for higher water use efficiency and land productivity in ASALs of Kenya.

Key words: *Phaseolus vulgaris,* soil moisture*, Sorghum bicolor*

RÉSUMÉ

Le déficit d'humidité du sol est une contrainte majeure à la productivité du sorgho (*Sorghum bicolor*) dans les terres arides et semi-arides à l'échelle mondiale. L'objectif de cette étude était de déterminer l'effet du billonnage et de la culture intercalaire sorgho-haricot (système additif) sur la conservation de l'humidité du sol et la productivité du sorgho. Le sorgho (gadam) était cultivé soit en monoculture, soit en association avec deux variétés de haricot (Phaseolus vulgaris L.) (KATx56 et KAT B1), sous deux types de billons (billons ouverts et billons liés), et un témoin sans billons pendant deux années. L'étude a été mise en place en parcelles divisées, dans une conception en blocs complets randomisés, à l'Organisation de recherche sur l'agriculture et l'élevage du Kenya, Kiboko, en 2019 et 2020. L'étude n'a montré aucune interaction significative entre le billonnage et la culture intercalaire. La teneur en humidité du sol a augmenté de 11 à 26 % en raison du billonnage ; et diminué de -11 et -7% en raison des cultures intercalaires sorgho-KAT B1 et Sorgho-KAT X56, respectivement. La teneur en humidité plus élevée due aux crêtes a été attribuée à la formation de structures de type bassin, ce qui a augmenté la collecte et l'infiltration de l'eau par rapport à l'absence de crêtes où le ruissellement de surface était prédominant. La teneur en humidité la plus élevée était sur le haricot unique, suivi du sorgho unique, puis de la culture intercalaire sorgho/haricot. La diminution de la teneur en humidité dans les cultures intercalaires de sorgho/haricot par rapport à leurs cultures uniques spécifiques a été attribuée à une densité de culture plus élevée, qui a réduit l'espacement des cultures, déclenchant une compétition pour l'humidité disponible du sol. Les rendements les plus élevés en grain de sorgho et en équivalent ont été obtenus dans les parcelles buttées. La culture intercalaire a entraîné une diminution du rendement en grains de sorgho, mais a entraîné une augmentation du rendement équivalent en sorgho (SEY) et du rapport d'équivalent en terres (LER). Les résultats montrent que le billonnage et la culture intercalaire conviennent à une plus grande efficacité de l'utilisation de l'eau et à la productivité des terres dans les TASA du Kenya.

Mots Clés : *Phaseolus vulgaris*, humidité du sol, *Sorghum bicolor*

INTRODUCTION

Sorghum (*Sorghum bicolor)* is a staple food crop in arid and semi-arid lands (ASALs) globally (Oyier *et al.,* 2016). Sorghum is a choice crop in Kenya, where more than 80% of the country's land is either arid or semi-arid (Kathuli and Itabari, 2015). The crop is adapted to a wide range of altitudes and survives in areas where production of major cereals such as maize is constrained due to dry spells (Hadebe *et al.,* 2017; Kugedera *et al.,* 2018; Kilambya and Witwer, 2019). Sorghum can maintain stomata opening at low levels of leaf water potential (Queiroz *et al.,* 2019) and selectively ensures that older leaves are senesced under drought stress, while the remaining young leaves retain turgor, stomatal conductance and assimilation because of high osmotic adjustment (Hadebe *et al.,* 2017). This attribute enables the crop to survive under harsh environmental conditions, though under reduced photosynthetic activity (Hadebe *et al.,* 2017).

The area under sorghum cultivation in ASALs in Kenya has increased in recent years due to promotion of the crop as a Traditional High-Value Crop and attractive prices from growing consumption (FAOSTAT, 2019; Njagi *et al.,* 2019). Sorghum productivity has, however, stagnated over the years (FAOSTAT, 2019). The ASALs of Kenya experiences late rainfall onset, intra-seasonal dry spells, poor rains and short rainfall seasons; and very high temperatures (Karuma *et al.,* 2014; Kwena, 2015). Soil moisture deficit is a major productivity constraint and a great hindrance to crop soil nutrients uptake, assimilation and in general crop growth and development (Assefa *et al.,* 2010; Ogeto *et al.,* 2013; Kugedera *et al.,* 2018). The amount of sorghum produced in the country is inadequate to meet the demand for food, feed and industrial needs; and Kenya is a key importer of sorghum from neighbouring countries (Titilola *et al.,* 2018; Kilambya and Witwer, 2019). Most ASALs residents live below the poverty line and Kenya perennially remains on the global hunger index (Titilola *et al.,* 2018), and therefore low crop yields is a threat to household food security.

Capitalising on soil moisture conservation, beside cultivation of drought tolerant crops such as sorghum, is necessary to optimise crop yield, fill production deficits and attain sustainable livelihood among ASALs residents. Although several moisture conservation strategies are available for use in ASALs, their applicability on-farm depends on their affordability and practicability (Hammel, 1996; Jinger *et al.,* 2017). These techniques enable crops to forego uncertain mid-season dry spells predominant in ASALs. For instance, intercropping is the growing of two or more crops in proximity to promote synergism for increased productivity (Assefa *et al.,* 2016). Cereals-legumes intercropping has the potential to improve soil moisture retention, although this depends on the type of legume used (Anil, 1998; Iqbal *et al*., 2018). Due to competitive interaction, component crops rapidly attain higher biomass accumulation and surface ground cover, which minimises impact of erratic rainfall on bare soil, and thus reduce rainwater loss through surface run off and evaporation (Egesa *et al.,* 2016).

Tied ridges are furrows with barriers, which transform farmland into small pockets where rainwater collects, reducing surface run off, improving water infiltration and thus plant water contact time (Chimdessa *et al.,* 2017). As such, many farmers have attempted to use ridging for moisture conservation (Tekle and Wedajo, 2015). However, so far, little information is available on the possibility of integrating ridging and intercropping and the effects on crop productivity. Miriti *et al.* (2007) integrated tied-ridging with organic and inorganic manure into maize farming systems and reported synergistic effects, suggesting that tied ridging, in combination with integrated nutrient management, has the potential to improve crop production in semi-arid eastern Kenya. It, however, remains unclear whether such synergies are achievable with tied-ridging-bean intercrop systems in similar ASAL environments. This study, therefore, sought to determine the effect of ridging and bean intercropping on soil moisture conservation and sorghum productivity in ASALs of Eastern Kenya.

MATERIALS AND METHODS

The study was carried out at the Kenya Agriculture and Livestock Research Organisation, Kiboko Station in May to August 2019; and repeated in May to August 2020. Kiboko research site is in arid and semi-arid lowlands of Makueni County in Kenya. The site falls in agro-ecological zone V, at 2°15’S latitude and 37°45’E longitude, at an elevation of 975 m above sea level (CIMMYT, 2013). Kiboko receives a bimodal type of rainfall with the long rains occurring from March to May and the short rains from October to December (Mutiso *et al.,* 2018). The rains are normally low and erratically distributed (545 - 629 mm); accompanied by very high temperatures (Mutiso *et al.,* 2018).

Site soils are well-drained, deep, dark reddish brown to dark red, friable sandy clay to clay (CIMMYT, 2013). The site is characterised by a mean minimum temperature of 14.5 ^{o}C and a mean maximum temperature of 31.5 ^{o}C (Mutiso *et al.,* 2018). The total amount of rainfall received was 5.5 mm, and this was supplemented with 161.6 mm of irrigation water in 2019. The total amount of rainfall received (26.5 mm) in 2020 was supplemented with 150.5 mm of water through irrigation. Data collected from ICRISAT meteorological site near the trials recorded a mean temperature range of 15.14 - 29.5 and 14.3 -30.7 ^{o}C in 2019 and 2020, respectively.

Sorghum (variety: *Gadam*) was planted as a sole crop and in inter-crops with beans (Varieties: *KAT x56* and *KAT B1*), under two ridging levels (tie ridging and open ridging) and a control without ridges. *Gadam* is a semi-dwarf sorghum variety that grow 100-130 cm tall in the drier lowlands with an elevation of 50-1800 m above sea level, and has a yield potential range of 1.7 to 4.5 t ha^{-1} (Karanja *et al.,* 2006). *Gadam* matures in 85-95 days, which is earlier than the other sorghum varieties making it an ideal crop for food deficient ASAL areas (Karanja *et al.,* 2006). *KAT B 1* and *KAT x56* are bean varieties, which have determinate growth pattern, with heights at maturity ranging from 35 to 40 cm; and maturity of 60 - 65 days. The two bean varieties have high preference in ASALs for their water use efficiency, high grain yielding capacity and high market demand; hence it is easily adopted (Johnson, 2018). Early maturity in the beans offers the component sorghum crop reduced competition for moisture at reproduction.

Experiment procedures. Seedbed preparation was done using a mouldboard plough. Certified seeds were obtained from Kenya Agricultural and Livestock Research Organisation Seed Unit (KSU) at Katumani. A randomised complete block design in split plot arrangement was used. Ridging was the main plot; while sorghum/beans cropping system was the sub plot. Ridges, 15 cm high and 37.5 cm apart were prepared by manually erecting soil bunds across the farm gradient. The ridges were cross-tied with soil bunds after every 1 m ridge in a pattern similar to that of bricks at a construction, in that the tying was not perpendicular to prevent possible erosion. Sorghum was spaced at 75 cm x 20 cm with either under mono or under intercropping of beans (additive system).

About 2-3 seeds were sown per hole on the side of the ridge at a depth of 3 cm. Thinning was then carried out three weeks after first weeding to retain only one healthy seedling per hole. Di-ammonium phosphate (DAP) was applied as basal fertiliser at the rate of 100 kg ha^{-1} and the cereal was top dressed with calcium ammonium nitrate (CAN) fertiliser six weeks after emergence at the rate of 100 kg ha^{-1} (Karanja *et al.,* 2006).

The trials were mainly under sprinkler irrigation. Water was applied six times in 2019 and 2020 with between season exposures to dryness simulating rainfall distribution in ASALs. Further, irrigation was curtailed deliberately at the onset of sorghum reproduction stage (50 days after first irrigation). Improvised measuring cylinders were installed systematically within the trial and used to monitor the total amount of water applied, which was then converted into millimetres of water received per square metre according to FAO (2019).

Data collection

Soil moisture content. This was determined at sorghum boot stage using the gravimetric method. The samples were drilled in all plots using a soil auger at a depth of 30 cm. The collected samples were then mixed thoroughly and immediately sealed in plastic bags. The samples were put into airtight soil moisture boxes, weighed using digital weighing machine and oven dried at 105 °C, until constant weight was achieved. The soil moisture boxes were then re-weighed and weight of the wet soil samples, dry soil samples and the moisture boxes were determined and the percentage moisture content (% mc) per sample computed using the formulae (Shukla *et al.,* 2014).

$$\%\ mc = \frac{\text{Wt of wet soil tare - wt of dry soil tare}}{\text{Wt of dry soil tare - tare}} * 100$$

Agronomic yield data. Sorghum and legume seedling vigour was assessed using a score of 1 to 4 based on rate of seedling germination and uniformity in the plots; where 1 represented excellent, 2 good, 3 fair and 4 poor. Days to 50% flowering was assessed from emergence date to when 50% of the specific legume or sorghum blossomed. Sorghum and legume plant heights, sorghum third leaf width and length in centimetres, were determined using a meter rule. The leaf length and width were used to compute the sorghum leaf area in square metres according to the Montgomery equation (He *et al.,* 2020). The number of productive tillers was assessed manually at crops physiological maturity stage and sorghum /legume stover yield and grain yield were determined using an electronic balance and then converted into tonnes per hectare.

Land productivity. Land Equaivalent ratio and Sorghum Equivalent Yield (SEY) was used to evaluate the land productivity. Land equivalent ration was determined using the equation (Iqbal *et al.,* 2019)

$$LER = LERS + LERL = \left(\frac{YS, I}{YS, S} + \frac{YL, I}{YL, S}\right)$$

Where:

LERS and LERL are the relative yield of maize and bean in intercropping, YS, S and YS, I are the sole and intercropped sorghum yield, whereas YL, S and YL, I are the sole and intercropped bean yield, respectively.

SEY was determined as the sum of component sorghum yield and component bean yield converted into sorghum yield by multiplying the legume yield with legume price kg^{-1} divided by sorghum price kg^{-1} (Assefa *et al.,* 2016). The standard market prices of sorghum and legume grain were obtained from the surrounding markets of Makueni, Machakos and Nairobi. The following formula was used to calculate SEY for the three ridging levels:

$$SEY = Ysl + \left(Yls * \frac{pl}{ps}\right)$$

Where:

Ysl = intercrop sorghum grain yield kg ha^{-1}; Yls = intercrop legume grain yield kg ha^{-1}; pl = price of legume grain kg^{-1}; ps = price of sorghum grain kg^{-1}.
NB: Prices at harvest were: sorghum kg^{-1} = 0.26 USD, KAT *x* 56 kg^{-1} = 0.71 USD and *KAT B1* kg^{-1} = 0.88 USD.

Data analysis. Data on percentage soil moisture content and sorghum/legume yield and yield component were subjected to analysis of variance (ANOVA) using GenStat statistical programme Version 21. Fisher's LSD was used for mean separation at 5% level of significance. Sorghum yield and yield component data were regressed against percentage soil moisture data.

RESULTS AND DISCUSSION

Soil moisture content. Moisture content increased significantly ($P<0.05$) due to open ridging (+11%) and tie ridging (+31%) relative to no ridges, regardless of the intercropping (Table 1). Increase in moisture content under ridging could have been due to increased water harvesting and withholding; while decrease in moisture content under no ridges may have been due to water loss through evaporation and surface run off ascribed to increased surface area on the flatbed relative to the rugged ground under ridges. Moisture content under open ridges was lower than for tie ridging due to water losses facilitated by the open furrows. Similar findings were reported by Chimdessa *et al.* (2017), who observed an increase in soil moisture content under tie ridging (+18%) and open ridging (+10%), which the authors attributed to formation of ridge basin and improved water infiltration.

Sole beans retained the highest moisture content, followed by sole sorghum and then sorghum bean intercropping (additive system) (Table 1). This could be due to extensive beans canopies, which may have reduced water loss through evapotranspiration. Sorghum/*KAT B1* and sorghum/*KAT x56* intercropping (additive system) exhibited a decrease in moisture content by -7% and -11%, respectively; relative to sole sorghum and by -12% and -9% relative to their respective sole legumes (Table 1). This was likely due to over extraction of the available soil water resulting from increased root density from sorghum and the additional component bean crop as has been suggested earlier by

TABLE 1. Soil moisture content in sorghum-legume cropping system as influenced by ridging, intercropping and bean variety

Factors	Treatments	Moisture content (%)
Ridging (R)	No ridging	7.8a
	Open ridging	8.9b
	Tied ridging	10.2c
Cropping system (CS)	Sole sorghum	9.2bc
	KAT B1	9.3c
	KAT x56	9.4c
	Sorghum/ *KAT B1*	8.2a
	Sorghum/*KAT x56*	8.6ab
$LSD_{0.05}$ (R)		0.52
$LSD_{0.05}$ (CS)		0.67
$LSD_{0.05}$ (R*CS)		ns
CV (%)		9.1

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

Ghanbari *et al.* (2010). Miriti *et al.* (2012) similarly reported soil moisture content decrease (-10%) under maize/cowpea intercropping relative to sole maize. In both sole crop and intercropping, plots with *KAT x56* retained higher moisture relative to those with *KAT B1* (Table 1). This could have been because, *KAT x56* accumulated biomass faster than *KAT B1*. Moreover, *KAT B1* was affected by blight which could have reduced leaf volume and ground cover, which could have resulted to higher water loss through evapotranspiration (Dahmardeh and Rigi, 2013).

Seedling vigour index. Ridging exhibited a significant (P<0.05) decrease in sorghum/ legume seedling vigour (Table 2). Seedlings under no ridging were more vigorous with either tie or open ridging. Low seedling vigour under ridging was attributed to water stress as the raised soil bunds drained water into the furrows, leaving the raised seed beds with insufficient moisture to support the germinating seeds. This was in accordance with Queiroz *et al.* (2019), who reported that seeds must attain a satisfactory hydration level to allow reactivation of seed metabolic processes; and seed water content of cereal crops must reach at least 35 to 45% of seed dry mass for germination to occur. Seedlings under tie ridging performed better than those under open ridging due to formation of ridge basins where harvested water could be accessed by the planted seeds through capillary action. This result concurs with that of Mwende *et al.* (2019), who reported poor germination under ridges relative to flatbed terrain conditions. Chimonyo *et al.* (2016) also found low soil water availability in the 0-0.1m layer at planting to affect sorghum seedling emergence. In either years, the influence of intercropping on the crops seedling vigour was not significant (P>0.05) (Table 2), possibly because the seedling were trivial to affect component cereal/legume crop.

Leaf area. The influence of ridging, with or without intercropping, on sorghum leaf area was not significant (P>0.05). However, sorghum leaf area was found to decrease significantly (P<0.05) under sorghum/*KAT B1* and sorghum/*KAT X56* intercropping (Table 3). This was attributed to reduced leaf turgor pressure associated with sorghum drought response mechanisms inhibiting cell division and leaf growth (Gano *et al.,* 2021). The results compare well with the finding of Assefa *et al.* (2016), who reported decrease in sorghum leaf area index under sorghum/cowpea intercropping due to competition for growth resources.

Plant height. Sorghum and beans plant heights were found to increase due to tie ridging (+4%) and (+7%) respectively (Table 4). This was likely due to adequate water supply enhancing the rate of plant growth and

TABLE 2. Seedling vigour in sorghum and beans as influenced by ridging and intercropping

Factors	Treatments	Sorghum seedling vigour	Legume seedling vigour
Ridging (R)	No ridging	1.1a	1.4a
	Open ridging	1.9c	1.8b
	Tied ridging	1.6b	1.7ab
Cropping system (CS)	Sole sorghum	1.5a	
	KAT B1		1.6a
	KAT x56		1.8a
	Sorghum/ *KAT B1*	1.6a	1.8a
	Sorghum/*KAT x56*	1.5a	1.5a
$LSD_{0.05}$ (R)		0.2	0.34
$LSD_{0.05}$ (CS)		ns	ns
$LSD_{0.05}$ (R*CS)		ns	ns
CV (%)		3.5	9.1

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

TABLE 3. Leaf area in sorghum as influenced by ridging and intercropping

Factors	Treatments	Leaf area (cm^2)
Ridging (R)	No ridging	179.0a
	Open ridging	177.0a
	Tied ridging	192.5a
Cropping system (CS)	Sole sorghum	196.1b
	Sorghum/ *KAT B1*	180.4ab
	Sorghum/*KAT x56*	172.0a
$LSD_{0.05}$ (R)		ns
$LSD_{0.05}$ (CS)		19.98
$LSD_{0.05}$ (R*CS)		ns
CV (%)		13.0

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

TABLE 4. Plant height in sorghum and beans as influenced by ridging and intercropping

Factors	Treatments	Sorghum plant height (cm)	Legume plant height (cm)
Ridging (R)	No ridging	122.6a	28.8a
	Open ridging	124.0a	29.0a
	Tied ridging	127.7b	30.7a
Cropping system (CS)	Sole sorghum	126.8b	
	KAT B1		28.3a
	KAT x56		31.0b
	Sorghum/ *KAT B1*	123.5ab	27.6a
	Sorghum/*KAT x56*	123.9a	31.2b
$LSD_{0.05}$ (R)		3.33	2.2
$LSD_{0.05}$ (CS)		3.16	2.6
$LSD_{0.05}$ (R*CS)		ns	ns
CV (%)		3.0	10.4

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

development (Karuma *et al.,* 2014). This was in agreement with the finding of Gano *et al.* (2021) who found well-watered sorghum to have taller plants than water stressed sorghum. Sorghum plant height decreased though not significantly (P>0.05) under intercrops of sorghum/*KAT B1* (-3%) and sorghum/*KAT x56* (-2%) (Table 4). Decrease in sorghum plant height under intercropping could be attributed to competitive interference by the component bean crop; which agrees with the finding of Karanja *et al.* (2012) who found out sorghum plant height to decrease under sorghum-cowpea intercrops. They attributed it to competition for soil moisture, soil nutrients and solar radiation. Bean plant heights did not also differ (P>0.05) due to intercropping, but *KAT X56*, exhibited significantly (P<0.05) higher plant height than *KAT B1* regardless of the intercropping type (Table 4). This was associated with the effect of variety.

Tiller numbers. The number of sorghum productive tillers increased (P< 0.05) under open ridging (+31%) and tie ridging (+58%) relative to no ridges (Table 5). This concurs with findings of Tekle and Wedajo (2015), where tied ridges produced the highest number of productive tillers per plant. They ascribed it to higher moisture retention and utilisation efficiency compared to conventional method. Intercropping sorghum with beans exhibited a significant (P<0.05) decrease in the number of sorghum productive tillers (Table 5). The decreasing trend was likely due to competition for available soil moisture and space. The results complement those of Chimonyo *et al.* (2016), who also found the number of sorghum tillers under intercrop of sorghum-cowpea to decrease relative to sole sorghum.

Days to 50% flowering. Days to 50% flowering did not differ significantly (P>0.05) under ridging or intercropping levels. However, both sorghum and beans were observed to flower earlier under no ridging to either open ridging or tie ridging. Earlier floral initiation under no ridges could have been due to soil moisture stress hastening the crop maturation. Chimonyo *et al.,* 2016 found reduced soil water content toward the end of the growing season to hasten crop development. Mesfin *et al.* (2009) found sorghum to flower 4-7% days earlier under traditional farming practice than in tied-ridging. Rapid crop development under moisture stress may cause the crops not achieve optimum production potential.

Stover yield. Sorghum and legume dry stover yield increased significantly (P< 0.05) under ridging regardless of the intercropping level (Table 6). Higher moisture content (%) under ridging could have improved delocalisation of soil nutrients, plant nutrients uptake, plant cell expansion hence boosting crop growth and biomass accumulation (Miriti *et al.,* 2012; Mwende *et al.,* 2019). Sorghum stover yield was found to decrease significantly (p d" 0.05)

TABLE 5. Sorghum number of productive tillers per square metre as influenced by ridging and intercropping

Factors	Treatments	Tillers (m^2)
Ridging (R)	No ridging	2.57a
	Open ridging	3.42b
	Tied ridging	4.05c
Cropping system (CS)	Sole sorghum	4.76b
	Sorghum/ *KAT B1*	2.64a
	Sorghum/*KAT x56*	2.64a
$LSD_{0.05}$ (R)		0.11
$LSD_{0.05}$ (CS)		0.55
$LSD_{0.05}$ (R*CS)		ns
CV (%)		9.4

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

TABLE 6. Stover yield in sorghum and beans as influenced by ridging and intercropping

Factors	Treatments	Sorghum stover yield (t ha^{-1})	Legume stover yield (t ha^{-1})
Ridging (R)	No ridging	2.5a	0.8a
	Open ridging	2.8a	0.8a
	Tied ridging	3.2b	1.0b
Cropping system (CS)	Sole sorghum	3.5b	
	KAT B1		0.9b
	KAT x56		1.1b
	Sorghum/ *KAT B1*	2.5a	0.6a
	Sorghum/*KAT x56*	2.4a	0.7a
$LSD_{0.05}$ (R)		0.42	0.14
$LSD_{0.05}$ (CS)		0.33	0.17
$LSD_{0.05}$ (R*CS)		ns	ns
CV (%)		13.8	24.2

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

under sorghum/*KAT B1* intercropping (-29%) and sorghum/*KAT x56* intercropping (-31%) regardless of the intercropping level (Table 6). This was likely due to the legume smothering effect. Iqbal *et al.* (2018) reported component crops in intercrops to suffer yield losses owing to limited space for the crops growth. Bean stover yield was significantly low, under intercrops of sorghum and beans, and this was mainly due to decreased plant population. Stover yield is beneficial to farmers in ASAl areas, who are mainly agro pastoralist.

Grain yield. Sorghum and legumes grain yield were found to increase significantly (P<0.05) due to ridging (Table 7). Increase in sorghum and beans grain yield was due to increase in soil moisture content. Ridging could have favored the crops water and nutrient uptake and thus better yields. The results compare well with those of Mesfin *et al.* (2009), who found sorghum grain yield to increase by 6–45% under tie ridging relative to traditional farming practice in ASALs of Ethiopia, which the author associated with increase in moisture content. Sorghum grain yield decreased significantly (P<0.05) under intercrops of sorghum/*KAT B1* (-34%) and sorghum/*KAT x56* (-38%) (Table 7). In a similar study, Egesa *et al.* (2016) found intercrops of sorghum and cowpea to decrease sorghum grain yield relative to sole sorghum. The authors associated this with the planting pattern and plant densities. Sorghum with broad leaves, higher plant height and biomass yield was found to produce highest grain yield, also as reported by Egesa *et al.,* 2016. This could have been because sorghum stem serves as a reservoir for labile non-structural carbohydrates that are mobilise by drought stress and translocated as sugars to the filling young grains (Mwende *et al.,* 2019). Significant (P<0.05) decrease in bean grain yield under sorghum/bean intercropping was likely due to decrease in the legume plant stand. Karanja *et al.,* 2014 found cowpea grain yield to decrease under intercropping with sorghum, which the author associated with decrease in plant population, shading effect of sorghum on cowpea and domineering effect of the sorghum, being a C4 plant species and cowpea, a C3 plant species. *KAT x56* performed better

TABLE 7. Grain yield in sorghum and beans as influenced by ridging and intercropping

Factors	Treatments	Sorghum stover yield (t ha^{-1})	Legume stover yield (t ha^{-1})
Ridging (R)	No ridging	1.9a	0.86a
	Open ridging	2.1b	0.88a
	Tied ridging	2.6c	1.01b
Cropping system (CS)	Sole sorghum	2.9b	
	KAT B1		1.02b
	KAT x56		1.19b
	Sorghum/ *KAT B1*	1.9a	0.66a
	Sorghum/*KAT x56*	1.8a	0.81a
$LSD_{0.05}$ (R)	0.19	0.085	
$LSD_{0.05}$ (CS)	0.27	0.172	
$LSD_{0.05}$ (R*CS)	ns	ns	
CV (%)	14.4	22.6(0.006)	

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

than *KAT B1,* regardless of the intercropping or ridging level (Table 7). This was due to the variety effect.

Land productivity. Land equivalent ration (LER) and Sorghum equivalent yield (SEY) were used to evaluate the intercrop efficiency in yield relative to monocropped condition. From the analysis, equivalent ration of sorghum intercropped with *KATX56* and *KAT B1* was greater than 1, regardless of the ridging level (Table 8a). Ridging and intercropping led to significant (P<0.05) increase in SEY (Table 8b). SEY increased by +41% and +34% due to sorghum/*KAT B1* and and sorghum *KAT x56* intercropping, respectively.

Higher SEY and LER under sorghum/bean intercropping was likely due to improved water use efficiency. Cereal-legume intercropping is reported to complement and enhance component crops growth resource capture through increased soil microbial activity, which improves soil resources conversion and effectiveness (Iqbal *et al*., 2018). In a similar study Ghanbari *et al.,* (2010) found maize cowpea intercropping to enhance land productivity resulting to a yield advantage of 2-63% over their sole crops, the author attributed this to increase in light interception; shading compared to sole maize and low water evaporation and improved soil moisture conservation.

TABLE 8a. Influence of ridging and intercropping on land equivalent ratio

Intercropping	Sorghum grain yield (t ha^{-1})			Legume grain yield (t ha^{-1})				LER	
Ridging	Sorgh Mono	*Sorgh/ KAT B1*	*Sorgh/ KAT x56*	*KAT B1*	*KAT x56*	*Sorgh/ KAT B1*	*Sorgh/ KAT x56*	*Sorgh/ KAT B1*	*Sorgh/ KAT x56*
No ridges	2.5	1.6	1.6	0.96	1.11	0.65	0.72	1.32	1.29
Open ridges	2.9	1.7	1.7	1.03	1.13	0.59	0.81	1.16	1.3
Tied ridges	3.3	2.3	2.1	1.09	1.33	0.73	0.91	1.37	1.32

TABLE 8b. Sorghum equivalent yield as influenced by ridging and intercropping

Factors	Treatments	Sorghum equivalent yield (t ha^{-1})
Ridging (R)	No ridging	3.2a
	Open ridging	3.5a
	Tied ridging	4.1b
Cropping system (CS)	Sole sorghum	2.9a
	Sorghum/ *KAT B1*	4.1b
	Sorghum/*KAT x56*	3.9b
$LSD_{0.05}$ (R)		0.41
$LSD_{0.05}$ (CS)		0.36
$LSD_{0.05}$ (R*CS)		ns
CV (%)		11.9

Means in a column bearing different letter (s) for each assessed treatment in a specific category of factors differ significantly (P<0.05) and ns = not significant

CONCLUSION

Ridging improved soil moisture content and this resulted to higher sorghum yield and sorghum equivalent yield. Intercropping sorghum with beans (additive system) led to decrease in soil moisture content and sorghum yield, but increased overall land productivity (SEY and LER). Although ridges produced the highest crop yield, seedling germination vigour was more vigorous under no ridges to ridged plot. This study, therefore, recommends the ridges to be prepared after seedling establishment. Intercropping sorghum and legume decreased the yield of component cereal crop but improved overall land productivity, which could mean higher economic benefit to the farmer.

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