Catchment area approach for enhancing traditional terrace cultivation for sorghum crop, Kassala State, Sudan

Moawia A. Mustafa[1], Mekki A. Omer[2] and Elwaleed M. Elamin[2]

[1] Kassala and Gash Research Station, Agricultural Research Corporation, Sudan.
[2] Agricultural Engineering, Water Harvesting and Irrigation Systems Research Center, Agricultural Research Corporation, Sudan.

ABSTRACT

Farmers traditional terrace system practiced in Kassala State was not conducive for sustained grain sorghum production. The objective of this study was to determine the suitable proportional catchment area to cultivated area that produces sufficient runoff water matching the crop water requirement and improving sorghum productivity in Kassala State.This experiment was conducted in *Alremeala* village near *Khashm Algirba* town in Kassala State, for two consecutive seasons (2013/14 and 2014/15). The experimental design was a randomized complete block design with three replicates. Treatments depended on the ratio between catchment area CA (runoff area) and farm area FA, (run-on area). These ratios were: (0.5:1) or (6:12 m^2), (1:1) or (12:12 m^2), (1.5:1) or (18:12 m^2), (2:1) or (24:12 m^2) and without catchment (control)**.** Due to relatively flat surface, an artificial slope was created immediately from the end of the CA into the FA by cutting 6-10 cm deep soil layer and moved down slope to build contour bunds every 15- 20 m spacing depending on the slope as inner bunds using tractor mounted scraper or manually with a hand-hoe. The areas between bunds were chisel ploughed to 25 – 30 cm and the whole plot was bound with a U-shape border earth embankment (75 cm and 30 cm bottom and top widths, and 40 cm high) and only opens from the upper slope where runoff is coming. Sorghum variety *Arfagadmak8* was planted in 80x50 cm rows and other cultural practices were performed as recommended by the ARC. Data consisted of rainfall, evapo-transpiration, runoff, soil moisture content and yield and yield components. Results indicated that the ratios 1:1, 1.5:1 and 2:1 were equally adequate to achieve improved sorghum grain and fodder yields by providing extra water harvesting and better distribution and conservation within the field. The two- year average yields were about the same for the CA: FA ratios 1:1, 1.5:1 and 2:1, but differences between them and the 0.5:1 and control were significant at the 1 % level. On average, the 1:1, 1.5:1 and 2:1 ratios produced 2312 kg/ha grain yield, increased by 20 % over the 0.5:1 ratios (1836 kg/ha) and 309% over the control (564 kg/ha). It is recommended to use a catchment area of 2:1 for improved sorghum production.

INTRODUCTION

Kassala State in eastern Sudan is characterized by arid and semi-arid climate. The annual rainfall in most of its localities is less than 250 mm. The majority of Kassala population is depending on rain fed agriculture as means of livelihood. The soil in this study area is non-cracking light clay with low infiltration rates. Land slope in this area is almost flat. Therefore, water harvesting seems to be a feasible solution for improving crop production.

The basic principle of these water harvesting techniques described are small – scale, a certain amount of land, catchment area is deliberately left uncultivated, rain water runoff this catchment area to the zone where crops are grown (cultivated area) (Critchley and Turner,1992).

Macro-catchment water harvesting and chisel ploughing results in western Sudan showed that harvesting of surface runoff water and conservation of soil moisture by creating vertical micro-pores increased the use efficiency of rainfall. Farmers are aware that the average available rain water is not adequate for sorghum production. Therefore, traditional terraces are normally constructed to control and conserve runoff water. The cultivated land is so flat that slope direction cannot be readily recognized by visual observation, but farmers rely on runoff flow observation to lay out their terrace system without taking into consideration the proper orientation of the contour lines. Secondary terraces are sometimes established inside the plot to improve water distribution within the field. The average size of a plot is about (2.1 ha) (FAO, 1993).

Although the plots are individually owned, the runoff water is managed at the community level. Indeed, the main terrace is acting as the main structure for the upward located field and field boundary for the lowland field. Water disposing outlets are opened on the side borders of the lower plots to collect runoff water coming from idle land areas. Thus, this continuous terrace system layout is penalizing the plots located at the lower part of the watershed mainly during low runoff events where most of the runoff water is retained in the upper fields (Elamin, 2007).

The terraces are laid down on the boundaries of the rectangular shaped fields without taking into consideration the contour lines. Farmers are establishing these terraces in U-shape pattern to form three boundaries of their fields while leaving the upper side open facing the general runoff direction in order to benefit from any runoff coming from outside the field. The main and the side (wing) terraces have the same dimensions (height and width) and both of them are lightly compacted. This layout shows that farmers are somewhat aware of the water harvesting concept, but present some weaknesses. The general runoff flow which is not parallel to the side terrace will strike it at an angle and lead to their destruction by undercutting and washing. Runoff water accumulates in one corner of the main terrace embankments and can lead to its destruction by overflow or erosion at the weak points since most of the terrace bunds are not stabilized by compaction or properly aligned with contour lines. The amount of water concentration in one corner of the field means uneven distribution of runoff water inside the plot which often results in water logging in this part of the plot while sorghum plants located elsewhere will not benefit from the runoff retention. Terrace implementation done by farmers is based on inherited experience and visual observation of the slope and runoff volume without proper measurements and, hence, explains the low performance of the system and poor crop yield in response to low rainfall (Martin,1999).

Furthermore, farmers are planting the whole area of their fields without leaving a catchment area for runoff generation and collection purposes. The main purpose of terrace construction along the boundaries by farmers is to intercept rainwater runoff within the field and prevent its escape out of the field boundaries during rainfall rather than to collect extra runoff water from a catchment area located up and between the fields. This explains the low sorghum yields, which is normally 238 –

476 kg/ha, where the average annual rainfall is 250 mm and well below the crop water requirement for sorghum crop (400 mm). Terraces built by farmers are neither set on contours nor dimensioned and compacted. Few farmers are using machinery to build their terraces although some of them use plowing to loosen the soil for easier construction of the bunds manually (Adam, 2000).

The poor crop yield can be traced back to this traditional method of water harvesting, which proved to be inefficient in providing enough water to match the crop water requirement. Therefore, the objective of this research was to enhance and improve the traditional terrace system by applying catchment approach and evaluate its performance.

MATERIALS AND METHODS

The experiment was conducted in *Alremeala* village, near *Khashem Elgirba* town in Kassala State, latitude 15◦ 28' N, longitude 35◦ 24' E and altitude of 500 m. The experiment was run during 2013/14 and 2014/15 rainy seasons.

The appropriate farms for conducting the experiments were selected on farmer's fields and contour lines and slopes were determined by the Survey Administration. The ratios between the catchment and farm areas (CA:FA) were determined for each experimental plot and laid in a randomized complete block design with three replicates. Treatments consisted of (0.5:1) or (6:12 m^2), (1:1) or (12:12 m^2), (1.5:1) or (18:12 m^2), (2:1) or (24:12 m^2), and without catchment (control). Due to relatively flat surface, an artificial slope was created immediately from the end of the CA into the FA by cutting 6-10 cm deep soil layer and moved down slope to build contour bunds every 15- 20 m spacing depending on the slope as inner bunds using tractor mounted scraper or manually with a hand-hoe. The areas between bunds were chisel plowed to 25 – 30 cm and the whole plot was bounded with a U-shape border earth embankment (75 cm and 30 cm bottom and top widths, and 40 cm high) and only opens from the upper slope where runoff is coming. Sorghum variety *Arfagadamak8* was planted in 80x50 cm rows and other cultural practices were performed as recommended by the ARC.

Runoff volume flowing into each plot from the specific CA was measured by direct collection of runoff water into a pit lined with plastic sheets.

Rainfall data during the study period was measured by a rain gauge near the plots. Climatic data were obtained from Kassala meteorological station (Table 1) and used for the calculation of the reference evapotranspiration (ET_o) using Penman-Monteith method. Crop factor (K_c) was reported by (Doorenbos and Pruitt, 1977). Sorghum crop evapotranspiration (ET_c) was calculated according to Allen *et al*. (1998) using the following formula:

$$ET_c = K_c \times ET_o \text{ …….. (1)}$$

where

ET_c = Crop evapotranspiration [mm d^{-1}], K_c = Crop coefficient and ET_o = Reference crop evapotranspiration [mm d^{-1}].

Soil samples for the determination of moisture content for all treatments was taken three times during the cropping season; the starting (establishment phase), mid-season (development/flowering phase) and late stage (maturity) from three depths of soil (0-20 cm, 20-40 cm and 40-60 cm). The gravimetric method, as described by Michael (1978), was used to determine the soil moisture content in dry and wet conditions. Samples were taken using an auger from each plot, weighed (Ww) and dried at 105˚C for 24 hours. The sample dry weight (Dw) was determined and the soil moisture content on mass basis (Ɵm %) was calculated using the following equation (Skaggs *et al.,* 1980).

$$\theta m\% = (Ww - Dw)/ Dw \times 100 \text{ ……… (2)}$$

The soil bulk density (pb) which was determined early in the season for each depth was used to convert the mass basis water content into volume basis water content (Ɵv), (equation 3) and multiplied by the soil profile depth (D) to obtain the equivalent depth of water content (De), (equation 4) and summed for the whole profile depth (60 cm) to obtain the total profile water content.

$$\Theta v = \Theta m \times pb \qquad (3)$$

$$De = \Theta v \times D \qquad (4)$$

Yield and yield components were determined.

Data was subjected to the analysis of variance procedure (Gomez and Gomez, 1984) , means of treatments were separated using Duncan's Multiple Range Test at P = 0.05.

RESULTS AND DISCUSSION

Rainfall

Table 2 shows the amount and distribution of rainfall during the study period for the two seasons at the experiment sites. In season 2013/ 14, July was completely dry, while October was also dry in season 2014/15. The seasonal rainfall during 2013/14 and 2014/15 were 323 mm and 359 mm, respectively. The month of August had the highest amount of rainfall in both seasons.

Table 1. Climatic data for Kassala State**.**

Month	Min temp (°C)	Max temp (°C)	Humidity (%)	Wind speed (km/day)	Sun shine (hours)	Radiation (MJ/m²/day)	ETo (mm/day)
July	23.9	36.1	57	233	7.5	20.8	6.41
August	23.4	34.9	63	233	7.5	20.8	5.90
September	24.0	36.8	55	156	8.9	22.5	5.95
October	24.3	38.7	44	112	9.3	21.6	5.60
November	21.4	37.0	47	156	9.1	19.5	5.46

Table 2. Rainfall (mm) at the experimental site during seasons 2013/14 and 2014/15.

Month	2013/ 14	2014 /15
July	0	95
August	245	175
September	40	89
October	38	0
Total	323	359

Crop water requirements

Table 3 shows crop water requirement (CWR) or ET_c calculation for sorghum by growth stage on daily basis and stage amount. For the total of 93 days growing period for sorghum variety *Arfagadamak8*, the CWR was 436 mm. Since July was completely dry, planting of crop has been in August and, hence, the calculation of CWR starts with this month. In the terms of total monthly rainfall compared to corresponding CWR, it was obvious that only the month of August was in excess, whereas other months showed water deficit.

Harvested runoff

The total harvested runoff water from each CA during season 2013/14 is shown in Table 4. Because of only two high rainfall intensity events (86 and 57 mm) that initiated runoff, the volume of runoff was rather small compared to total seasonal rainfall. The highest harvested runoff was obtained from CA that was twice or one and half the FA. The amount of harvested runoff (Ro), the rainfall contribution (P) and the water held by the soil profile (Δs), which is the difference between the water content at planting (ϴp) and at harvest (ϴh), were used to estimate the total seasonal water use by the crop (equation 5).

$$WU = Ro + P + I + \Delta s - Dp = Ro + P + I + (\Theta p - \Theta h) - Dp \ldots\ldots\ldots\ldots(5)$$

where

WU = Water use (mm).

I = irrigation (zero).

Δs = Change in profile soil water content (mm).

Dp = Deep percolation (zero).

Table 3. Calculated crop water requirement for sorghum crop.

Month	Period (days)	Age of crop (days)	Kc	ETo (mm/day)	ETc (mm/day)	ETc (mm/stage)
August	10					
	10	20	0.35	5.9	2.07	41.3
	10				4.43	
September	10					
	10	30	0.75	5.95	4.46	133.5
	10				6.55	
October	10					
	10					
	10	40	1.1	5.6	6.16	250.2
November	10	3	0.65	5.46	3.55	11
Total	-	93	-	-	-	436

Kc: Crop coefficient. ETo: Reference evapotranspiration. ETc: Crop evapotranspiration.

Table 4 also shows the total seasonal available water for use by plants using CA: FA ratio. The 1:1 and 1.5:1 and 2:1 ratios sufficiently provided extra runoff water and increased soil moisture content by 100 %, 104 % and 111 % of sorghum plant water needs, respectively. The ratio of 0.5:1 and the control failed to provide enough water to satisfy the crop water needs. This result agreed with that of Justine *et al*., (2003) who reported that the CA:FA ratio was estimated generally from 1:1 to 1:3, and also more water could be harvested from the uncultivated area.

Table 4. Seasonal runoff, water use and ET satisfaction for sorghum provided by the water harvesting catchment approach (2013/14).

Ratio of CA:FA	Runoff harvested water (mm)	Rainfall (mm)	Soil moisture content (mm)	Water use (mm)	ET (mm)	ET satisfaction (%)
0.5:01	09	323	044	376	436	086
01:01	16	323	100	439	436	100
1.5:01	28	323	104	455	436	104
02:01	40	323	121	484	436	111
Control	00	323	055	378	436	087

Soil moisture content

Soil moisture content for *Alremeala* during 2013/14 cropping season were shown in Table 5. Moisture content differences between stages of growth were obvious. It was high during early stage of growth where plant water needs were small and decreased to lower values with the progress in the season until it reached minimum values at the harvest time. Differences in soil moisture content ranged from significant to highly significant values among treatments and larger catchment ratios (1:1, 1.5:1 and 2:1) contributed significantly to increased soil moisture content compared to small ones.

In the combined analysis of the soil moisture content for the two seasons 2013/14 and 2014/15, the same pattern of differences between stages of growth existed (Table 6). All treatments were significantly different from the control and, however, differences between catchments ratios appeared from mid stage to maturity stage at the time of peak plant water needs.

Table 5. Profile soil moisture content (%) by growth stages for the first season during 2013/14.

Ratio of CA:FA	First stage			Mid stage			Maturity stage		
	Profile depth (cm)								
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
0.5:01	29.0 b	28.6 b	29.0 a	16.3	25.0	28.3	11ab	13.0 a	16 a
01:01	32.6 a	31.6 ab	30.6 a	16.0	25.0	29.3	10bc	13.6 a	15 a
1.5:01	32.6 a	31.0 a	30.3 a	17.3	25.3	29.3	12ab	14.0 a	16 a
02:01	34.0 a	32.3 a	30.6 a	17.3	25.6	29.6	13 a	14.0 a	16 a
Control	25.0 c	24.0 c	23.0 b	14.0	24.0	27.6	08 c	10.0 b	11 c
Means	30.7	29.6	28.9	16.3	25.0	28.8	11.1	13.0	15
SE(±)	0.87	0.67	0.89	0.53	0.79	0.90	0.52	0.58	0.76
C.V. (%)	3.9	10.8	4.5	11.6	9	5.09	10	5	8

Means in a column having the same letter(s) are not significantly different according to Duncan's multiple Range Test.

Table 6. Combined analysis of soil moisture contents (%) for two seasons 2013/14 and 014/15.

Ratio of CA:FA	First stage			Mid stage			Maturity stage		
	Profile depth (cm)								
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
0.5:01	34a	32.0 a	26a	15.0ab	24 a	26 ab	12.0	14.6	15.0a
01:01	35 a	33.0 a	29a	17.0a	24 a	27 a	12.8	15.0	16.6a
1.5:01	36 a	33.8 a	26a	15.6 a	25 a	26 ab	13.0	15.0	15.0a
02:01	35 a	33.5 a	27a	15.8 a	23 ab	27 a	12.0	15.8	15.0 a
Control	28 b	26.0 b	22b	13.0 b	21 b	13 b	10.8	14.0	12.5b
means	33.8	31.8	26	15.4	23.7	26	12.0	14.7	14.9
SE(±)	0.84	0.81	0.76	0.37	0.55	0.75	0.50	0.53	0.45
C.V(%)	6	8	10	11	10	9	22	16	13

Means in a column having the same letter(s) are not significantly different according to Duncan's multiple Range Test.

Yield and yield components

Sorghum grain yield and yield components for season during 2013/14 are presented in Table 7. Significant difference in yield components at 5 % and 1 % levels were observed among the catchment treatments and control. Sorghum grain has often shown a positive yield response to the amount of harvested runoff water added by the catchment ratios except with the control. The drought alleviation factor, which is defined as the absolute, total number of sorghum plants reached physiological maturity (produced heads) to the, total number of plants per unit area; was increased when water was not a limiting factor i.e. with relatively large catchment areas (1:1,1.5:1 and 2:1) and plant heights increased significantly as catchment area increased.

The growing season 2014/15 was characterized by higher (359 mm) and good distribution of rainfall, and deviation from normal did not appear to be associated with dry spells. Yield and yield components for this season (Table 8) indicated that catchment approach using CA: FA ratios (1:1, 1.5:1 and 2:1) usually had a yield advantage over the 0.5:1 and control in both years. There were significant differences in grain and straw yields, at the 1% and 5 % level for other yield components. Differences in grain yield were more likely to be associated with plant germination and soil moisture content.

Table 7. Sorghum grain yield and yield components during season 2013/14.

Ratio of CA:FA	Yield kg/ha)(	Straw ton/ha)(	Plant height (cm)	100 seeds wt(g)	Drought alleviation(%)
0.5:01	1443 a	4.9 a	106 ab	3.5 ab	71 b
01:01	1481 a	4.3 a	107 ab	3.7 ab	75 ab
1.5:01	1517 a	4.6 a	113 a	3.8 a	79 a
02:01	1593 a	4.2 a	113 a	3.7 ab	98 a
Control	0369 c	2.9 b	090 b	2.9 b	71 b
Mean	1281	4.2	106	3.5	74
SE(±)	150	0.23	4.1	0.13	4.4
C.V. (%)	27	11	10	11.97	13

Means in a column having the same letter(s) are not significantly different according to Duncan's multiple Range Test.

Table 8. Sorghum grain yield and yield components during season 2014/15.

Ratio of CA:FA	Yield (kg/ha)	Straw (ton/ha)	Plant height(cm)	100 seeds wt(g)	Drought(%)
0.5:01	2150 b	5.5 a	106 b	5.1	170 b
01:01	3195 a	5.8 a	113 ab	5.0	160 b
1.5:01	3102 a	4.4 ab	113 ab	5.2	150 b
02:01	3060 a	5.3 a	123 a	5.3	260 a
Control	0757c	0 3 b	104 b	4.9	160 b
Mean	2452	4.7	111	5.0	180
SE(±)	250	0.35	2.74	0.12	15
C.V. (%)	6	21	5	10	19

Means in a column having the same letter(s) are not significantly different according to Duncan's multiple Range Test.

Table 9 presents the combined analysis of sorghum grain yield and other yield components during the two cropping seasons. The two- year average yield attributes were about the same for the CA: FA ratios 1:1, 1.5:1 and 2:1, but differences among them and the 0.5:1 and control were significant at the 1 % level of significance. On average, the 1:1, 1.5:1and 2:1 ratios produced 2312 kg/ha grain yield which increased by 20 % over the 0.5:1 ratio (1836 kg/ha) and 309% over the control (564 kg/ha). Differences in sorghum response to water harvesting levels were slight because only two rainfall events resulted in relatively additional harvested and collected runoff water.

It is interesting to note that treatments, which have been shown to conserve soil moisture, increased yields in both years irrespective of rainfall distribution of rainfall. Catchment treatments had no significant effect on100 seeds weight.

Table 9. Combined analysis of yield components for seasons 2013/14 and 2014/15.

Ratio of CA:FA	Yield (kg/ha)	Straw (ton/ha)	100 seeds wt (g)	Plant height (cm)	Drought alleviation(%)
0.5:01	1836a	5.2 a	4.4	115ab	119.0 b
01:01	2338a	5.1 a	4.5	119 ab	119.0 b
1.5:01	2326a	4.5 ab	4.5	126 a	128.0 b
02:01	2271a	4.6 a	4.2	118 ab	188.0 a
Control	564 b	3.6 b	4.2	107 b	123.0 b
Mean	1867	4.59	4.36	117	135.8
SE(±)	173	0.18	0.17	2.5	12.5
C.V. (%)	28	16.2	11	10	30

Means in a column having the same letter(s) are not significantly different according to Duncan's multiple Range Test.

CONCLUSIONS

It is concluded that CA: FA ratios of 1:1, 1.5:1 and 2:1 were adequate to achieve improved sorghum grain and fodder yields by providing extra runoff harvested water and better distribution within the field.

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طريقة حصاد المياه لتحسين زراعة محصول الذرة الرفيعة فى التروس التقليدية، ولاية كسلا ، السودان

معاوية عبد الفتاح مصطفى[1] ومكى عبداللطيف عمر[2] والوليد محمد الامين[2]

[1]محطة البحوث الزراعية كسلا والقاش، هيئة البحوث الزراعية، السودان.

[2] مركز بحوث الهندسة الزراعية وحصاد المياه ونظم الرى الحديثة، سوبا، هيئة البحوث الزراعية، السودان.

الخلاصة

نظام التروس التقليدية فى ولاية كسلا لايساعد المزارعين فى انتاج الذرة الرفيعة. الهدف من هذه الدراسة هو تحديد الانسب لمساحة مستجمع مائي الي مساحة مزروعة لتعطى مياه جريان تتناسب مع الاحتياجات المائية للمحصول وتحسن من انتاجية محصول الذرة الرفيعة فى ولاية كسلا. أجريت هذه التجربة فى قرية الرميلة قرب مدينة خشم القربة فى ولاية كسلا فى موسمين متتابعين (2014/13 و2015/14).استخدم تصميم القطاعات العشوائية الكاملة في ثلاث مكررات، وخمسة معاملات تعتمد على نسبة بين مساحة للستجمع المائى (منطقة جريان) للمساحة منطقة المزروعة CA (منطقة مستقبل جريان) وكانت النسب كالاتى (1:0.5) او (12:6م^2), (1:1) او (12:12م^2), (1:1.5) او FA (12:18م^2), (1:2) او (12:24م^2) و نظام التقليدى بدون مستجمع مائي. ونسبة لسطح االمنبسط تم انحدار صناعى بين نهاية المستجمع المائي وداخل المنطقة المزروعة وذلك بقطع وتحريك الطبقة السطحية للتربة بعمق 6-10سم لعمل حاجز ترابى كل 15-20متر تعتمد على خط الانحدار. أنشات هذه الحواجز عن طريق زحافة او يدويا.المنطقة بين الحواجز الداخلية تحرث بالمحراث الازميلي بعمق 25-30سم ونهاية المربع تاخذ شكل U. ابعاد الحواجز الترابية (75 سم العرض الاسفل و30 سم العرض الاعلى و40 سم العمق) يكون مفتوح من ناحية الانحدار حيث جريان المياه . زرع صنف الذرة ارفع قدمك فى خطوط 50×80 سم وأجريت عليه بعض العمليات الفلاحية الاخرى الموصى بها من هيئة البحوث الزراعية. المعلومات التى تم قياسها ومتابعتها تشمل الامطاروتبخر-نتح والجريان ونسبة الرطوبة التربة والانتاج ومكونات الانتاج. تشيرالنتايج الى ان النسب 1:1, 1:1.5 و1:2 أدت الى زيادة إنتاجية الذرة والعلف وذلك بسبب حصاد جريان المياه وتحسين توزيعه وحفظه داخل الحقل. متوسط الانتاج فى الموسمين متشابه فى النسب 1:2 , 1:1.5 و 1:1 ولكنه يختلف عن نسبة 1:0.5 و الزراعة التقليدية اختلاف معنوى عند مستوى 1%. متوسط انتاج الذرة فى معاملات النسب 1:1, 1:1.5 و1:2 كان 2312 كجم/هكتار يزيد بحوالى 20% عن معاملة نسبة 1:0.5 (1836 كجم/هكتار) و 309% عن معاملة الزراعة التقليدية (564 كجم/هكتار). يوصي باتستخدم نسبة المستجمع المائي 1:2 لتحسين انتاجية الذرة.