Effect of Rainwater Harvesting Techniques and supplemental Irrigation on Productivity of Sorghum Forage (*Sorghum bicolor* L.Moench) under Semi-Arid Conditions, Sudan

Abstract: The current study was conducted at El Rawakeeb Research Station of the National Research Center located on the eastern bank of Wadi El Rawakeeb, about 45 km west of Omdurman between latitudes 15° 20´ and 15° 36´N and longitudes 32 ° 0´ and 32° 10´E and altitude 420 m above mean sea level during two successive seasons (2006 and 2007) to investigate the effect of rainwater harvesting techniques and supplemental irrigation on crop productivity of sorghum (Abu Sabein) forage (*Sorghum bicolor* L.Moench) in semi-arid conditions, Sudan on a sandy clay loam soil. The treatments included two supplemental irrigations and three water harvesting techniques (tied-ridging, ridging, basin). Split plot experimental design with four replications was used in which the two supplemental irrigations (with and without supplemental irrigation (control)) were assigned to the main plots while three water harvesting techniques (Tied-ridging, Ridging and Basin) were allocated to the sub plots. Crop water requirement was determined using CROPWAT version 8 computer model. The parameters tested were; soil moisture content (%), green forage (ton/fed) and dry forage (ton/fed). The results showed that soil moisture content in the effective plant root zone and crop productivity significantly ($P \leq 0.05$) was affected by two supplemental irrigations with three rainwater harvesting techniques. The tide-ridging technique with supplemental irrigation gave the highest values of green and dry forage productivity as compared to the other treatments during both seasons, while the control (without supplemental irrigation) recorded the lowest values of the productivity. Hence, rainwater harvesting techniques will help to increase crop yield and optimize the water resource productivities.

Keywords: Rainwater Harvesting Techniques; Productivity; Supplemental Irrigation; Sorghum Forage

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المستخلص:

أجريت هذه الدراسة بمحطة أبحاث الرواكيب التابعة للمركز القومي للبحوث والتي تقع في الجانب الشرقي لوادي الرواكيب ، وتبعد 45 كلم غرب أم درمان بين خطي عرض 15° 20´ و 36´ 15° شمالاً وخطي طول 0´ ° 32 و 10´ 32° شرقاً وعلي إرتفاع 420 متراً فوق سطح البحر خلال موسمين متتالين (2006 ،2007) لبحث تأثير تقنيات حصاد المياه والري التكميلي علي إنتاجية الذرة العلفي (أبوسبعين) تحت ظروف الاراضي شبه الجافة بالسودان ، في تربة رملية طمية . وشملت المعاملات نوعين من الري التكميلي (مع ري تكميلي ، وبدون ري تكميلي) وثلاث معاملات لتقنيات حصاد المياه (الخطوط المترابطة ، الخطوط والاحواض) . نفذت التجربة بتصميم القطع المنشقة باربع مكررات وخصصت معاملات الري التكميلي للقطع الرئيسية ومعاملات تقنيات حصاد المياه للقطع الفرعية. استخدم برنامج الحاسوب CROPWAT-8 لتحديد الاحتياجات المائية. تضمنت القياسات المحتوي الرطوبي للتربة (%) ، إنتاجية العلف الأخضر(طن / فدان) و إنتاجية العلف الجاف (طن / فدان) . أوضحت النتائج أن المحتوي الرطوبي في منطقة الجذور الفعالة وأنتاجية المحصول تأثرت إيجابياً ($P \leq 0.05$) بالري التكميلي و تقنيات حصاد المياه. معاملة الخطوط المترابطة مع الري التكميلي أعطت أعلي القيم لانتاجية العلف الأخضر والجاف مقارنة مع المعاملات الأخري خلال الموسمين بينما سجلت معاملة الشاهد بدون ري تكميلي أقل القيم للانتاجية. وعليه فأن تقنيات حصاد المياه والري التكميلي تساعد في زيادة انتاجية المحاصيل وتحسين أنتاجية الموارد المائية.

1. Introduction:

The growing water scarcity and misuse of water resources are the main serious problems facing agricultural production in the world. Water harvesting techniques are envisaged to provide feasible solutions for desertification, erosion hazards, ground water recharging and eventually leading to increased agricultural production. The use of water harvesting techniques and supplemental irrigation is known to be beneficial for increasing crop yields. Karrar *et al.*, (2012) reported that the tied-ridging rainwater harvesting technique is effective in reducing runoff and increasing soil water storage. Rockstrom *et al.* (2001) stated that there is a significant scope for improving water productivity in rain fed farming through Supplemental irrigation, especially if combined with soil fertility management. Water harvesting such as tied ridges and contour bunds, micro-basins, mulching, runoff harvesting and other conservation farming technologies approach to enhance water productivity in smallholder rain-fed agriculture (Gurtner *et al.,* 2006). Water used in supplemental irrigation had the highest marginal productivity and increase in rain fed production above 12% was achievable even under traditional practices (Sharma *et al.,* 2010). Thereby water harvesting seeks to raise crop water productivity, yields and yield stability (Rockstrom and Barron, 2007). In Texas area, tied-ridges rainwater harvesting technique increased the yield of Sorghum by 20% (1700 kg /ha) compared to control as stated by Jones and Clark (1987), while corn yield was increased by12% at Lincoln, Nabresaka (Duely, 1960) and barley yield was increased by 44% in the semi-arid region of northern Ethiopia (Araya and Stroonijder, 2010). In semi-arid Kenya, the supplemental irrigation with improved nutrient application increased average yield by 70% (Barron and Okwach, 2005). While in Burkina Faso, supplemental irrigation combined with fertilizer application, increased the yield level three folds as compared to the normal farmer´s practices (Fox and Rockstrom, 2003). In north Kordofan state-Sudan, rainwater harvesting technique increased sorghum productivity by 152% compared to control as stated by Omer and El Amin (1996). According to Abdel Latif and Abdel Rahman (2003), the use of water harvesting techniques in the Sudan increased the productivity of fodder crops from 0.33 to 2.3 ton/fed. Rainwater harvesting is possible for the average annual rainfall of 100-150 mm as claimed by Bloum (2003) or may be down to the level of 50-80 mm as reported by NAS (1974). West Omdurman, where Rawakeeb area is located lies slightly above the 120 mm per season isohyets. Thus the amount of rainfall was quite satisfactory for water harvesting. Taking into consideration, that there is little information regarding the rainwater harvesting techniques and water management their effect on crop productivity in Sudan and the limited scope under which these techniques are used now. The study was then conducted to evaluate the effects of three rainwater harvesting techniques (tied-ridging, ridging and basin) and supplemental irrigation on crop productivity of sorghum forage (*Sorghum bicolor* L. monech) under semi-arid conditions, Sudan.

2. Materials and Methods

2.1 The Study Area:

The experimental work was carried out at Rawakeeb Desert Research Station which is located on the eastern bank of Wadi El Rawakeeb, about 45 km west of Omdurman between latitudes 15° 20´ and 15° 36´N and longitudes 32 ° 0´ and 32° 10´E and altitude 420 m above mean sea level during two successive seasons (2006 and 2007) to investigate the effect of rainwater harvesting techniques and supplemental irrigation on crop productivity of sorghum (Abu Sabein) forage (*Sorghum bicolor* L. Moench) in the tropical semi-arid conditions, Sudan on a sandy clay loam soil. The climate is characterized by a short rainy season (July- October) and high evaporation potential. The relative humidity values are low and thus indicating the general aridity of the area. Air temperature fluctuates and shows a marked rise in May and drop in August due to the incidence of the rains (above the 120 mm per season). Thus the amount of rainfall is quite satisfactory for water harvesting. The main geological formations in the area including the recent deposits of the quaternary period (Aeolian, alluvial and eolluvial deposits) are underlain by Nubian sandstone formations of the late Paleozoic to the cretaceous period bearing water aquifer (Fadul et al,.2005). The natural vegetation of El Rawakeeb area is composed mainly of Acacia spp. (*Acacia tortilis*) and different grasses (*Aristida spp.*). This natural vegetation is replaced in the cultivated sites by some cereal crops such as sorghum (*Sorghum bicolor* L._Moench) and few legumes (*Cajuns cajana*) (Abdel Latif and El Hag, 2005).

2.2 Layout of the experimental area:

An area of 4684 m^2 was selected with its natural slop and uniformity of soil texture. A split- plot experimental design with four replicates was used in which the two supplemental irrigation (with and without supplemental irrigation (control)) were assigned to the main plots while the three water harvesting techniques (Tied-ridging, Ridging and Basin) were allocated to the sub plots. Spacing of three meters between the experimental units and four meters between different replications were kept as buffer areas and water ways and limit inter plot interference. The experimental units were surrounded by guarded area planted by Abu Sabein.

2.3 The cultural practices:

The experimental area was prepared by disc plough followed by chisel plough and leveler. Forage sorghum (Abu Sabien) of local cultivar (Aliab) was planted in the last week of July. The cultivar sorghum was planted on flat rows and hills at a seed rate of 25 kg/fed, with 7-8 seeds/holes, thinned to five plant/ hole after three weeks of sowing date. The rows were arranged along the slope and space 80 cm apart and holes were spaced 10 cm within the row. Nitrogen fertilizer (urea) was added to the experimental plots at rate of 87 kg/fed as recommended by Abu Suar,(2005).

2.4 Water Harvesting Techniques:

2.4.1 Tied- Ridging (TR):

In this technique lower ridge (cross-ties) 15 cm high, 30 cm at base 150 cm apart were constructed with hoes across the afore mentioned ridges creating mini-basins as exhibited.

2.4.1 Ridging (R):

Hand tools such as hoes and shovels were used to construct small earth bunds parallel to the contours. Ridges were raised 20 cm with base of 30 cm and 130 cm apart. Where water would accumulate and infiltrate in the soil.

2.4.3 Basin (B):

Each 3mx 1m plot was divided into three equal basins, 20 cm in height.

2.4.4 Control (C):

The control plots were left flat to represent the conventional field practice as adopted by the local farmers.

2.5 Supplementary irrigation treatments:

In supplemental irrigation treatments, each replicate was divided in two sections. One section was only rain fed and the other was supplemented with predetermined amount of irrigation water from raised tank.

2.5.1 Supplemental irrigation facilities:

The supplemental irrigation system used was low-cost irrigation hose, which consisted of a water tank fitted with a 1.5 inch PVC hose for water delivery. The tank was filled by a pump from the farm deep borehole. The hose discharge was calibrated volumetrically by using a plastic container of 16 liter capacity and stop watch. This measurement was done 15 times and the mean was taken to represent the hose discharge.

2.5.2 Amount of the supplementary irrigation:

The mount of supplemental irrigation water was calculated by subtracting the mount of the effective rainfall in (mm) from the crop evapotranspiration (ETc) in (mm).

2.6 Crop water requirement (CWR):

Crop water requirement was predicted using the meteorological data obtained from Khartoum metrological station employing the

FAO –Penman –Monteith equation and the CROPWAT computes the reference evapotranspiration in mm per day (mm day $^{-1}$) for each month of the growing season upon entry of the required meteorological data. Crop evapotranspiration was calculated using the equation mentioned by Michael (1978) as follows:

ETc = ETo* Kc…………………………………………..… (1)

Where:

ETc = Crop evapotranspiration (mm day $^{-1}$)

ETo = Reference crop evapotranspiration (mm day $^{-1}$)

Kc = Crop coefficient.

2.7 Measurement of rainfall:

Daily rainfall is measured using the standard ordinary rain gauge exposed 1 m above level ground away from buildings and trees. The diameter of the standard gauge is 5 inches (12.7 cm). There is a measuring Jar calibrated to read the rainfall in mm. This Jar should be used only with 5in diameter rain gage. A recording rain gauge is used to give a continuous record of rainfall. The type of rain gauges is very important because it gives the intensity of rainfall (Adam, 2014).

2.7.1 Effective rainfall:

Effective rainfall is defined as the fraction of rainfall that is effectively intercepted by the vegetation or stored in root zone and used by the plant – soil system for evapotranspiration. It can be estimated by the following equation mentioned by Adam (2014):

Pef = E. Ptot + A ………………………………. (2)

Where:

Pef = Effective rainfall over the growing season.

E = Ratio of consumptive use of water (cubic) to Ptot.65.

Ptot = Total rainfall over the growing season.

A = Average irrigation application.

2.8 Amount of water to be applied:

The amount of water to be applied to each plot was determined using the following equation mentioned by Stren (1979):

$$V = \frac{Si*A*0.001}{\mu\ Total} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

Where:

V= volume of water applied to each plot per irrigation (m^3),

Si= the amount of supplemented water per irrigation (mm),

A= plot area (m^2).

µ Total= total irrigation efficiency taken (60%).

2.9 Soil moisture content (%):

Soil samples were randomly taken from a depth of 40 cm at three locations per plot, by an auger (or direct digging when dry). Composite samples were taken, for gravimetric soil moisture determination. The soil samples were taken before sowing, mid-season and after harvesting. The soil samples were weighed fresh, oven-dried at 105 °C for 24 hours and reweighed. Gravimetric moisture content was then calculated by expressing the percentage moisture on dry mass basis (Michael, 1978):

Soil moisture content (%) =

$$\frac{\text{Mass of moist sample- mass of oven-dry sample * 100}}{\text{Mass of oven-dry sample}}. \ (4)$$

Soil moisture content per unit per mass is converted to volumetric data using bulk density.

Volumetric moisture content (%) =

Moisture content on mass basis (%) * soil bulk density……………………..…. (5)

2.10 Yield components (Green and Dry forage productivity):

2.10.1 Green forage productivity (ton/fed):

The areas 1 m *1 m were selected randomly from each plot and the plants in those plots were cut at the end of season. The plants were then tied in bundles, labeled and weighed to obtain the green forage productivity. The green forage productivity weight was expressed as ton per fed.

2.10.2 Dry forage productivity (ton/fed):

The bundles used for the weight of green forage determination were sun dried for ten days and reweighed to obtain the dry forage productivity. The dry forage productivity weight was expressed as ton per fed.

2.11 Statistical analysis:

Statistical analysis of the results of soil moisture content and Yield components (Green and Dry forage productivity) variables was performed using split- plot design arrangement with four replicates following the procedures described by Gomez and Gomez (1984). The plot means provided the basis for data analysis and were subjected analysis of variance from which the Duncan´s Multiple Range values were calculated for $p \leq 0.05$ and used to test for significant differences among treatment mean.

3. Results and Discussion

3.1 Soil moisture content as affected by rainwater harvesting techniques and supplementary irrigation:

As presented in Table 1, soil moisture content wassignificantly ($P \leq 0.05$) affected by the different techniques of rainwater harvesting and supplementary irrigation. Tied-ridging with supplementary irrigation gave the highest mean values of soil moisture content as compared to control without supplemental irrigation. This may be attributed to the reduced water runoff by the tied- ridging and consequently greater soil water storage. The results were in conformity with the result obtained by Gebreyesus *et al.* (2006) and agreed by Karrar *et al.* (2012) who reported that the tied-ridging rainwater harvesting technique is effective in reducing runoff and increasing soil water storage.

Table 1**.** Average values of soil moisture content (%) as influenced by water harvesting techniques and supplemental irrigation

Treatment	Before sowing	Mid-season	After harvesting

Tied-ridging with supplemental Irrigation	3.64 [a]	9.59 [a]	5.50 [a]
Basin with supplemental Irrigation	3.68 [a]	7.44 [b]	5.04 [a]
Ridging with supplemental Irrigation	3.65 [a]	6.48 [c]	4.54 [b]
Control with supplemental Irrigation	2.98 [abc]	6.16 [c]	4.05 [c]
Tied-ridging without supplemental irrigation	3.39 [ab]	5.61 [d]	4.38 [bc]
Basin without supplemental Irrigation	3.01 [abc]	4.97 [d]	3.80 [d]
Ridging without supplemental Irrigation	2.77 [bc]	4.91 [d]	3.63 [d]
Control without supplemental Irrigation	2.35 [c]	4.38 [e]	3.22 [e]

- Any two means under the same column having the same letters are not significantly different at ($P \leq 0.05$) level of significance using Duncan´s Multiple Range Test.

3.2 Green and dry forage productivity of Abu Sabein (*Sorghum bicolor* L.)**:**

As shown in Table 2, green and dry forage productivity of Abu Sabein was significantly ($P \leq 0.0$) affected by the different rainwater harvesting techniques and supplemental irrigation in the two seasons. Tied-ridging with supplemental irrigation gave the highest mean values of green and dry forage productivities as compared with control without supplemental irrigation. These results may be attributed to the fact that the tide-ridging gave more time for rain and supplemental irrigation to penetrate, infiltrate and allow crops to use water and at the end reduce water runoff. On the other hand the reduction of runoff by the tied ridges increasing soil water storage, ultimately increased yield of crops. These results were in agreement with Araya and Stroosnijder (2010). The lowest values of green and dry forage productivity may be attributed to the effect of water stress as stated by Hassan (1987).

Figs. 1and 2, showed the effect of different rainwater harvesting techniques and supplemental irrigation on green and dry crop productivity. Green and dry forage productivities were significantly affected by the different treatments (P ≤ 0.05). Supplemental irrigation with tied-ridging rainwater harvesting technique recorded the highest mean values as compared with the control without supplemental irrigation. This result may be attributed to the fact that water harvesting such as tied-ridges and contour bunds, micro-basins, mulching, runoff harvesting and other conservation farming technologies approach to enhance water productivity in small holder rain-fed agriculture as mentioned by Gurtner *et al.* (2006). The results were in conformity with Sharma *et al.* (2010) who reported that, water used in supplemental irrigation had the highest marginal productivity and that the increase in rain fed production above 12% is achievable even under traditional practices.

Table 2**.** Means values of the green and dry forage productivity of Abu Sabein (*Sorghum bicolor* L.) as affected by supplementary irrigation and water harvesting techniques in season 2006 and 2007

Treatment	Season 2006		Season 2007	
	Green forage (ton/fed)	Dry forage (ton/fed)	Green forage (ton/fed)	Dry forage (ton/fed)
Tied ridging with supplemental irrigation	9.42 [a]	4.15 [a]	9.38 [a]	4.52 [a]
Basin with supplemental irrigation	8.02 [ab]	3.22 [ab]	8.41 [b]	3.55 [b]
Ridging with supplemental irrigation	6.83 [b]	2.38 [b]	7.69 [c]	3.06 [b]
Control with supplemental irrigation	5.01 [bc]	1.72 [bc]	6.20 [c]	2.45 [c]
Tied ridging				

without supplemental irrigation	4.58 [c]	1.58 [c]	2.71 [d]	1.25 [d]
Basin without supplemental irrigation	3.41[cd]	1.16 [cd]	1.71 [e]	1.10 [d]
Ridging without supplemental irrigation	2.64 [d]	0.76 [d]	1.39 [e]	0.99 [de]
Control without Supplemental Irrigation	2.02 [e]	0.70 [e]	0.70 [f]	0.47 [e]

- Any two means under the same column having the same letters are not significantly different at ($p \leq 0.05$) level of significance using Duncan´s Multiple Range Test.

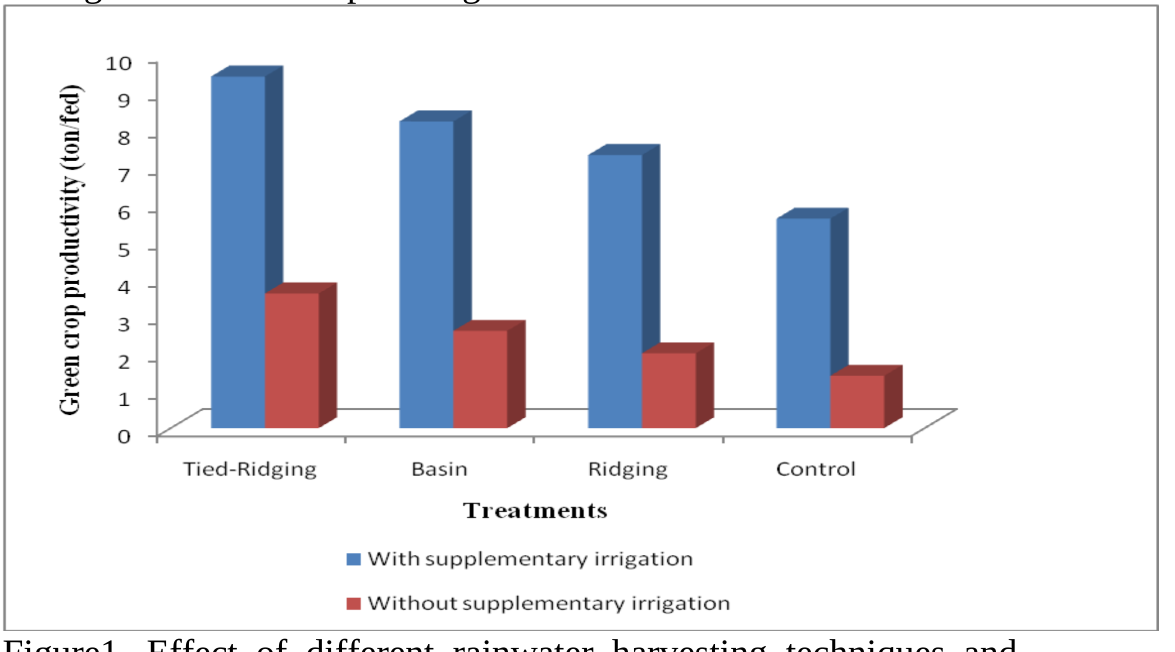

Figure1. Effect of different rainwater harvesting techniques and supplemental irrigation on green crop productivity.

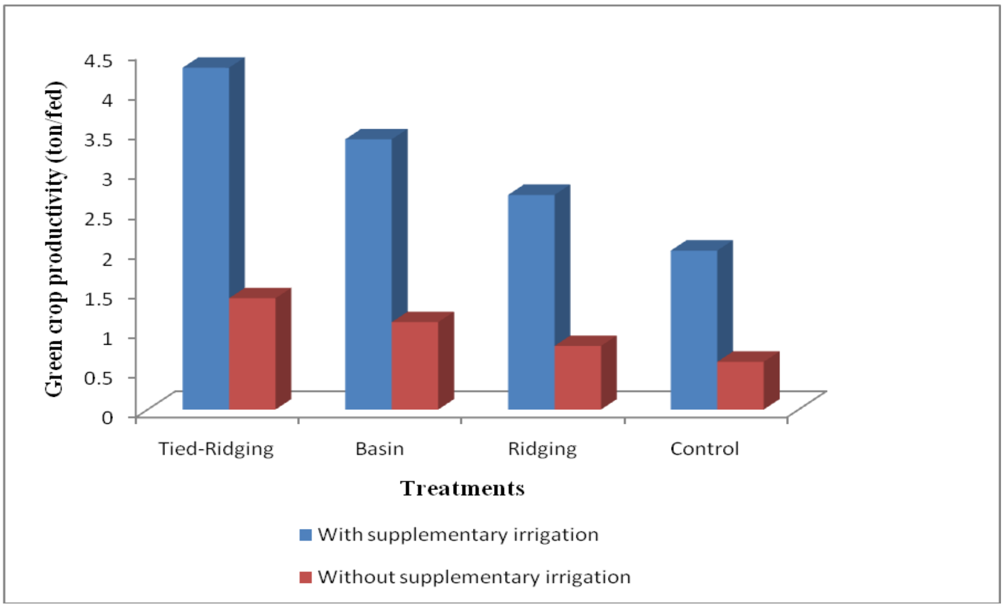

Figure 2.Effect of different rainwater harvesting techniques and supplemental irrigation on dry crop productivity.

4. Conclusions:

Rainwater harvesting technique coupled with supplemental irrigation; increase the productivity of Abu Sabien(*Sorghum bicolor* L.) forage crop. The tide-ridging technique with supplemental irrigation gave the best result of productivity of Abu Sabein (*Sorghum bicolor* L.)as compared with the other techniques used in this study. Superiority in soil moisture conservation can be achieved by tide- ridging, basin, and ridging in respective order.

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