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IMPACT OF TILLAGE SYSTEMS ON RAINFALL WATER RUNOFF IN THE DOKA WATERSHED, GADARIF, SUDAN

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Abstract
A field experiment was carried out during the growing seasons 2017/18 and 2018/19 under rainfed conditions to study the impact of some tillage systems on rainfall water runoff in the Doka Watershed, Gadarif State, Sudan. The 100 feddan experimental site was located at a latitude of 12° 45´ N, longitude of 35° 15´ E, and elevation of 540 m above mean sea level. Three water harvesting treatment systems were implemented: contour tillage (CT) (chisel plow + earth contour embankments), zero tillage (ZT) (conservation tillage), and the traditional farmer's practice using the wide level disc (WLD) plow which was taken as the control. The experiment was conducted in a Randomized Complete Block Experimental Design (RCBD) with three replications. The sorghum (Sorghum bicolor) Wad Ahmed variety was used as an indicator plant. The statistical analysis software MSTAT was used to analyze the data. The results show that contour tillage produces the lowest amount of surface runoff compared to the control. There was positive correlation between the rainfall characteristic and the volume of surface runoff. It is evident that contour tillage had a noticeable positive impact on the management practices of vertisol by reducing surface runoff.

Introduction

Water is one of the most basic human needs. It impacts agriculture, energy, health, and human livelihoods. Watersheds are commonly used for the management of natural resource in mountainous areas for several reasons. One of the basic and important components of agricultural production technology is soil tillage (Ayman, et al. 2021). Tillage is defined as any physical loosening of soil during a range of cultivation operations, either manually or mechanically (Ahn and Hintze, 1990). Soil tillage is a crop production technology that is among the leading anthropogenic activities influencing water and soil hydrological functioning by regulating water flow processes (Tapia-Vargas et al., 2001; Van de Giesen et al., 2011). Soil tillage is one of the main factors influencing soil properties and crop yield Gondal. et al. (2021). Tillage contributes up to 20% of crop production factors (Khurshid et al., 2006)

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Runoff occurs when there is more water than land can absorb. (FAO, 1976) defined Runoff as the portion of precipitation, snowmelt, or irrigation water that appears in uncontrolled surface streams, rivers, drains, or sewers. Runoff from agricultural land can carry with it deplete plant nutrients, such as nitrogen and phosphorus, into streams, lakes, and groundwater and deprive soil of essential plant nutrients. Soil erosion refers to the wearing a way of a field's topsoil by the natural physical forces of water and wind Balasubramanian (2017). Soil erosion is a natural process in which the topsoil of a field is carried away by physical sources such as wind and water. Conservation tillage is a generic term for the use of tillage techniques to promote in situ moisture conservation. Rainfall in the semi-arid tropics (SAT) generally occurs in short torrential downpours. Most of this water is lost as runoff, eroding significant quantities of precious top soil. The current rainwater-use efficiency for crop production is low, ranging from 30% to 45% (Wani, et al. 2005)

The reduction or elimination of tillage enables minimal soil disturbance and permanent soil cover to be achieved (Shahzad et al., 2016, Tarolli et al., 2019). Many previous studies have investigated the effects of soil tillage systems on surface runoff generation (Ahuja et al., 1998; Green et al., 2019). Machado et al., (2015), Baumhardt et al., 2017 and Mitchell et al., (2017) reported that conservation tillage involving reduced soil tillage and minimal disturbances of the soil ecosystem enhances the reduction in surface runoff by improving the soil structure, increasing soil aggregation and organic matter content, increasing storage of soil moisture, and improving the water infiltration rate (Kahlonet al., 2013; Mitchell et al., 2017; Roper et al., 2013). However, Capowiez et al., (2009) reported no noticeable differences in the surface runoff and infiltration rate between conventional and conservation tillage practices. Singh et al (2023) concluded that conservation tillage was effective in reducing runoff and soil loss compared to conventional tillage.

Elwaleed (2019) examined the Effect of Some Tillage Systems on Surface Runoff and Soil Erosion. The results showed that the second season had the best distribution and satisfaction pattern, and post-harvest tillage reduced the average annual runoff and soil loss to the lowest values. Ayman, et al (2021) studied the effect of some conservation tillage practices on the growth and yield attributes of rainfed sorghum, the Results showed that plant height, stem diameter, number of leaves per plant, plant population, and grain yield (kg/ha) were not significantly affected by the tillage practices during the first season Therefore, the objective of this study was to seek the best water harvesting management practices to control surface runoff, which leads to better and improved rainfed sorghum productivity in a specific watershed area at Doka, Gadarif State, Sudan.

Material and Methods

Experimental Site:

Field experiments were carried out during the growing seasons of 2017/18 and 2018/19 under rain-fed conditions to study the impact of some Tillage systems on surface water runoff in the Doka Watershed, Gadarif State. The 100-feed experimental site was located at latitude 12° 45´ N, longitude 35° 15´ E, and an elevation of 540 m above mean sea level.

The Gadaref state is generally divided into three distinct agro-ecological zones based on the amount of rainfall and main agricultural characteristics. The northern zone receives less than 500 mm of rainfall annually. The central zone has annual rainfall ranging from 500 and 600 mm, while the southern zone has rainfall ranging from 600 and 900 mm. The annual rainfall is concentrated in a single relatively short summer during June to September. The topographical features of the study area include undulating relief from several major drainage systems. It has two main drainage patterns to the east and west and is comprised of various large and small cross-sectional seasonal streams (Ministry of Agriculture, Gadarif state, 2000).

The temperature ranged from a mean minimum of 21° C in January to a mean maximum of 37° C in April and May.

Experimental design:

The experiment was conducted in randomized complete block design (RCBD) with three replications. Sorghum (variety Wad Ahmed) was grown as an indicator crop.

Tillage system treatments:

The following tillage treatments were implemented:

1. Contour tillage (chisel plow + earth contour embankment):

Contour tillage system on which the contour lines were determined inside the farm land in the direction perpendicular to the slope, then dirt gears were made on those lines completely at distances ranging between 10 and 30 m to ensure that rainwater was distributed fairly and to prevent water accumulation at one place at the end of the field. The land was then plowed with chisel plow following the contours to ensure that water was conserved in the soil using 70 hp tractors.

2. Zero tillage (conservation tillage):

A no-till tillage system, which limits soil disturbance, was applied to the soil except for opening small holes for seed placement using hand tools locally known as Gerraya. The seed holes were carefully dug through the stand stubble of the previous season crop.

3. Wide-level discs as traditional farmers' practice:

The wide level disc was used as a primary tillage implement during the summer time in July, just before the rainy season, to mix the previous crop residues in the soil and as green discing after a few showers to control newly germinated weeds by early August. The depth of cut for the WDL was less than 7.8 cm.

Data collection and measurements:

Rainfall measurement:

A rain gauge was used to measure the rainfall. The rain gauge was installed in the experimental site at 60 cm above the ground (FAO 1976). Measurements were taken in the morning at 8:00 am after each rain event and recorded as daily data for the previous day. A graduated measuring cylinder was used to measure the collected rainfall amount, which was expressed as depth in millimeters.

Surface runoff measurement

To evaluate the effect of the tillage system on water loss through surface runoff during the growing seasons, a 3 m 3 m plot was identified and installed in each treatment plot, surrounded by earth embankments. A PVC pipe leading from this identified plot was connected as a supply runoff line to an excavated pit (2.5x2.5x1 m) lined with plastic sheet to prevent water seepage. The pit was protected with 30-cm earth embankments. After each rain storm, the runoff water collected from the pit was measured. Then, the runoff water volume for each rain storm was calculated as follows (Yousif 2011):

Net runoff volume = measured runoff volume – volume of direct rainwater falling into the pit (liters) ------------------------------------- (1)

The volume of direct rainfall = record of rain gauge divided by the area of collecting pit -------------- (2)

Percent soil moisture content determination:

Soil samples were randomly collected from three depths, (0-15 cm, 15-30 cm and 30-45 cm) at three locations per plot using an auger for gravimetric soil moisture determination.

The soil samples were weighed fresh; oven- dried at 105°C for 24 h, reweighed, and gravimetric moisture content was calculated by expressing the percentage of moisture on a dry mass basis (Michael, 1978):

$$\text{Soil moisture content\%} = \frac{\text{Mass of moist sample – Mass of oven dry sample}}{\text{Mass of oven dry sample}} \times 100 \text{ -------------------- (3)}$$

Plant parameters:

The effects of the tillage system treatments on crop performance were evaluated by measuring the following parameters:

1. Plant height(cm)
2. Hundred (100) seed grain weights
3. Grain yield (kg/ha)
4. Fodder yield (kg/ha)

Crop Husbandry Practices:

The local sorghum late mature (Wad Ahmed) was selected as the indicator crop. It was sown at a rate of 4–5 seeds per hole in rows 80 cm apart with an intra-row spacing of 20 cm. Plants were thinned to 1-2 plants per hole after 2 weeks of germination. Sowing was performed manually using hand tools locally known as Gerraya.

Results and Discussion

Rainfall:

The rainfall data recorded at the watershed site (season 2017-2018) and (season 2018-2019) is shown in Figures 1 and 2, respectively. The measured rainfall amounts were 685 mm and 784 mm for two consecutive seasons. The highest amount was recorded in August for the two seasons. It appears that figure 2 has a better and normal rainfall distribution than figure 1. Both seasons can be considered normal seasonal records. This result is consistent with the findings of Salih et al. (2017) and Hermance (2020)

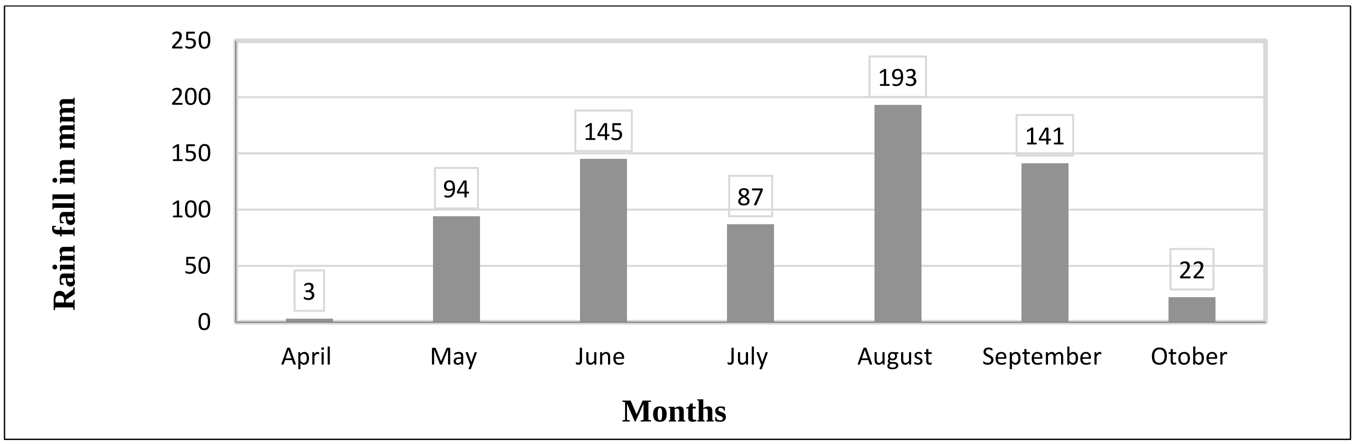

Figure 1: Rainfall (mm) for Watershed recorded season (2017/2018)

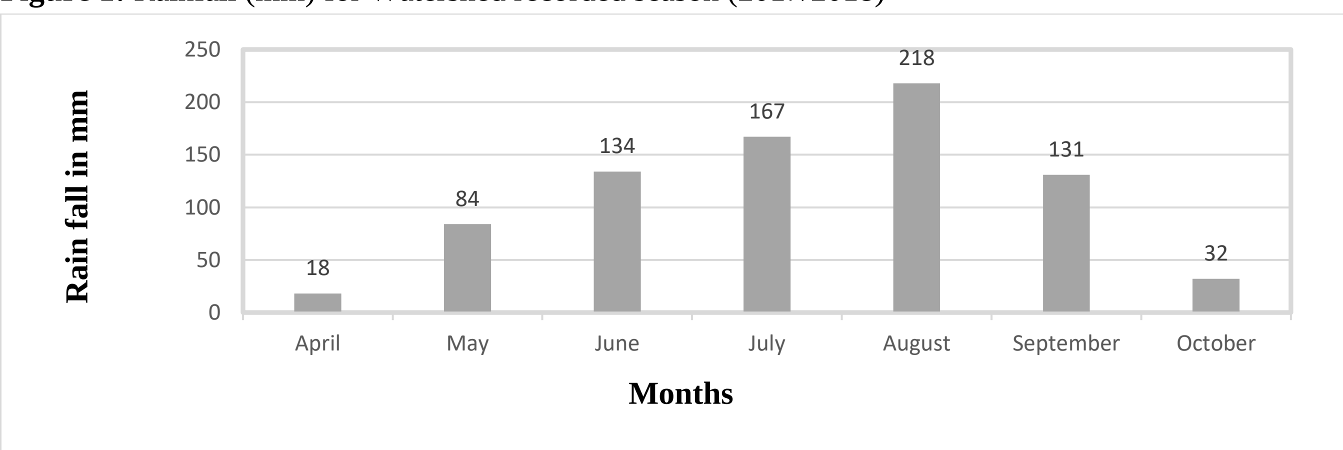

Figure 2: Rainfall (mm) for Watershed recorded season (2018/2019)

Effects of Tillage treatments on Runoff:

During the 2017/18 season, three rainfall events were recorded for which runoff was measured, as shown in Table 1. The conservation tillage treatment (ZT) produced the highest runoff in all measured events compared with the other two treatments; contour tillage (CT) produced the lowest runoff. The analysis of results indicated that for the catchment, the runoff presented about 70 %, 69 %, and 59 % of 51 mm, 21 mm, and 71 mm, respectively. Similarly, in the first season, three levels were recorded during which runoff was measured, as shown in the table 2. The conservation tillage (ZT) treatment resulted in the highest runoff in all measured events compared with the other two treatments. Contour tillage (WLD) resulted in the recorded lowest runoff. There is a positive correlation between the rainfall characteristic and the volume of surface runoff. This result agreed with Elamin. et al. (2019); Singh et al; (2023); Descroix.et al (2001) reported that was high linear correlations were found between erosion rates and runoff coefficients. An et al (2020) fined that the rainfall intensity significantly affected the loss of aggregate, which was due to that erosion process and.

Table 1: Effects of tillage treatments on surface run off (m^3/ha) Season (2017/2018)

Tillage treatments	Date: 28-8-2017 Rainfall: 51 mm	Date: 29-8-2017 Rainfall :21 mm	Date :1-9-2017 Rainfall :71 mm
	Runoff m^3/ha	Runoff m^3/ha	Runoff m^3/ha
Contour tillage (CT)	409.9	129.7	328.7
Conservation tillage (ZT)	470.6	172.7	476.9
Wide-level disc traditional framer practice control (WLD)	220.7	134.2	459.1
Mean	367.1	145.5	421.5

Table 2: Effects of tillage treatments on surface run off (m^3/ha) Season (2018/2019)

Tillage treatments	Date: 30-7-2018 Rainfall: 51 mm	Date: 23 -8-2018 Rainfall: 24.1 mm	Date: 10 -9-2018 Rainfall: 42 mm
	Runoff m^3/ha	Runoff m^3/ha	Runoff m^3/ha
Contour tillage (CT)	218.1	32.2	128.7
Conservation tillage (ZT)	247.9	49.75	276.9
Wide-level disc traditional framer practice–control (WLD)	248.73	61.20	259.1
Mean	238.2	47.71	221.5

Effects of tillage treatments on Soil moisture content:

Table 3 shows that the results of soil moisture content in the first season showed no significant differences between the tillage treatments; however, conservation (ZT) conserved more water than the other treatments. In the second season, the results show significant differences between the tillage treatments: contour tillage treatment (CT) recorded a higher percentage of soil moisture content on average of 33.7%, while conservation tillage (ZT) recorded 29.2% on average the least value of moisture content 28.4 obtained by Wide level Disc control (WLD) record. The results obtained agreed with Modiba et al. (2024), who reported that the mean values of soil moisture content (SMC) are affected by tillage and soil depth; tillage significantly impacted SMC. Gondal et al. (2021) concluded that contour tillage (CT) is effective in increasing crop yields due to improved soil properties and increased soil moisture.

Table 3: Effects of tillage treatments on soil moisture content (%) Season (2017/2018)

Tillage treatments	Germination stage			Development stage			At harvesting		
	0-15 cm	15- 30 cm	30- 45 cm	0-15 cm	15- 30 cm	30- 45 cm	0-15 cm	15- 30 cm	30- 45 cm
Contour tillage (CT)	21.1	24.4	19.3	29.3	26.5	27.6	15.4	20.8	17.9
Conservation tillage (ZT)	26.1	30.1	28.4	30.8	30.7	29.1	15.8	18.4	20.9
Wide-level disc traditional framer practice–control (WLD)	26.6	27.5	25.5	30.1	28.9	29.7	18.3	19.7	19.8
Mean	24.6	27.3	24.4	30.1	28.7	28.8	16.5	19.6	19.5
Cv	15.7	7.9	7.8	4.1	9.5	1.6	11.2	5.4	10.0
SE+	2.22	1.24	1.10	0.71	1.58	0.27	1.07	0.61	1.13

Table 4: Effects of tillage treatments on soil moisture content (%) Season (2018/2019)

Tillage treatments	Germination stage			Development stage			At harvesting		
	0-15 cm	15- 30 cm	30- 45 cm	0-15 cm	15- 30 cm	30- 45 cm	0-15 cm	15- 30 cm	30- 45 cm
Contour tillage (CT)	39.9a	34.2a	26.4a	42.5a	34.5a	30.1a	39.7a	33.3a	23.2a
Conservation tillage (ZT)	33.6c	29.3b	22.7ab	39.6b	33.6b	25.0b	35.5b	24.9b	18.6a
Wide-level disc traditional framer practice control (WLD)	36.90b	22.8b	21.4b	37.4b	31.2b	26.2ab	35.1b	24.2b	20.5a
Mean	36.8	30.4	23.5	39.8	33.1	27.1	36.6	27.5	20.8
Cv	5.8	11.1	17.1	13.2	9.6	14.1	7.9	6.1	30.5
SE+	0.88	1.4	1.6	2.2	1.3	1.6	1.2	0.68	2.84

4.1 Effects of tillage treatments on sorghum yield and yield components

Tables 5 and 6 reveal the effect of tillage treatments on sorghum yield and yield component, in the first season, Contour tillage (CT) and conservation tillage (ZT) interventions resulted in significantly higher over the Wide level Disc (WLD) practice for yield. Contour tillage (CT) out-yielding farmer practices by 187% and 130% for grain and Fodder yields, respectively (Table 5). In the second season, contour tillage (CT) resulted in significantly higher Plant height, 1000 seed, and grain yield over the Wide level Disc (WLD) practice, whereas no significant differences were detected between contour (CT) tillage and conservation tillage (ZT). However, wide-level Disc (WLD) intervention resulted in significantly higher over conservation (ZT) tillage and Contour tillage (CT) for the number of plants and fodder weight (table 6). The results agree with those of Ayman, et al (2021), LI. (2015), and Gondal et al (2021), who found contour tillage (CT) to be effective in increasing crop yields due to improved soil properties and increased soil moisture.

Table 5: Effects of tillage treatments on Sorghum yield and yield component Season (2017/2018)

Tillage treatments	Plant height (cm)	No of plant /m²	1000 seed wt. (g)	Fodder wt. (t/ha)	Seed yield (kg/ha)
Contour tillage (CT)	131.0	6.7	26.1	5.68 a	3213.33 a
Conservation tillage (ZT)	130.6	5.6	26.5	4.15 ab	2426.67 ab
Wide-level disc traditional framer practice control (WLD)	116.3	8.3	25.9	2.47 b	1120.00 b
Mean	126.0	6.8	26.1	4097.78	2253.33
CV	10.3	21.7	4.0	28.2	37.8
SE+	7.48	0.86	0.59	665.91	491.34

Table 6: Effects of tillage treatments on Sorghum yield and yield component Season (2018/2019)

Tillage treatments	Plant height (cm)	No of plant /m²	1000 seed wt. (g)	Fodder wt. (t/ha)	Seed yield (kg/ha)
Contour tillage (CT)	125.0 a	9.8 b	39.3 a	3.1 b	1578.23a
Conservation tillage (ZT)	127.0 a	10.6 b	37.0 b	3.5 a	1350.98b
Wide-level disc traditional framer practice control (WLD)	121.9b	11.2 a	34.8 c	3.6 a	1225.37c
Mean	124.0	10.5	37.0	3.4	1394.32
CV	1.23	4.1	3.0	6.0	5.03
SE+	063	0.18	0.04	0.05	28.6

Conclusions

- The Doka watershed in the southern Gadaref region is characterized at a high rate of rainfall from May to September.
- Contour tillage (CT) practices produced low surface water runoff, enhanced the conservation of soil moisture, and gave high yields, whereas traditional farmer practices (WLD) by wide level disc resulted in high plant populations and low yields.

Recommendations:

Contour tillage (CT) is recommended as an appropriate technique under such environmental and soil conditions. Further study along similar lines are highly recommended.

References

Balasubramanian A. Soil Erosion- Causes and Effects, Center for Advanced Studies in Earth Science, University of Mysore, Mysore, Technical Report February 2017, DOI: 10.13140/RG.2.2.26247.39841.

Abubakr A.M. Saliha,d, Nadir Ahmed Elagibb, Michael Tjernströma,d and Qiong Zhang 2017, Characterization of the Sahelian-Sudan rainfall based on observations and regional climate models, Atmospheric Research, Volume 202, 1 April 2018, Pages 205-218.

Ahn, P.M., Hintze, B., 1990. No tillage, minimum tillage, and its influence on soil properties. In: Organic-matter Management and Tillage in Humid and Sub-humid Africa. pp. 341-349. IBSRAM Proceedings (No. 10. Bangkok: IBSRAM.

Ahuja, L.R., Fiedler, F., Dunn, G., Benjamin, J., Garrison, A., 1998. Changes in soil water retention curves due to tillage and natural reconsolidation. Soil Sci. Soc. Am. J. 62 (5), 1228–1233.

J. An, Y. Zhang: & Wang, Y. Rainstorm patterns affect the size distribution of soil aggregates in eroded sediment within contour ridge systems. J Soils Sediments 20, 2192–2206 (2020). https://doi.org/10.1007/s11368-019-02561-7.

Ayman Hassan Suliman Khalil1, Amir Bakheit Saeed and Moayad Mohamed Balel, 2021, Effect of Some Conservation Tillage Practices on Growth and Yield Attributes of Rainfed Sorghum (Sorghum bicolor (L.) Moench) At Alfula, West Kordofan State, Sudan. Journal of Agricultural Science and Engineering Innovation (JASEI), U.S. ISSN 2694-4812, Vol. 2, No. 1, 2021, DOI: http://doi.org/10.5281/zenodo.6419710.

Baumhardt, R., Schwartz, R., Scanlon, B., Reedy, R., Marek, G., 2017. Long-term conventional and no-tillage effects on field hydrology and yields of a dryland crop rotation. Soil Sci. Soc. Am. J. 81 (1), 200–209.

Capowiez, Y., Cadoux, S., Bouchant, P., Ruy, S., Roger-Estrade, J., Richard, G., Boizard, H., 2009. Effects of tillage type and cropping system on earthworm communities, macroporosity, and water infiltration. Soil Tiller Res. 105 (2), 209–216.

Elwaleed M. Elamin and Mekki A. Omer. Effect of Some Tillage Systems on Surface Run off and Soil Erosion in Northern Gedarif Area, Sudan, 8 International Conference on Water Resources and Arid Environments (ICWRAE 8): 502-509, 22-24 January 2019, Riyadh, Saudi Arabia.

FAO (1976) Report of an Expert Consultation held in Rome 22-26 November soil bulletin no. 33 FAO, Rome.

FAO, 1976. Watershed Development: With Special Reference to Soil and Water Conservation. FAO Soils Bull. 44. FAO, Rome.

Gondal, A. H., Zafar, H., Yousaf, H., Farooq, Q., Bisma Imran Ch, Toor, M. D., Tahir, M. S., Amin, M., Tariq, M., Parveen, A., Usama, M., & Saleem, S. (2021). Impacts of Tillage Technologies on Soil, Plants, Environment, and Its Management: A Short Communication, Ind. J. Pure App. Biosci. 9(3), 76-83. doi: http://dx.doi.org/10.18782/2582-2845.8682.

Green, J.K., Seneviratne, S.I., Berg, A.M., Findell, K.L., Hagemann, S., Lawrence, D.M., Gentine, P., 2019. The influence of soil moisture on long-term terrestrial carbon uptake. Nature 565 (7740), 476–479.

Hongwen L, Jin HE, Huanwen GAO, 2015, Ying CHEN, Zhiqiang ZHANG, The effect of conservation tillage on crop yield in China, Front. Agric. Sci. Eng. 2015, 2(2): 179–185DOI: 10.15302/J-FASE-2015058.

John F. Hermance, Historical Variability of Rainfall in the African East Sahel of Sudan Implications for Development, Springer Briefs in Earth Sciences, ISSN 2191-5369, ISBN 978-3-319-00574-4, DOI 10.1007/978-3-319-00575-1.

Kahlon, M.S., Lal, R., Ann-Varughese M. (2013). Twenty-two years of tillage and mulching impacts on soil physical characteristics and carbon sequestration in Central Ohio. Soil Tiller Res. 126, 151–158.

Khurshid, K., Iqbal, M., Arif, M.S. and Nawaz,A. (2006). Effects of tillage and mulching on soil physical properties and growth maize. International Journal of Agriculture and Biology, 8(5), 593-596

L Descroix. D. Viramontes, M Vauclin,J.L Gonzalez Barrios, M Esteves. 2001, Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico), CATENA. Volume 43, Issue 2, 5 March 2001, Pages 115-135, https://doi.org/10.1016/S0341-8162(00)00124-7.

M. Shahzad et al. Weed, .(2016). spectrum in different wheat-based cropping systems under conservation and conventional tillage practices in Punjab, Pakistan. Soil Till. Res.

Machado, S., Pritchett, L., Petrie, S., 2015. No-tillage cropping systems replace traditional summer fallow in north-central Oregon. Agron. J. 107 (5), 1863–1877.

Michael, A. M. (1978). Irrigation: theory and practices (1st ed). vikas publishing house PVT Ltd, New Delhi, PP 285-472.

Ministry of Agriculture, Natural and Animal Resources and Irrigation, Bank of Sudan, Gadarif branch, and the Ministry of Agriculture, Natural and Animal Resources and Irrigation, Gadarif state (2000).

Mitchell, J.P., Shrestha, A., Mathesius, K., Scow, K.M., Southard, R.J., Haney, R.L., Schmidt, R., Munk, D.S., Horwath, W.R., 2017. Cover cropping and no-tillage systems improve soil health under arid irrigated cropping systems in California’s San Joaquin Valley, USA. Soil Tilling Res. 165, 325–335.

Modiba, M.M.; Ocansey, C.M.; Ibrahim, H.T.M.; Birkás, M.; Dekemati, I.; Simon, B. Assessing the Impact of Tillage Methods on Soil Moisture Content and Crop Yield in Hungary. Agronomy 2024, 14, 1606. https://doi.org/10.3390/ agronomy14081606.

P. Tarolli et al. High-resolution morphologic characterization of conservation agriculture, Catena (2019), 172, January 2019, 846-856.

Roper, M., Ward, P., Keulen, A., Hill, J., 2013. Under no-tillage and stubble retention conditions, soil water content and crop growth are poorly related to soil repellency. Soil Tiller Res. 126, 143–150.

Singh, D.; Mishra, A.K.; Patra, S.; Dwivedi, A.K.; Ojha, C.S.P.; Singh, V.P.; Mariappan, S.; Babu, S.; Singh, N.; Yadav, D.; et al. Effects of Long-Term Tillage Practices on Runoff and Soil Erosion in Sloping Croplands of Himalaya, India. Sustainability 2023, 15, 8285. https://doi.org/10.3390/su15108285.

Tapia-Vargas, M., Tiscare~no-L_opez, M., Stone, J.J., Oropeza-Mota, J.L., Vel_azquez- Valle, M., 2001. Tillage system effects on runoff and sediment yield in hillslopeagriculture. Field Crop. Res. 69 (2), 173–182.

Van de Giesen, N., Stomph, T.J., Ajayi, A.E., Bagayoko, F., 2011. Scale effects of Hortonian surface runoff on agricultural slopes in West Africa: field data and models. Agric. Ecosyst. Environ. 142 (1-2), 95–101.

Wani, S P and Ramakrishna, Y. S. (2005) Sustainable Management of Rainwater through Integrated Watershed Approach for Improved Rural Livelihoods. In: Watershed Management Challenges: Improving Productivity, Resources and Livelihoods. International Water Management Institute, Colombo, Sri Lanka, pp. 39-60. ISBN 92-9090-611: 92-9090-611 1 Item availability is restricted.

Yousif, E. M. E (2011). Effect of Some Tillage Systems on Surface Runoff and Soil Erosion in Northern Gadarif Area, Sudan. Ph. D. thesis, Faculty of Sudan Academic sciences.