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INTERACTIVE EFFECTS OF STREAM SIZES AND FURROW GEOMETRY ON FURROW IRRIGATION EROSION, GROWTH AND YIELD OF MAIZE IN SAMARU-ZARIA NORTHERN NIGERIA

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Abstract

Erroneous choices of furrow irrigation characteristics trigger soil erosion with several negative impacts. Soil erosion and sediment yield in furrow irrigation has not been fully evaluated in Samaru-Zaria. This study sought to establish the interactive effects of irrigation stream sizes (2.5, 1.5, and 0.5 l/s); furrow lengths (90 and 45 m); and furrow widths (0.75 and 0.9 m) randomized in a split-plot design on soil erosion, growth, and yield of maize (*Zea mays L.*). The 90- and 4-m long furrows were herein referred to as long and short furrows respectively, while the 0.75- and 0.9-wide furrows were termed narrow and wide furrows for convenience sake. The field experiment involved irrigating maize on the normal straight furrow irrigation method on a sandy loam soil in the Irrigation Research Farm of Institute for Agricultural Research (I.A.R), Samaru-Zaria, in 2009/2010 and 2010/2011 dry irrigation seasons. Maize plants irrigated at 2.5 l/s on long narrow furrows were most stunted (118.396 m) while irrigating at 1.5 l/s in long wide furrows produced tallest maize plants (169.034 m). Irrigating at 2.5 l/s in long narrow furrows delayed days to 50 % tasseling (77.632 days) and days to 50 % plant maturity (79.125 days). Highest average sediment concentration (41.697 g/l) and runoff volume (147.861 ltr) were recorded in short narrow furrows irrigated at 2.5 l/s. The long narrow furrows irrigated at 2.5 l/s produced largest soil erosion (0.603 t/ha). Best grain yield (5.19 t/ha) was achieved in long wide furrows irrigated at 1.5 l/s. The severity of soil erosion and its impact on crop production were greater in long narrow furrow irrigated at 2.5 l/s. Irrigation at 1.5 l/s in long wide furrows trimmed down soil erosion and better maize growth and yields. Furrow irrigation should be designed and operated professionally to avert ecological deterioration, and sustain soil's quality and crop productivity.

Keywords: Furrow stream sizes, Furrow geometry, Furrow irrigation, Soil conservation, Performance of maize, Sandy loam soil, Northern Nigeria.

1. Introduction

Globally, irrigation has taken central position in insuring against food insecurity, and is a major contributor in establishing a successful commercial agriculture. About 90% of irrigated farms are under surface irrigation, mainly, furrow irrigation (Creviosier *et al*., 2008). Furrow irrigation is practiced on about 60% of irrigated lands in Nigeria, and has been acknowledged as the most conventionally practiced surface irrigation method in northern Nigeria, and particularly in Samaru-Zaria (Dibal *et al*., 2014). The practice and magnitude of furrow irrigation in upholding food production and socio-economic wellbeing of the people in Samaru-Zaria cannot be overemphasized (Dibal *et al*., 2014) Furrow irrigation is most recommended for growing row crops on medium-to-heavy textured soils due to its simplicity and low capital obligation. When properly managed, it is effective in minimizing water application, cuts irrigation costs, reduces chemical leaching, and produces higher crop yields

(Creviosier *et al*., 2008). However, furrow irrigation method has the drawback of occasioning soil erosion in the irrigated farms thereby posing a great threat to sustainability of surface-irrigated agricultural productivity and to clean water. Soil erosion impacts negatively both on the environment and on crop productivity and it translates directly to depression of farmers' socio-economic status (Korkmaz and Avci, 2012) Khamidov *et al*. (2009) reported furrow irrigation-induced erosion (FIIE) has destroyed more than 660 thousand hectares of agricultural land in Uzbekistan. Apparently, FIIE could considerably be of high economic repercussion to farmers and a nation.

The occurrence, and severity of soil erosion is never a function of individual factor, but rather a combined or interactive effects of soil and irrigation characteristics such as field slope and length, soil texture, furrow inflow rate, irrigation duration, furrow width, tillage practices; current and previous crops grown; soil water content; and soil and water chemistry and the farmers' irrigation skill (Mofoke *et al*., 2003). But due to the erratic spatio-temporal distribution of rainfall in Nigeria, irrigation continued to be an indispensable tool for the sustenance farming predominantly in the arid and semi-arid regions (Dibal *et al*., 2014). Prudent selection of stream size and furrow geometry throughout the phonological stages of crop growth thus occupies central position in irrigation planning (Dibal *et al*., 2014).

Ramezani *et al*. (2011) reported that growth and yield of maize was significantly influenced by row width and length. Furrow irrigation instream sizemay vary from 0.5 to 2.5 l/s (Dibal, *et al*., 2014).The longest furrow that permits the application of the accurate amount of water to the crops while circumventing the damage of ecosystem is considered optimum (Sojka *et al*., 2008). Furrow lengths commonly vary between 200 and 400 m, and are a function of soil type. Shorter furrow lengths are encouraged on light textured soils (Khamidov *et al*., 2009). Equally, it is crucial to decide on appropriate furrow width that will ensure proper spreading of water to the sides into the furrow ridges and root zone of the crop to replenish the soil moisture uniformly (Khamidov *et al*., 2009).While Trout (1996) worked on 256-m long furrows on silt loam soil, Carrol *et al*. (1995) studied soil erosion in 50-m long furrows on sandy loam soil. They both concluded that furrow lengths and widths are the major variables in the hydraulic radius of the furrows and they hold enormous implication in furrow irrigation design and erosion control.

Successful growth and yield of different crops depends on quite a number of factors in addition to ecosystem management (Naor *et al*., 1999; Mojid *et al*., 2012). Exploring the circumstances and best management practices under which crops would optimally perform is very imperative. Naor *et al*. (1999) studied the interactions of water stresses and crop levels on the performance of Nectarine water potentials. While in their efforts to gain understanding of the respective key roles of some variables in enhancing soil productivity under the rainfed ecosystem of sub-humid region in eastern India, Sarkar and Singh (2007) brought forth information on interactive effects of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley. In same vein, Mojid *et al*. (2012) established the interaction effects of irrigation by municipal wastewater and inorganic fertilizers on wheat cultivation in Bangladesh.

In Nigeria, considerable resources have been expended by researchers geared toward achieving environmentally friendly surface irrigation methods that would sustain the productive capacities of lands. Yet, knowledge gap that still exist is the dearth of information on the interactive effects of furrow irrigation stream sizes, furrow lengths and furrows widths on FIIE and crop productivity to inform decision making on furrow irrigation. This research work examined the interactive effects of different inflow rates, furrow lengths, and furrow widths on growth and yield of quality protein Maize (QPM), and on soil erosion in Samaru-Zaria, a semi-arid agro-ecological environment.

2. Material and Methods

2.1 Study Area

The Field experiments were conducted during the 2009/2010 and 2010/2011 irrigation seasons at the Irrigation Research Field of the Institute for Agricultural Research (IAR) farm, Samaru Zaria, along the Zaria-Sokoto road ($11^o1´$N, $7^o38´$E, on the altitude of 686 m above mean sea level). Samaru Zaria is situated within the Northern Guinea savanna zone of Nigeria. It receives average 1,100 mm of rainfall spread between the months of May and October with the soils of the same study area (Igbadun and Idriss, 2007). The soil of the experimental site was classified as luvisols (Igbadun and Idriss, 2007). This belongs to sandy loam textural class on the USDA textural triangle with a mean bulk density of 1.6 gcm^{-3}. The mean values of organic carbon, *p*H, and cation exchange capacity of the soil were 1.18, 5.5, and 7.45; implying that the soil is poor in organic content and slightly acidic in nature. (Igbadun and Idriss, 2007) There was no rainfall recorded during the studies.

2.2 Experimental Treatments and Field Layout

The experimental factors studied were stream size Q, furrow length L, and furrow widths W at 3, 2 and, 2 levels respectively. The stream sizes were 2.5, 1.5, and 0.5 l/s; furrow lengths were 90 and 45 m; and furrow widths were 0.75 and 0.9 m. The combination of the stream sizes, furrow length and furrow widths resulted in to twelve (12) different treatments that were imposed on the field (Table 2). The layout of the experiment was a randomized complete block laid in a split plot design with four replications in both 2009/2010 (trial 1) and 2010/2011 (trial 2) seasons. The stream sizes were placed in the main plots, while furrow lengths and furrow widths were studied in the sub-plots. In both seasons, each replication comprised of three plots, and each experimental plot had three and two ridges in trials 1 and 2 respectively. A ridge was used to separate plots while two ridges to separated two adjacent replications. A total of 0.36 ha and 0.2 ha were used in trials 1 and 2, respectively The experimental field was ploughed, harrowed, and ridged at 0.75 m spacing. Plots were marked out and treatments allocated in accordance with the randomization. Short (45 m long) and long furrows (90 m long); and narrow (0.75 m wide) and wide (0.9 m wide) furrows were marked out and adjusted accordingly manually

2.3 Data collection

2.3.1 Irrigation/Erosion related data

Prior to commencement of irrigations, water-sediment collection stations were established 5 m before the end of each furrow by placing a 30-cm wooden peg. Flow of water in the furrows were measured using a cutthroat flume installed 5 m from entry at the upstream of each of the furrows, and at the tail end of the furrows for the measurement of outflows. Water flowing out of the furrows was measured as runoff. One-liter of water-sediment samples were collected at each of the established measurement points for determination of sediment concentrations. These samples were filtered into pre-weighed metal containers; the collected residues were oven-dried at 105^{o}C over 24-hour period and re-weighed in laboratory. The sediment concentrations (g/l) that were calculated from the dried residues and the runoff volumes were used to calculate soil erosion per furrow. Runoff volume was calculated as the product of the runoff discharge (l/s) (from the downstream flumes) and duration of runoff discharge. Soil erosion at the end of the furrows was calculated as the product of the sediment concentrations and runoff volumes divided by the wetted area. The wetted areas were calculated as the product of the top widths of flow of water and the lengths of the furrows (Carter, 1993)

2.3.2 Determination of Maize Growth, and Yield Parameters

Growth parameters

Plant height (PH) was taken from a sample of 12 randomly selected maize plants tagged within each plot. A 2.5-m graduated wooden plank was used for measuring the height from the ground level to the top-most leaf or tassel. Days to 50 % tasselling was recorded from the date of planting till when 50 % plants in each plot produced tassels. Days to maturity (DM) was also recorded from the date of planting till 75 % of the plants were matured. A plant was assumed to be physiologically matured when 75 percent of the glumes of the primary spike turned yellow.

Yield and yield parameters

The numbers of Cobs per plant (CPP) was obtained by visual counting of Cobs on the 12 randomly selected plants from each plot, and their average worked out. The grains were shelled from each subplot and weighed to obtain the grain yield (GrY) for that plot and were then converted in to tones per hectare (tha-^{1}) basis.

2.4 Data Analysis

All data collected related to soil erosion, and growth and yield of Maize were analyzed with the General Linear Model (GLM) procedure using the SAS package (SAS institute, 2008). The combined analysis was used to analyze the results for the two trials with split-plot arrangement. Treatment means were compared by using the Duncan Multiple Range Test (DMRT)'s Least Significant Difference (LSD) test at the 0.05 and 0.01 probability levels.

3. Results and Discussion

Irrigating with 2.5 l/s in short furrows with width of 0.75-m resulted in to significantly highest average sediment concentration (ASC) of 41.697 g/ltr (Table 1). It was followed by the ASC of 39.908g/ltr that came up due to irrigating with 1.5 l/s in the same types of furrows. There was about 10 % difference between the ASC generated in the short furrows relative to those generated in long furrow that were irrigated with 2.5 l/s. The least value of ASC was a product of irrigating with 0.5 l/s in short and wide furrows. Table 1 shows the sediment concentration that had been generated in narrow furrows compared to that of the wide furrows, but the difference between the total sediments generated in long and short furrows was not significant. This implies that the furrow length alone does not significantly influence sediment generation during furrow irrigation. Similar trend was observed with run off volume (R.O.V.) where the largest ROV (147.861 ltr) was found in narrow, short furrows irrigated with 2.5 l/s, and the least was in wide, short furrows irrigated at 0.5 l/s.

The most severe soil erosion (0.603 t/ha) occurred in long narrow furrows that were irrigated at 2.5 l/s (Table 1).This was followed by the 0.575 t/ha that was eroded in short narrow furrows irrigated at 2.5 l/s. The least soil erosion was found in the short wide furrows that were irrigated at 0.5 l/s. Irrespective of furrow geometry, irrigating at 2.5 l/s resulted into elevated soil erosion, and least erosion corresponded to irrigation at 0.5 l/s.

Table 1: Interactive Effects of Furrow Stream Sizes and Furrow Geometry on Average Sediment Concentration, Runoff Volume and Soil Erosion

	Long furrows		Short furrows	
Stream sizes (l/s)	Narrow furrows	Wide Furrows	Narrow furrows	Wide furrows
Average sediment concentration (g/ltr)				
2.5	37.611^{cd}	31.196^{ef}	41.697^{a}	34.154^{e}
1.5	37.988^{c}	31.013^{f}	39.908^{b}	23.140^{j}
0.5	30.987^{g}	29.511^{h}	36.944^{d}	26.969^{j}
SE	*0.763*			
Runoff volume (ltr)				
2.5	126.223^{e}	114.867^{fg}	147.861^{a}	132.483^{c}
1.5	129.184^{d}	102.874^{ij}	135.486^{b}	117.185^{f}
0.5	107.336^{h}	105.221^{i}	116.594^{g}	93.287^{j}
SE	*3.250*			
Soil erosion (t/ha)				
2.5	0.603^{a}	0.482^{d}	0.575^{b}	0.380^{fg}
1.5	0.542^{c}	0.511^{cd}	0.399^{f}	0.358^{h}
0.5	0.401^{e}	0.303^{j}	0.337^{i}	0.294^{k}
SE	*0.031*			

Means values followed by the same letter within the same column are not significantly different at 5% level of significance using DMRT

This put forward that the 2.5 l/s was large enough to cause severe soil erosion, even though larger stream sizes were reported to be convenient on silty loam soils (Trout, 1996). Similarly, Cater (1993) found that a stream size of 2.0 l/s yielded soil erosion of 821.4 kg/m^2 and ROV of 504 l on sandy loam soil compared to erosion of 87.2 kg/m^2 and 608.4 l runoff on a silty clay soil in only one hour furrow irrigation. Stream size was reported be exponentially related to soil detachment, and is therefore an important erosion factor in furrow irrigation. It should only be large enough to supply and convey irrigation water through the entire furrow length (Dibal *et al.*, 2014)

Table 2 shows that the tallest plants (169.034 m) were found in long wide furrows that were irrigated at 1.5 l/s, while the irrigating at 0.5 l/s led to shortest plants. Irrigating at 2.5 l/s had generally brought about taller plants relative to the other two stream sizes tested irrespective of the furrow geometry. Irrigating in long narrow furrows had generally translated to reduced plant’s growth. For instance, maize plants irrigated at 2.5 l/s on short wide furrows were 18.5 % taller than their counter parts grown on long narrow furrows. This could be attributed to higher instances of runoff and soil erosion in narrow furrows that must have gone away with the plants' nutrients, and hence the drop in their growth. Soil drifting is a fertility-depleting process that can lead to poor crop growth and yield reductions. Wenyi *et al*., (2011) had similarly reported the reciprocal relationship between soil nutrients and plants' growth. The research of Buah *et al*. (2009) demonstrated the importance of soil nutrient in crop production while Panagos *et al*. (2015) pointed out that land management practices may alter soil and land cover characteristics, which in turn, influence the magnitude of soil erosion and its outcome on crops.

The numbers of Days to 50 %Tasseling and Maturity took similar trend in which maize plants grown on narrow long furrows irrigated at 2.5 l/s had the longest (46.134) and (79.125) days to 50 % Tasseling and maturity respectively (Table 2). Plants grown on short wide furrows matured earliest (75.364 days). This result could also attributed to the loss of nutrients as a consequence of runoff and soil erosion that were relatively severer in narrow furrows. It was observed from the Table 2 that Maize plants grown 2.5 l/s stream size on short narrow furrow matured lately.

Table 2: Interactive Effects of Furrow Stream Sizes and Furrow Geometry on some growth parameters of Maize

	Long Furrows		Short Furrows	
Stream sizes (l/s)	Narrow furrow	Wide Furrow	Narrow furrow	Wide Furrow
	Plants' Heights (cm)			
2.5	118.396g	148.898d	160.035b	145.521d
1.5	124.745f	169.034a	157.170bc	136.415e
0.5	148.492d	148.962d	145.842d	158.579bc
SE	*1.797*			
Days to 50 % Tasseling				
2.5	46.134a	37.232ef	46.109bc	42.634d
1.5	44.207bc	44.663b	43.446c	44.410bc
0.5	36.497f	40.808e	4035.787g	33.453h
SE	0.082			
Days to 50 % Maturity				
2.5	77.632c	76.790c	79.125a	77.012c
1.5	76.728cd	72.617h	78.260b	75.364g
0.5	76.256ed	76.654d	75.859f	77.165bc
SE	0.344			

Means values followed by the same letter within the same column are not significantly different at 5% level of significance using DMRT

Table 3 contains the interactive effects of stream sizes, and furrow geometry on yield parameters of maize. The numbers of cobs per plants (NCPP), cob weight (CWt) and Maize grain yield (GrY) all took similar trend. Irrigating in long wide furrows at 1.5 l/s generally triggered highest CPP (1.954), CWt (289.73g) and GrY (5.19 t/ha) irrespective of the furrow geometry. This GrY (5.19 t/ha) was 24 % larger than the GrY of 3.94 t/ha obtained in long narrow furrow irrigated at 2.5 l/s. This finding is again attributed to the reduced runoff and soil erosion in the wide furrows under the stream size of 1.5 l/s. The least CPP (0.985) and grain yield (3.07 t/ha) were recorded in long narrow furrows irrigated at 0.5 l/s which is similar to the works of Khamidov *et al*. (2009) that reported yield reduction due to erosion during furrow irrigation. This corroborate the close correlation linking maize yield parameters and irrigation stream size (Pandey *et al*., 2000), and with furrow geometry (Dibal *et al*., 2014). The yields reported here could however, be rated adequate, in view of the report that improved maize varieties have the potential to produce 4–6 t/ha of grain (Buah *et al*., 2009).

Table 3: Interactive Effects of Furrow Stream Sizes and Furrow Geometry on some yield parameters of Maize

	Long Furrows		Short Furrows	
Stream sizes (l/s)	Narrow furrow	Wide Furrow	Narrow furrow	Wide Furrow
Numbers of Cobs per plant (NCPP)				
2.5	1.620d	1.814b	0.795k	1.026g
1.5	1.745c	1.954a	1.023h	1.232e
0.5	1.002i	1.113f	0.642k	0.985j
SE	*0.084*			
Cob Weight (CWt) (g)				
2.5	217.55e	261.05b	155.62i	168.224gh
1.5	253.33c	279.73a	251.23cd	244.32d
0.5	135.88j	165.23h	169.28g	202.36f
SE	319.03			
Grain Yield (GrY) (t/ha)				
2.5	4.02f	3.94fg	3.66hi	3.89h
1.5	4.54b	5.19a	4.38c	3.91g
0.5	3.19i	4.08e	3.07j	4.11d
SE				

Means values followed by the same letter within the same column are not significantly different at 5% level of significance using DMRT

4. Conclusion

Furrow irrigation erosion problems are central issues at a local and global scale nowadays. No adequate effort expended in a bid to check it in Nigeria and hence the need for investigating the relationship among furrow irrigation characteristics and soil erosion, and crop production. This study revealed that using 2.5 l/s to irrigate narrow long furrows had translated into severer soil erosion and reduced maize growth and yield. The soil erosion, growth and yield of maize are however not appreciable in furrows irrigated with 0.5 l/s. The 1.5 l/s stream size that resulted into reduced soil erosion and higher maize growth and yield thus emerged optimum. Greater soil erosion and associated decline in maize crop productivity were also realized in narrow short furrows. Evidently, using large stream size of 2.5 l/s and above to irrigate maize is not advisable. Furrows should also be wide enough to reduce erosivity of flowing water stream in the furrows. Furrows should also be long enough to encourage sediment re-distribution along the furrows to minimize runoff and soil loss and their corresponding consequences on crop productivity. This study supported the need for developing and implementing erosion control practices in irrigated farms. Irrigating farmers are also encouraged to be proficient in soil erosion prevention and control in their farms to conserve the soil and increase their agricultural productivity. Engineering measures are also to be incorporated in the design of irrigation to minimize soil erosion and optimize crop production. The results of the study can be used to make tentative recommendations, which can be refined through multi-location testing over a wider area.

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