2014 2nd International Conference on Sustainable Environment and Agriculture
IPCBEE vol. 76 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V76. 2

Farmers Adaptation to Climate Change: An Evaluation of Small-Scale Upland Irrigation in the Sokoto-Rima Basin, Nigeria

William B. Richard Graham+, Vanacius Chinaemerem Ama and Simon Chibuzor Ekwealor

Department of Agricultural and Bio-Environmental Engineering, Waziri Umaru Federal Polytechnic, Birnin Kebbi, Nigeria

Abstract. Climate change is a major problem affecting the sustainability of agricultural production. This study assesses the soil/water quality and water productivity of irrigated dry season upland farms in northwestern Nigeria. The soils were predominantly coarse textured and the fertility indicators (organic-C, Total-N, Available-P and exchangeable bases) all fell below the critical limits reported for soils in the area. Another major concern being the moderate-high levels of ESP. The water quality was however, excellent in all regards. With the exception for one farm which had very low relative water supply, most of the farms indicated very excessive applications of irrigation. The onion farms had high crop water productivity (CWP). While the maize farms had low CWP, which is however consistent with crop production practices within the region.

Keywords: Soil Quality, Water Quality, Water Productivity.

1. Introduction

Water is a precious and at most times, a scarce resource in semi-arid ecosystems [1] and is rarely available at the right place and the right time because of precipitation patterns [2]. Spatial and temporal rainfall variability in the semi-arid parts of northern Nigeria is a major problem affecting the sustainability of agricultural production. This is further exacerbated by evidence of climate change through rainfall decline in recent years (Fig. 1). Under such circumstances, land productivity becomes rather low and conventional schemes designed to improve water supply (e.g. irrigation) are expensive [3]. However, the shallow depth aquifers (most of which are rechargeable) that are scattered throughout northern Nigeria provide possibilities for successful smallholder schemes [4]. Within the study area, most small scale irrigation takes place in the river floodplains or in depressions locally called *Fadama.* The major sources of water for irrigation are shallow tube-wells and the river system itself. However, some innovative farmers within the area have discovered that irrigation is possible on the uplands, the shallow depth aquifers being the source of water (Fig. 2a and Fig. 2b).

The irrigation system shown in Fig. 2a and Fig. 2b though, quite innovative within the context of local conditions tend to result in losses of prodigious amounts of water through runoff, evaporation and seepage. Lack of water control remains a considerable constraint to their ability to engage in high-value crop production, which requires timely and consistent irrigation.

Irrigation projects are prone to degradation with time, mainly through the deterioration in soil and water quality. Therefore, an understanding of the soil and water quality is essential for the sustainability of irrigation systems. Furthermore, improving water productivity, i.e. the physical quantity derived from the use of a given quantity of water, is one important strategy for addressing future water scarcity. The irrigated farms shown in Fig. 2a and Fig. 2b are a recent innovation, however, no systematic effort has been made to ascertain any threats to the sustainability of the system. This project was an attempt in this direction. It was

+ Corresponding author. Tel: +234(8066685208)
E-mail address: grayhomestead@gmail.com

undertaken with the following major objectives: (1) To establish some base-line data on the current soil and water quality status as well as ascertain any potential threat; (2) To evaluate the performance and efficiency of the irrigation systems by quantifying the amount of water used for irrigation and comparing it to water demand; and (3) To identify potential management strategies for the sustainability of the system.

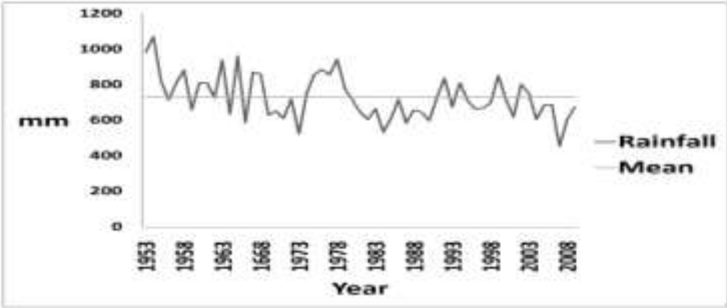

Fig. 1: Long-term rainfall trend in the study area (1953-2009)

Fig. 2 a & b: (A) Small-scale upland irrigation in the study area. At the foreground is the water source; (B) The same farm showing water application

2. Materials and methods

2.1. Location of Study

The study area lies at approximately an altitude of 200m above sea level between Latitudes 12^0 17’ to 12^0 24' N and longitudes 4^0 17’ to 4^0 29' E. The climate consists of a long dry (October to May) and a short wet season (June to September). The mean annual rainfall of 727.6 mm, averaged over the period 1953 to 2009 (Fig. 1) [5], is far exceeded by the potential evapotranspiration of 1770mm [6]. The soils of the area have been classified as Plinthic Acrisols [5]. Geologically, the area overlies the Gwandu Formation of the Sokoto Basin, which constitutes the Nigerian sector of the Iullemeden sedimentary basin centered in Niger Republic.

2.2. Field Studies

The study was carried out during the 2012/13 dry season. After a detailed survey, six irrigated farms were selected from five communities in the study area. The characteristics of the farms are presented in Table 1. Primary data was collected by means of observations and semi-structured questionnaires generally relating to management practices, such as irrigation schedule and crop yield. Meteorological data was collected from the weather station located at WUFEDPOLY, Birnin Kebbi about 15 km west of the sites.

The amount of water used for irrigation was determined by measuring the discharge rate (L s^{-1}) using a container of known volume. This was then multiplied by the irrigation period for each farm. Composite soil samples were collected at four locations at a depth of 0-30 cm from each farm. Triplicate water samples were also collected from the water source at each farm.

Table 1: Characteristics of the studied farms

Location	Farm size (ha)	Years of practice	Crop cultivated	Depth of water table (m).
Dakala-1(Site A)	0.08	8	Onion	42.5
Dakala-2 (Site B)	0.04	1	Maize	11.3
Sabiyel (Site C)	0.12	7	Sweet pepper	18.4
Hiccinga (Site D)	0.64	>10	Onion	13,8
Gulumbe (Site E)	0.14	2	Maize	12.1
Aliero (Site F)	12.5	9	Onion	79.3

2.3. Laboratory Methods

The collected soil samples were air-dried, passed through a 2 mm sieve and analyzed for the following parameters [7]. Particle size by the Hydrometer method. Soil pH in was measured using a pH meter, while Electrical conductivity (Ec) was measured with a conductivity meter. Organic carbon, total nitrogen and available phosphorus were determined by the Walkley-Black, Macro-Kjeldahl Digestion-Distillation and the Bray No-1 methods, respectively The ammonium saturation method was used to determine the cation exchange capacity (CEC). The exchangeable bases were extracted with neutral normal ammonium acetate solution analyzed for calcium as well as magnesium by EDTA titration and potassium as well as sodium by flame photometry. Exchangeable sodium percentage (ESP) was calculated using the formula:

$$ESP = \frac{Na^{+}}{CEC} x100 \tag{1}$$

With respect to water, the total dissolved solids (TDS) was determined by the evaporation and drying method. The pH and Ec_w were read on a pH-meter and conductivity - meter, respectively. Nitrate-nitrogen ($N0_3$-N) PO_4 and Chloride were measured spectrophotometrically after reduction with appropriate solutions. The Ca^{2+} and Mg^{2+} were determined by the EDTA titration method while Na^+ and K^+ were determined by flame photometry [8]. The sodium adsorption ratio (SAR) for water was calculated using the equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \tag{2}$$

Where: Na, Ca and Mg are in meq l^{-1}.

2.4. Water Productivity Assessment

Agricultural performance indicators are used to analyze the output from an agricultural system in relation to the inputs into the system. Relative Water Supply (RWS) is used for comparison of the efficiency of irrigation systems. Actual relative water supply is defined as the supply of irrigation water divided by the demand associated with the crops actually grown, with the cultural practices actually used, and for the actual irrigated area [9]:

$$RWS = \frac{I_s}{ET_c} \tag{3}$$

Where: I_S= supply of irrigation water (cm); and ET_c= evapotranspiration from the crops (cm), otherwise known as consumptive use. ET_c was calculated using the Penman-Montheith method [10].

The crop water productivity (CWP) was expressed by the equation:

$$CWP\left(kg / m^{3}\right) = \left[C \frac{Y}{ET_c}\right] \tag{4}$$

Where: Y is the crop yield (in kg ha^{-1}) and C is the conversion factor (0.10 ha/mm/m^{-3}).

3. Results and Discussion

Table 2 presents the soil quality status of the soils. Soil textures ranged from loamy sand to sandy loam. The fertility indicators all fell below the critical limits of; organic-C (10 g kg^{-}1), total-N (1.5 g kg^{-1}) and available-P (10 mg kg^{-1}) [11], [12]. This is however, with the exception of CEC in which the soils all had high levels. The soils all had very low Ec but moderate to high ESP. Similar results have been obtained in the area [13], [14]

With more than 70% sand separates, the soils are expected to present difficulties in their management. Crops growing on such soils would experience frequent moisture stress. Besides being prone to erosion, such soils invariably do not keep shape and capacity of the irrigation channels which render water losses in transit. Their low nutrients and moisture retention capacities would lead to losses of plant nutrients through leaching. Excessive irrigation water percolating down the profile may raise the groundwater table, therefore, the risk of soil salination/sodification. The moderate to high ESP may result in infiltration problems. However, judicious application of organic matter/crop residues may protect the soil from erosion besides improving its physico-chemical properties.

Table 2: Results of soil physico-chemical analysis (Units: Particle size, ESP in %; OC, TN in g kg^{-1} ; AP in mg Kg^{-1} ; CEC, Na, K, Ca, Mg in Cmol kg^{-1} ; Ec in mS cm^{-1})

Site	Sand	Silt	Clay	pH	OC	AP	TN	Na	K	Ca	Mg	CEC	ESP	Ec
A	74.2	22.0	3.8	7.6	6.5	0.07	0.8	1.9	0.2	0.5	0.95	12.4	15.3	0.10
B	70.3	17.8	11.9	7.2	4.8	0.08	0.9	1.5	1.2	0.7	1.2	15.8	9.5	0.14
C	74.2	19.1	6.8	7.0	3.3	0.07	0.8	1.6	1.6	0.6	1.0	16.2	9.8	0.15
D	72.2	15.2	12.6	6.8	4.8	0.07	0.8	1.7	1.8	0.7	1.1	15.5	11.0	0.18
E	74.2	14.9	10.9	7.3	4.9	0.08	0.8	1.7	1.5	0.6	0.95	15.1	11.2	0.28
F	83.9	11.2	4.8	7.0	6.0	0.09	0.8	0.6	1.8	0.7	1.1	17.3	3.5	0.18
Mean	74.8	16.7	8.5	7.1	5.1	0.08	0.8	1.5	1.4	0.6	1.0	15.4	10.1	171.7
CV	9.28	22.8	44.8	3.9	21.6	10.0	6.3	40.7	43.6	13.3	10	9.8	37.6	35.1

OC = organic-C; AP = Available-P; TN = Total-N; CV = coefficient of variation (%)

Irrigation water quality is presented in Table 3. In contrast to the soils, the water used for irrigation is of excellent quality [15] and poses no potential threat at least for now. These results corroborate results obtained earlier [16]-[18].

There was a very wide variability in RWS values obtained for the farms (Table 4). Irrigation systems with an RWS value of 2.5 or greater indicate that water stress may not be an important factor that would affect irrigation performance [9]. This indicates that water stress would be a problem in Site F. The depth of the water table in Site F (Table 1) could be a contributing factor to the low RWS. However, the results for the other farms (particularly Sites A & B) indicate very excessive water application. This may be a response by the farmers to the coarse soil textures. A very high soil-water infiltration rate may result in more frequent irrigations.

The farms also exhibited a very wide spatial variability in CWP (Table 4) mainly due to variation in different crops and crop yields. The CWP values for the onion farms (A, G and F) were much higher than the other farms. The pepper farm had a moderate value for CWP. Although the CWP for the maize farms seem to be quite low, they fall within the ranges reported from other locations in West Africa [19], [20]. These low CWP values for maize may be attributed in general to low crop yield due to poor crop timing, excessive water application, and poor field crop management.

Table 3: Result of water quality analysis (units: Ec_w in uS cm^{-1}; TDS, Na, K, Ca, Mg, NO3, PO4, Cl in mg L^{-1})

Site	pH	Ec_w	TDS	Na	K	Ca	Mg	SAR	NO_3	PO_4	Cl
A	8.6	300.8	241.0	0.2	0.1	3.2	4.2	0.104	0.9	14.5	0.27
B	7.6	1228.8	983.0	0.7	0.6	3.7	6.1	0.316	1.0	14.2	0.53
C	7.8	601.3	481.0	0.2	0.1	2.9	10.2	0.078	0.8	4.7	0.22
D	8.4	262.4	210.0	0.3	0.1	0.5	2.5	0.245	1.0	8.3	0.24
E	7.8	204.8	164.0	0.2	0.1	0.5	3.0	0.151	0.6	4.3	0.14
F	7.4	236.8	190.0	0.2	0.1	0.8	2.0	0.169	0.6	8.3	0.15
Mean	7.9	472.5	378.2	0.3	0.20	1.93	4.7	0.18	0.83	9.1	0.26
CV	5.6	69.4	84.0	66.7	100	77.1	66.0	50.0	25.3	48.4	53.8

Table 4: Results for water productivity

Site	RWS	CWP (Kg m^{-3})
A	376.6	4.9
B	2428.6	0.29
C	46.8	1.59
D	52.1	2.68
E	54.6	1.13
F	0.48	5.5
Mean	476.5	2.69
SE	374.6	0.86
CV	192.6	78.1

4. Conclusion

The farmers in the area have shown some innovativeness albeit with numerous accompanying problems. This innovativeness must be appreciated due to their minimal education and the fact that they receive little or no extension support from governmental/international agencies. The following conclusions can be drawn from this study:

- The soils of the area have very poor physico-chemical properties. However, this is an inherent characteristic of most upland soils (irrigated or rainfed) in the area.
- The water used for irrigation is of excellent quality at least for now.
- In most cases the farmers do not understand the potential threat associated with excess extractions of groundwater, perhaps due to its present abundance.
- The CWP reported in this study is similar to that reported for other parts of the greater region. However, that does not mean there isn't room for improvement.

Possible ways of increasing productivity and efficiency would be the introduction of micro-irrigation technologies and the use of biochar as a soil amendment. Biochar use would in an economically viable way, improve soil structure which would lead to a great improvement in the soil quality and ameliorate the effects of high ESP. It would also improve water holding capacity (thereby reducing the frequency of irrigations) and increase water use efficiency.

5. References

[1] R. Oygard, T. Vedded and J. Aune 1999.*Good Practices in Dry Lands Management.* Noragric, Agricultural University of Norway, As.

[2] N. Myers, N. 1989.The environmental basis of sustainable development. In. Schramm, G. and J.J. Warford (Eds). *Environmental Management and Economic Development.* Johns Hopkins University Press, Baltimore. pp 57-68.

[3] W.B.R. Graham, J.B. Alabi and I.W. Pishriria 2003. Water and agriculture in the Sokoto Rima Basin. 1. An appraisal of the current status . *Proceedings of the 4th International Conference of the Nigerian Institution of Agricultural Engineers.* Vol. 25, pp94-100.

[4] M. Kay 2001. Smallholder Irrigation Technology: Prospects for Sub-Saharan Africa FAO/IPTRID, IPTRID Secretariat, Food and Agriculture Organization of the United Nations Rome, 2001

[5] W.B.R. Graham 1999. Characteristics of the soils in the Birnin kebbi area. 1. The soils of the Polytechnic Farm. *Nigerian J. Basic Appl. Sci.* 8: 51-61

[6] J.M. Kowal and D.T. Knabe 1972. *An Agricultural Atlas of the Northern States of Nigeria with Explanatory Notes* .ABU Press Zaria..

[7] A.L. Page, R.H. Miller, and D.R. Keeney (Eds.) 1982. *Methods of soil analysis.* Part 2. Chemical and microbiological properties. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison,WI.

[8] S.L. Chopra and J.S. Kanwar 1991. *Analytical Agricultural Chemistry* 4th Edition, Kalyani Publishers, New Delhi.

[9] G. Levine 1999. Understanding Irrigation Behavior: Relative Water Supply as an Explanatory Variable. International Water Management Institute, Mexico.

[10] R.G Allen, Pereira, L.S., Raes, D., Smith, M. 1998. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements.* FAO Irrigation and Drainage Paper 56, Rome, Italy.

[11] W.O. Enwezor, Ohiri A.C., Opowaribo E.E., Udo E.J. 1990. A review of soil fertilizer use in crops in Southeastern zone of Nigeria. Federal Ministry of Agriculture and Natural Resources. Lagos, Nigeria.

[12] I.E. Esu 1991. Detailed Soil Survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

[13] W.B.R. Graham, W.B.R. 1999. Characteristics of the soils in the Birnin kebbi area. 1. The soils of the Polytechnic Farm. *Nigerian J. Basic Appl. Sci.* 8: 51-61.

[14] W.B.R. Graham, W.B.R. 2010. Characteristics of the Soils of Gayi Area, Northwestern Nigeria. Nigerian Journal of Science and Technology, Volume 6, Number 1. 2010 p. 1-14

[15] R.S. Ayers and D.W. Wescot 1985. *Water Quality for Agriculture.* Irrigation and Drainage Paper No. 29. FAO, Rome.

[16] W.B.R. Graham 2001. Ground water fluctuation and irrigation water quality in the Birnin Kebbi area. *Nigerian J. Soil Res.* 2:66:71.

[17] W.B.R. Graham, Adeyanju, E. and Ambursa, F.I. 2010. Soil and Water Quality for Irrigation in Kebbi State,

Northwestern Nigeria: A Study of the Center Pivot Sprinkler Irrigation Scheme, Zauro. Nigerian Journal of Science and Technology, Volume 6, Number 1. 2010, p. 64-76

[18] W.B.R Graham, I.W. Pishiria and O. Ojo 2006. Monitoring of Groundwater Quality for Small-scale Irrigation: Case Studies in the Southwest Sokoto-Rima Basin, Nigeria. *Agricultural Engineering International: the CIGR Ejournal*. Manuscript LW 06 002. Vol. VIII. June, 2006.

[19] L. Some, Y. Dembele, M. Ouedraogo, B.M. Some, F.L. Kambire, S. Sangare 2006. Analysis of crop water use and soil water balance in burkina faso using CROPWAT. CEEPA discussion paper no. 36, CEEPA, University of Pretoria, p. 66.

[20] M. Diop 2006. Analysis of crop water use in Senegal with the CROPWAT model. CEEPA Discussion Paper, No. 34, CEEPA, University of Pretoria. p18.