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Full Length Research Paper

Characterizing sites for the design and restoration of Kalacha irrigation scheme, Chalbi district, Kenya: Socio-economic and biophysical considerations

E. M. Muya[1]*, K. Gitau[1], S. Obanyi[1], M. Ngutu[2], S. Kuria[2], H. Sharfi[2], D. G. Dub[2], H. Bulle[2], D. M. Miano[3], J. Muriethi[3], G. Keya[3], I. V. Sijali[1], S. Mamo[2], P. M. Maingi[1], M. Okoti[2] and Eng. M. J. Omedi[4] and A. Esilaba[3]

[1]National Agricultural Laboratories, P. O. Box 14733, Nairobi, Kenya.
[2]KARI-Marsabit, P. O. Box 147, Marsabit, Nairobi, Kenya.
[3]Kenya Agricultural Research Institute, P. O. Box 57811, Nairobi, Kenya.
[4]Ministry of Water and Irrigation, P. O. Box 29703, Nairobi, Kenya.

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Site characterization was carried out in Kalacha irrigation scheme for the design and restoration of the scheme. Detailed soil survey was carried at the scale of 1:2,000, through systematic observations, where the soils were described in terms of depth, texture, structure and consistence. Based on these characteristics, four soil units were identified and designated as block A, B, C and D, covering 23, 18, 17 and 42% of the scheme, respectively. In each unit, representative soil profiles were identified, characterized in terms of soil physical and chemical properties, and classified according to FAO-UNESCO system of classification. The soils in block A, B, C and D were classified as Petric Calcisols, Salic Fluvisols, Calcic Solonetz and Calcaric Fluvisols, respectively. The aggregate stability of the topsoils for Block A, B, C, and D was found to be 40, 10, 2 and 4%; while the water uptake capacity was 218, 158, 76 and 86 mm, respectively. The highest level of nutrients was found in Block A, followed by Block B, while block C and D had relatively lower levels. The most limiting factors were found to be high salinity, high sodicity, low aggregate stability and high soil pH, hence low nutrient availability.

Key words: Irrigation layout and design, soil quality, irrigation blocks.

INTRODUCTION

Kalacha irrigation scheme was started in 1984 through community initiative with little technical inputs into the design. The result of soil investigation indicated that the soils in the scheme varied considerably in terms of the physical and water-related properties that influence the choice of irrigation methods and practices (Muya et al., 2008). With little technical capacity to face these challenges (of designing the irrigation system), the farmers applied the same irrigation methods and scheduling for different soils and crops. This caused excess water application for the soils and crops which needed relatively less water and under irrigation for those requiring more. Excess water application caused loss of nutrients through leaching and raised the ground water table with salt to the upper soil horizon, hence, increased salt accumulation within the root zones. In order to attain sustainable production of the degraded scheme, the first task is to design the irrigation layout to ensure efficient use of the limited water supply followed by restoration of soil quality and productivity (Muya et al., 2008).

The development of economically viable production system will depend on the interactions between the efficiency of water supply system, the integrated management strategies for restoring soil quality, and the market for envisaged farm products. To improve the efficiency of water supply systems, the necessary physical and

*Corresponding author. E-mail: edwardmuya@yahoo.com.

hydraulic structures must be designed and constructed, based on the conventional design criteria (Muchangi et al., 2005). With the current water deficit, poor water distribution networks and inefficient irrigation practices, agricultural production will not only fail to meet the potential human and market demands, but also lead to further environmental degradation, unless appropriate design and construction of the scheme as well as restoration of the degraded soils are achieved (Muya et al., 2008). The starting point of this important development is to examine the pertinent socio-economic issues that prompted the need for the reconstruction of the scheme, along with the baseline biophysical factors, on the basis of which to delineate soil units (irrigation blocks).

For this purpose, detailed topographical and soil survey were carried out in the area to provide the physical data to assist in planning the layout of the scheme. Apparently the cost of design, construction and restoration of the scheme is frustrating. However, it is a mandatory exercise from the long term standpoint. This is because land degradation has resulted into tremendous loss in soil structure and soil tilth and the available physical and hydraulic structures have failed to distribute water to a level that meets the crop water requirements. A combination of these two factors has lead to the decline in agricultural production to an extent that hardly any farm enterprises are practiced on the ground (Muya et al., 2008). Therefore, this paper examines four important components of irrigation development, namely: socio-economic issues, biophysical factors and the tasks to be addressed in designing the system.

MATERIALS AND METHODS

The community perceptions of the declining production trends and the anthropogenic factors contributing to the decline were captured through structured questionnaires and focus group discussions. Topographical survey was carried out at the scale of 1:2000 using theodolite. Grids were laid down at a 50 m interval. In each grid, detailed observations were made on soils, current irrigation methods and water distribution networks, micro-relief and degree of land degradation. Soil survey, delineation, description and classification were carried out following the standard procedures (FAO, 1977, Kenya Soil Survey Staff, 1987 and FAO-UNESCO, 1997). Observations were made on a rigid grid at 50 m interval, using minipits, in which descriptions were made in terms of soil depth, texture and consistence. Based on these characteristics, the soil units (irrigation blocks) were identified and delineated. The criteria used in differentiating the soils into different units included differences in soil depth, texture, aggregate stability and soil water uptake and retention capacity. For each unit (block), representative soil profile was identified which was characterized in details in terms of physical and chemical characteristics. The selection of the representative soil profiles was achieved by grouping the observation points according to the specified range of soil characteristics. The observation point with soil characteristics similar to other observation points within a given range was identified as a representative profile. The physical characteristics determined included aggregate stability, bulk density, porosity, infiltration rate, and water uptake and storage capacity. Aggregate stability was determined through dry sieving analysis (Hillel, 1982). Porosity, water uptake and storage capacity were determined by subjecting the saturated soil samples to stepwise incremental suctions and calculating the equilibrium moisture content (Hillel, 1982). Infiltration rate was determined using double ring infiltrometers, while hydraulic conductivity was assessed using Inverse Auger Hole methods (Hinga et al., 1980). From each representative soil profile, composite samples were collected at the depth of 20 cm for laboratory determination, using standard procedures provided by Hinga et al. (1980). The soil properties analyzed were plant nutrients such as P, K, Ca, Na, and Mg, using Mehlich Double Acid Method (Anderson and Ingram, 1993), total organic carbon, using Calometeric Method (Nelson and Somers, 1982), total nitrogen, using Micro-Kjeldahl Method, soil pH in 1:1 (W/V) soil-water suspension and micro-nutrients, using Okaleb et al. (2002).

The chemical characteristics (soil quality attributes) of soils were used to determine the productivity of each soil unit delineated, based on their thresholds (Table 1) and response functions (Aune and Lal, 1997; Kamoni and Wanjogu, 2006). These characteristics were soil pH, nitrogen, soil organic carbon (SOC), phosphorous (P) and potassium (K). The productivity index was calculated using the response functions provided by Aune and Lal (1997). The response functions are regressed relationships between each of the soil quality attributes selected and relative yield (RY) of maize, this being the staple food crop in Kenya. Productivity index was calculated using the following soil productivity equation:

$$PI = SQI_1 + SQI_2 + SQI_3 + SQI_4 + SQI_5$$

Where, PI = Productivity index, based on the compounded sufficiency of all the soil quality attributes. $SQ1_1$, SQ_2, SQ_3, SQ_4, and SQ_5 are the soil quality index of pH, soil organic carbon, nitrogen, phosphorous and potassium, respectively. The soil quality index for each soil quality attribute was deduced from the respective response curve on the vertical scale of values ranging from 0.0 - 1.0 (relative yield) against the value of the attribute read on a vertical scale, provided by Aune and Lal (1997). These values were applied into the soil productivity equation to calculate the productivity index.

RESULTS AND DISCUSSION

Socio-economic issues

In Kalacha, irrigation started through the community initiative with little technical inputs into the design. However, the soil productivity was reasonably high in the beginning but after twenty years of continuous irrigation, agricultural production declined to a point where most farmers stopped crop farming. The scheme started in 1984 and by the year 2005, the production had gone down by over 80% for most agricultural products (Muya et al., 2008) (Table 2). The farmers attributed this to low soil quality, which they described as toxic, smeary and slippery when wet and extremely hard when dry. They also claimed that water disappeared in the soil before reaching their crops, thereby causing low crop yields.

From Kalacha perspective, there seems to be less agreement regarding the contentions that sustainable agriculture must be also economically viable and socially acceptable. In this area, the socio-economic sciences and societal expectations are apparently different from

Table 1. Thresholds of soil quality indicators.

Soil quality attributes	Threshold values	Source
K (me%)	0.2 - 1.5	Kamoni and Wanjogu (2006)
K (me%)	0.83	Aune and Lal (1997)
N (%)	0.2	Kamoni and Wanjogu (2006)
C (%)	1.08	Aune and Lala (1997)
P (ppm)	20 - 80	Kamoni and Wanjogu (2006)
Ph	5.5 - 7.0	Kamoni and Wanjogu (2006)
Electrical conductivity (EC)	4.0 mS/cm	Kamoni and Wanjogu (2006)
ESP	6.0	Kamoni and Wanjogu (2006)
Aggregate stability	50%	Kamoni and Wanjogu (2006)

Table 2. Agricultural production in 1984 and 2004 in Kalacha irrigation scheme.

Crop	Yield in Kg/ha	
	1984	2004
Maize	2000	500
Cabbage	2500	480
Kale	3500	350
Tomatoes	3700	300

Source: Muya et al. (2008).

the physical, ecological and agricultural sciences that form important components of environmental sustainability. In this area, urgent human and societal needs for survival require that the envisaged production system be of immediate impacts and economically viable. Anything short of this may be dismissed as socially unacceptable and hence not a viable enterprise. In physical and ecological sense, a production system is said to be sustainable if the compounded sufficiency of soil quality indicators are restored and remains without deterioration over a realistic time span. This means that the soil quality indicators must be sustained or restored within the acceptable environmental thresholds. In Kalacha irrigation scheme, nearly all soil quality indicators have values that have fallen out of the environmental thresholds following severe land degradation in the past. This indicates that the system is in adverse state, thus requiring heavy capital investment for restoration to a functional state. In this case, a healthy and productive system attained through reclamation or amendment may not be profitable and socially acceptable in the short term. Therefore, inherent conflicts exist between the short term interests of individual irrigators and long term interests of the society as a whole. Resolving the conflicts between the short run and long run interests starts by defining the current state and trying to predict what will happen to the environment, individuals and the society as whole if it remains unchanged through intervention. The degraded state defined in Kalacha irrigation scheme consisted of soils whose productive capacity had gone down to an extent that hardly any return would be realized unless restored. Further delay in taking action would result into further degradation until no production would be realized even with heavy capital investments. In this scheme, over 50% of the irrigated area is approaching this undesirable state, which would be a loss to the society in the long run. Design and restoration of the scheme require baseline information on soil followed by understanding the most important challenges associated with the design work.

Biophysical factors

Four soil units were arrived, each with a representative soil profile. They exhibited considerable variations between different soil profiles in terms of soil depth, aggregate stability, infiltration rates and soil moisture holding capacity (Figures 1, 2, 3 and 4). Based on these characteristics, four irrigation blocks (soil units) were identified, namely block A, B, C and D whose representative soil profile were classified as Petric Calcisols, Salic Fluvisols, Calcaric Fluvisols and Salic Solonetz, respectively. Generally, the results showed remarkable variations between different blocks as expressed in the characteristics of representative soil profiles, each profile representing one soil mapping unit (Table 3). The aggregate stability was found to be generally low for all the soil profiles, being less than 50%. Profile 1 had the highest aggregate stability within 20 cm depth, which decreased with the depth. The water holding capacity (WHC) and hydraulic conductivity (HC) were also found to be highest in profile 1. The lowest values were found in profile 3, which had also the lowest soil aggregate stability. The variations in aggregate stability, hydraulic conductivity and soil water holding capacity in different soil profiles could be attributed to differences in sodium concentrations and organic carbon, both being the principle determinants of soil aggregate stability. Since the physical and hydraulic characteristics of soils are the principle determinants of soil moisture

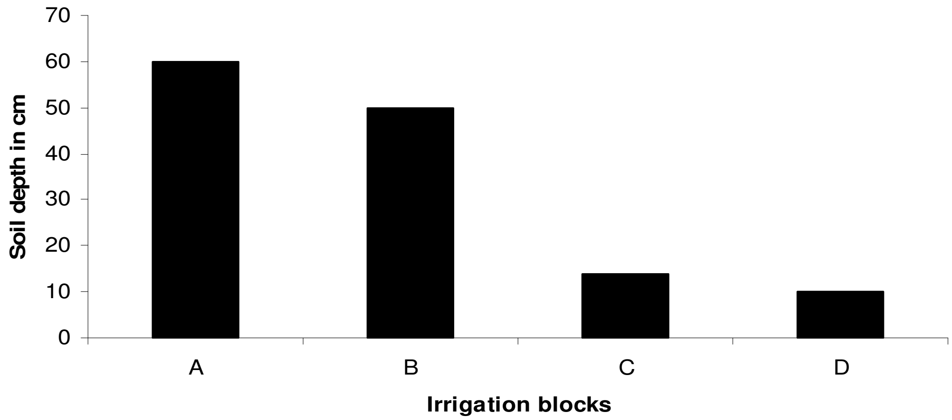

Figure 1. Variation in soil depth.

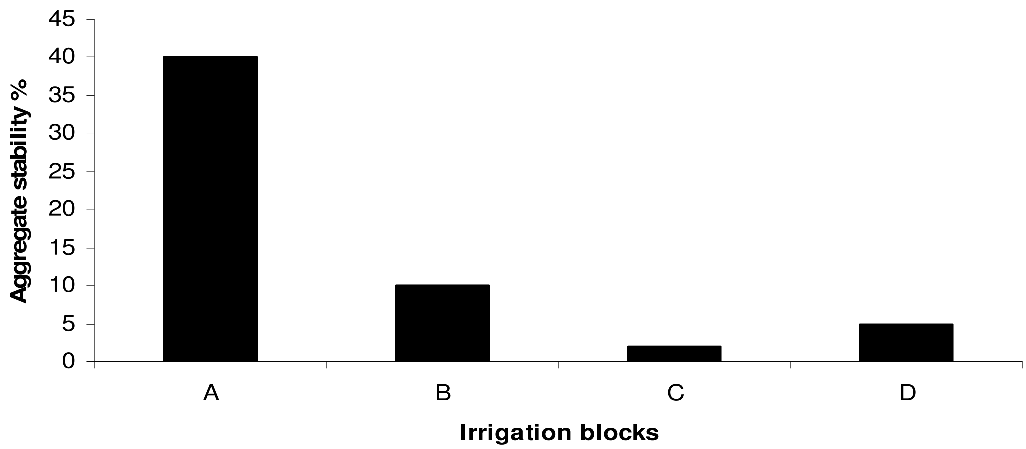

Figure 2. Variation in A. stability.

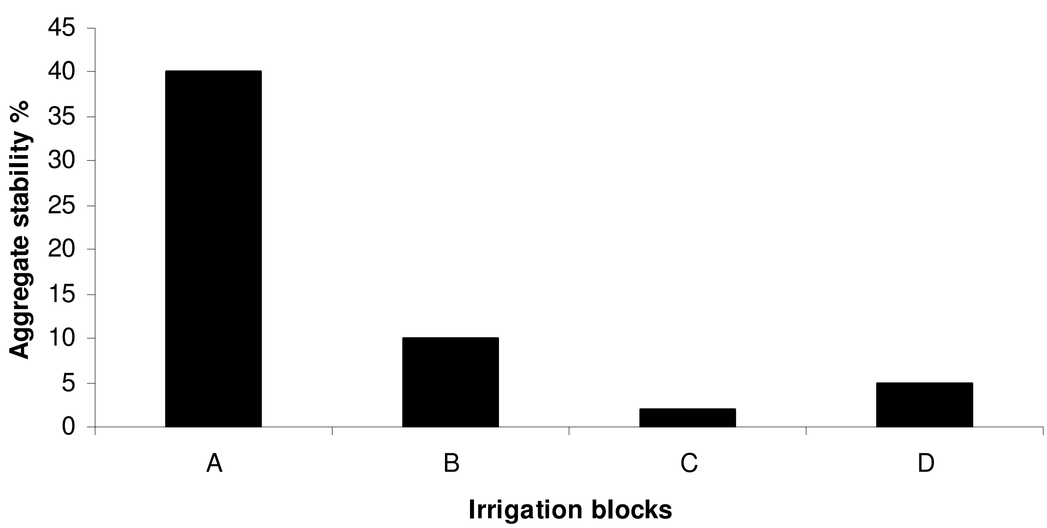

Figure 3. Variation in infiltration.

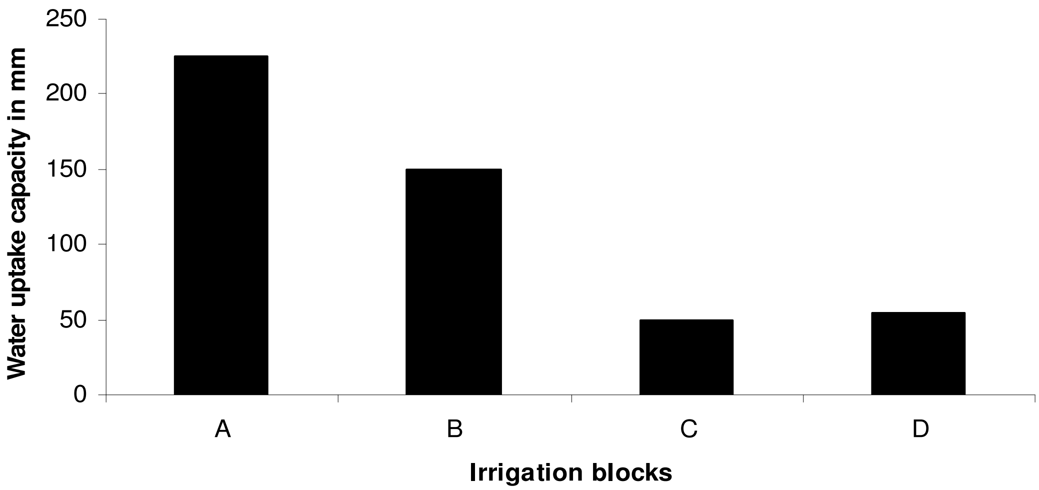

Figure 4. Variation in water uptake.

Table 3. Physical and hydraulic characteristics of soils.

Profile No 1, Block A	**Values at different depths**				
Soil depth (mm)	0 - 10	10 - 20	20-40	40 - 60	60 - 100
Texture	Clay loam	Clay loam	Clay	Clay	Clay
Aggregate stability (%)	40	35	14	15	5
HC (mm/hr)	12.5	11.8	10.6	10.5	3.3
WHC (%)	10	10	22	27	44
Profile No 2, Block B					
Soil depth mm	0 - 10	10 - 15	15 - 30	30 - 60	
Texture	Sandy clay loam	Sandy loam	Clay loam	Clay	Clay loam
Aggregate stability (%)	10	9	9	5	
HC (mm/hr)	10.7	9.6	6.3	4.8	
WHC (%)	8.8	7.6	9.1	33.4	
Profile No 3, Block C					
Soil depth (mm)	0 - 10	`0 - 20	20 - 30		
Aggregate stability (%)	2	2	2		
Texture	Sandy loam	Sandy clay	Loamy sand	Clay	Clay
HC (mm/hr)	1.0	0.9	0.1		
WHC (%)	5	5	11		
Profile No 4, Block D					
Soil depth (mm)	0 - 10	10 - 20	20 - 30	30 - 40	
Texture	Silty clay	Clay	Clay	Clay	
Aggregate stability (%)	4	3	2		
HC (mm/hr)	1.2	0.9	0.1		
WHC (%)	8	10	11		

Table 4. Chemical characteristics of bloc A.

Soil attributes	Values at different depths				
	0 - 10	10 - 20	20 - 40	40 - 60	60 - 100
Soil pH-H_2O (1:2.5)	7.89	7.97	8.1	9.3	9.6
Electrical conductivity (mS/cm)	0.56	1.70	1.88	1.80	1.9
Carbon (%)	1.48	1.22	0.56	0.2	0.2
Nitrogen (%)	0.39	0.22	0.12	0.01	0.01
Phosphorous (ppm)	30	20	25	15	10
Potassium (m.e.%)	1.22	4.8	7.9	6.48	6.22
Calcium (m.e.%)	23.6	17.17	18.8	11.7	18.6
Magnesium (m.e%)	10.4	3.41	4.31	3.21	9.88
Sodium (m.e.%)	1.39	3.5	15.05	17.7	18.8
Sum	36.61	38.88	46.5	39.09	53.5
ESP	3.7	9.02	33.3		

Table 5. Chemical characteristics of bloc B.

Soil attributes	Values at different depths				
	0 - 10	10 - 15	15 - 30	30 - 40	40 - 60
Soil pH-H_2O (1:2.5)	8.5	8.8	9.1	9.3	10.8
Electrical conductivity (mS/cm)	1.02	1.38	1.50	1.5	3.7
Carbon (%)	0.8	0.5	0.1	0.1	0.07
Nitrogen (%)	0.18	0.1	0.09	0.09	0.02
Phosphorous (ppm)	15	20	10	10	5
Potassium (m.e.%)	1.9	2.2	2.2	1.7	2.1
Calcium (m.e. %)	32.8	25.8	36.8	31.7	33.8
Magnesium (m.e %)	9.7	10.2	10.9	11.7	6.7
Sodium (m.e %)	3.8	4.8	7.9	8.7	11.9
Sum	48.2	43.0	57.8	53.8	54.5
ESP	7.88	11.2	13.6	16.17	21.8

uptake and storage capacity, their variation requires different water application time, hence different irrigation scheduling.

There were also variations in the soil chemical characteristics between the four soil profiles (Tables 4 - 7). The variations in the soil macro-nutrients, that is, nitrogen, phosphorous and potassium, indicated that each block require different types and quantity of fertilizer inputs. Similarly, variations in organic carbon indicated that different quantities of organic inputs were required to replenish the level of carbon in different blocks. The levels of salts and sodium also varied with the highest level being recorded in block C. However, the salinity problem being observed only in block C, the overall soil-related constraint is the problem of alkalinity, which requires appropriate management strategies to bring the level of sodium to acceptable limits. The compounded sufficiency of all the soil quality attributes in different irrigation blocks is compared in terms of productivity index (PI) in order to indicate the baseline status of soil quality and productivity (Table 8). As a rule of thumb, the threshold productivity index being 50% (Driessen and Konijn, 1992), all the irrigation blocks had very low productivity. The most limiting factors were found to be high salinity, high sodicity, low aggregate stability and high soil pH, hence low nutrient availability. These are as a result of increased land degradation processes due to unfavorable irrigation and soil management practices, and the situation is bound to be more severe if the current state remains unchanged through appropriate intervention. Block D requires priority intervention because it has the largest acreage and highest number

Table 6. Chemical characteristics of block C.

Soil attributes	Values at different depths				
	`0 - 20	`0 - 15	15 - 20	20 - 25	25 - 30
Soil pH-H_2O (1:2.5)	9.8	9.8	9.9	9.9	9.9
Electrical conductivity (mS/cm)	23.6	23.6	18.8	18.1	19.1
Carbon (%)	0.30	0.30	0.1	0.1	0.1
Nitrogen (%)	0.3	0.3	0.01	0.01	0.01
Phosphorous (ppm)	20	20	17	20	17
Potassium (m.e. %)	1.39	1.39	1.87	1.86	1.76
Calcium (m.e. %)	23.8	23.8	27.9	28.2	29.8
Magnesium (m.e %)	9.8	9.8	9.9	9.7	10.7
Sodium (m.e %)	11.6	11.6	10.8	12.6	13.7
Sum	46.59	46.59	50.47	52.4	55.1
ESP	24.9	24.9	21.3	23.4	24.2

Table 7. Chemical characteristics of bloc D.

Soil depth (mm)	Values at different depths				
	0 - 10	10 - 15	15 - 20	20 - 30	30 - 40
Soil pH-H_2O (1:2.5)	8.40	8.60	9.3	9.3	10.1
Electrical conductivity (mS/cm)	1.03	1.38	1.49	1.61	2.2
Carbon (%)	0.89	0.61	0.2	0.17	0.11
Nitrogen (%)	0.18	0.13	0.05	0.05	0.01
Phosphorous (ppm)	20	20	12	9	7
Potassium (m.e.%)	3.4	3.7	3.2	3.6	3.8
Calcium (m.e. %)	32.7	28.9	22.7	24.6	28.6
Magnesium (m.e %)	11.1	10.1	6.4	6.7	6.5
Sodium (m.e %)	6.4	9.6	12.6	14.7	12.9
Sum	53.6	52.3	44.9	49.6	51.8
ESP	11.9	18.35	28.1	29.6	24.9

Table 8. Soil productivity of different irrigation blocks (soil units).

Block	Extent (%)	PI	Most limiting factors
A	23	60	High soil pH and low soil organic carbon
B	18	48	High soil pH, low aggregate stability, nitrogen and phosphorous
C	17	13	High soil pH, low water holding capacity, low soil organic carbon and high sodium concentration
D	42	5	High soil pH, low water holding capacity, low aggregate stability, low soil organic carbon, low nitrogen and high sodium concentration

of limitations.

The challenges of designing irrigation system

The poor design of the canal system was found to be the main cause of inefficient water distribution. This is because haphazard layout of the canals delayed the flow and increased the opportunity time for water to be lost through seepage and evaporation.

Conclusion and recommendation

The results of topographical survey indicated that the design of the current canal layout was not based on the conventional design criteria and as such was inefficient in distributing water into the irrigated fields. There were considerable variations in soil physical, hydraulic and chemical characteristics that lead to the differentiation of the irrigation fields into four irrigation blocks (soil units), namely: Block A, B, C and D, covering 23, 18, 17 and 42% of the area, respectively. The soils in block A, B, C and C were classified as Petric Calcisols, Salic Fluvisols, Calcic Solonetz and Calcaric Fluvisols respectively. The aggregate stability of the topsoils for Block A, B, C, and D was found to be 40, 10, 2 and 4%; while the water uptake capacity was 218, 158, 76 and 86 mm respectively. The highest level of nutrients was found in Block A, followed by Block B, while block C and D had relatively lower levels. Most of the soils were found to be highly degraded, resulting into low quality and productivity. The most limiting factors were found to be high alkalinity, low aggregate stability and high soil pH, hence low nutrient availability.

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