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Soil Fertility Status of the Kano River Irrigation Project Area in the Sudan Savanna of Nigeria

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Abstract: This study was conducted to assess the soil fertility status and the extent of soil sodicity and salinity in the Kano River Irrigation Project (KRIP), located between latitudes 11°32'N to 11°51'N and longitudes 8°20'E to 8°40'E in the Sudan Savanna of Nigeria. Soil samples were collected from the entire project area using stratified random sampling technique. Questionnaires were used to obtain information on farmers' soil and water management practices. Soil sodicity was the most serious problem in the area. The exchangeable sodium percentage in the top soil ranged from 3.1 to 34.4 with an average of 14.8, while in the subsoil the range was from 3.1 to 40.6 with an average of 17.5. Soil pH values ranged from 5.6 to 9.5 and 4.8 to 9.6 in the top and subsoil, respectively. About 53% of the farmers interviewed cultivated on their field drains, a practice that has led to the blockage of most of the field drains in KRIP and resulted in waterlogging.

Key words: Soil fertility, sodicity, irrigation

INTRODUCTION

The need to grow more food to meet the demands of the population in Nigeria has led to intensification of land use, especially around irrigated and fadama areas. Agricultural practices often result in a mismatch between land quality and land use leading to soil fertility decline and general land degradation (Batjes, 2001; UNEP, 2003). The environmental costs of such mismatch are usually significant, such as waterlogging and the build-up of salinity and/or sodicity, depletion and pollution of groundwater and increase in pests and diseases (Hartemink, 1997; Datta and de Jong, 2002; Bationo *et al*., 2004). Worldwide, about two-thirds of all agricultural lands have been degraded to some extent within the last half century (World Resources Institute, 2000). About 1 to 2% of irrigated land is lost annual as a result of salt-related problems, especially in arid and semi-arid areas (Xiao Gang *et al*., 2002; Guarnieri *et al*., 2005). According to Oldeman (1994) and FAO (2002), most salt-related land degradation problems are, to a large extent, human-induced. In the Kano River Irrigation Project (KRIP) area located in the Sudan Savanna of Nigeria, there is evidence of soil fertility decline and land degradation as a result of land use intensification and mismatch between land quality and land use (HJRBDA, 1999; Abubakar *et al*., 2004). At inception about 30 years ago, KRIP was designed to supply irrigation water for two seasons in a year: dry season when the peak water supply will reach a maximum of 24 m^3 sec^{-1} for complete irrigation; and wet season with supply of 6.0 m^3 sec^{-1} for supplementary irrigation between April and August. This implies that the system was designed for a maximum of 200% cropping intensity. Recent studies, however, show that farmers have introduced third crop thereby raising the cropping intensity to 300% in some sectors of the project (HJRBDA, 1999). This has led to increase in water demand rapid decline in soil fertility due to continuous cultivation. Traditional crops like millet and sorghum grown during the wet season have been replaced by high water-and nutrient-demanding crops, such as rice and maize.

The negative impacts of the changes in cropping pattern and land and water management practices are reflected in the declining crop yields and the appearance of waterlogging and signs of soil sodicity in many parts of the project (HJRBDA, 1999; Abubakar *et al*., 2004). According to HJRBDA (1999), average yields of 5 tons of wheat per hectare were recorded at the inception of the irrigation scheme in the 1970s and 1980s compared to the current average yield of less than 2 t ha^{-1}.

The objectives of this study were to assess soil fertility status and the extent of soil sodicity and salinity in the project area; and to document existing soil and water management strategies of farmers and the rationale behind such strategies.

MATERIALS AND METHODS

The study area: The Kano River Irrigation Project I (KRIP) is located between latitudes 11°32'N to 11°51'N and

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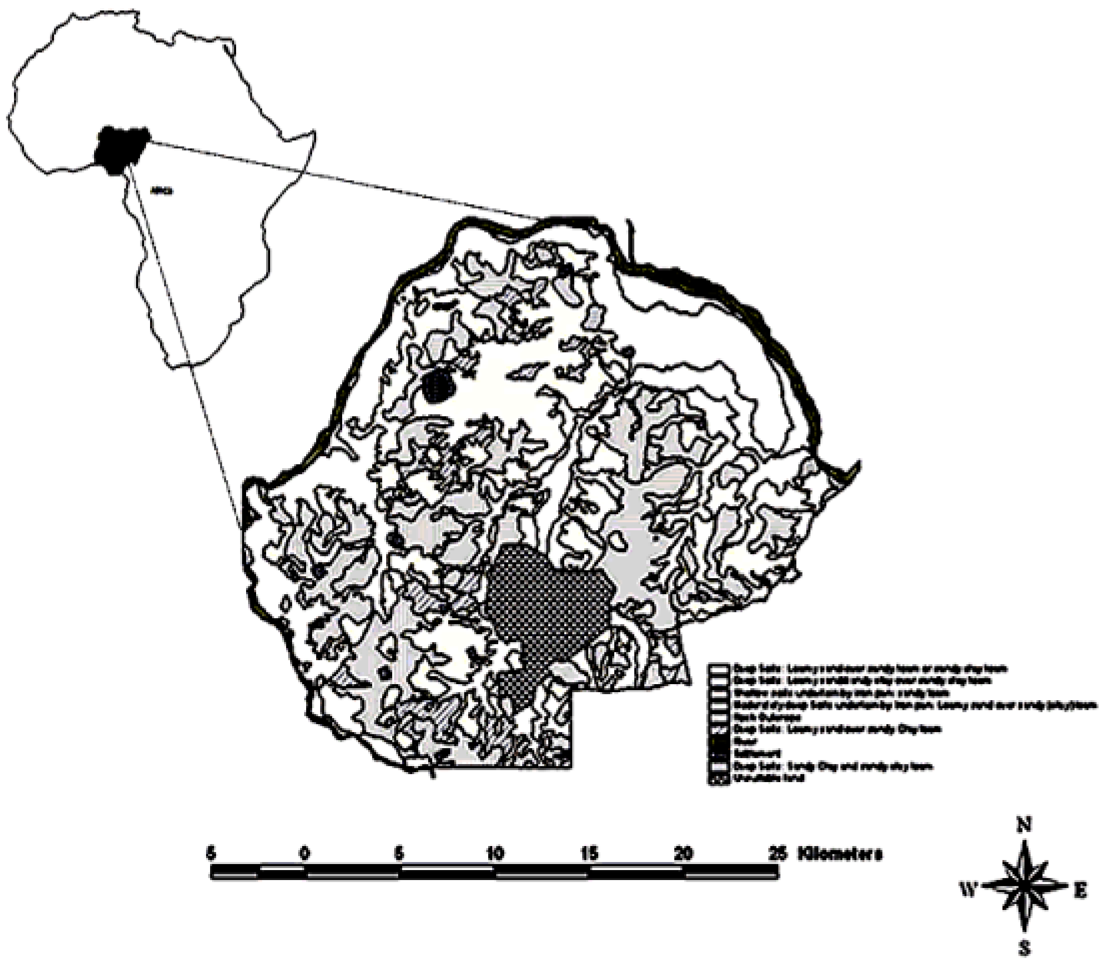

Fig. 1: Maps of Africa and Nigeria showing the location of KRIP and soil map of KRIP (source map for KRIP NEDECO, 1974)

longitudes 8°20'E to 8°40'E within the Sudan savannah zone of Nigeria. It has a planned gross irrigable area of 25, 606 ha comprising two main canals called the West Branch and East Branch canals (Raja, 1975). However, only 13, 280 ha was fully developed and being utilized for irrigation as at now. The area is characterized by a mean annual rainfall of about 830 mm all of which falls between June and October (Singh and Balasubramanian, 1983). The mean daily temperature ranges from 29 to 38°C (Kowal and Knabe, 1972). The geology of the area is dominated by older granites and younger metasediments of Precambrian to lower palaeozoic age (McCury, 1976). The soils are mostly moderately deep to deep and well drained with sandy loam textured surface and sandy clay loam textured subsoil (NEDECO, 1976; IAR, 1994) (Fig. 1). Malgwi (2001) classified the soils of the area as Aquic Natrustalfs and Aquic Haplustalfs following the USDA soil taxonomy and Gleyic Solonetz, Haplic Solonetz and Calcic Luvisols in the FAO classification system.

Soil sampling and analysis: Soil samples were collected from the entire project area using stratified random sampling technique based on the soil map prepared by NADECO in 1976 (Fig. 1). Soil samples from 0-20 and 20-40 cm depths were taken with soil auger. Particle size analysis was carried out by the hydrometer method (Day, 1965). Soil pH was determined in water and in 0.01 M $CaCl_2$ at a soil/solution ratio of 1:2.5 (weight/volume) with a glass electrode pH meter. Organic carbon was determined by the wet oxidation method of Walkley and Black as described by Allison (1965). Exchangeable acidity was determined by shaking the soil with 1 N KCl and titrating with 0.5 N NaOH (Juo, 1979). Exchangeable bases were displaced with 1N NH_4OAC buffered at pH 7.0.

Potassium and Na in the extract were determined by flame photometry while Ca and Mg were determined by atomic absorption spectrophotometry. Cation exchange capacity was determined using the NH_4OAC (pH 7.0) method. Total N was determined by the macro-Kjeldahl procedure described by Bremner (1965). Copper, Mn, Zn and Fe were extracted in 0.1 N HCl and determined by atomic absorption spectrophotometry. Available phosphorus was determined by the Bray 1 method (Juo, 1979).

Survey of farmers' soil and water management practices: The Kano River Irrigation Projects is administratively divided into two; the west branch and the East branch. The west branch is made up of 30 sectors while the East branch has 17 sectors. For this study, farmers were purposefully selected from 9 sectors in the west branch and 4 sectors in the East branch. The criteria used for selection of the sectors were: the existence of soil degradation and fertility problems in the sectors, intensity of the problem and the hydrological position of the sectors relative to the storage dam (i.e., head, middle or tail). A total of 70 farmers (40 from the west branch and 30 from East branch) were surveyed using structured questionnaires and focus group discussions to obtain information on their soil and water management practices.

RESULTS AND DISCUSSION

Soil fertility: The levels of exchangeable bases, Cation Exchange Capacity (CEC) and pH are shown in Table 1 and 2. The CEC varied widely but was generally moderate with mean values of 14.4 and 14.8 cmol(+) kg^{-1} for the topsoil and subsoil, respectively. Calcium was generally the dominant base in the exchange complex. However, the levels of exchangeable sodium are somewhat high in some areas and appear to increase with soil depth ranging from 0.2 to 8.1 cmol(+) kg^{-1} and 0.3 to 12.4 cmol(+) kg^{-1}, respectively in the topsoil and subsoil. The relatively high level of exchangeable Na is reflected in the high Exchangeable Sodium Percentage (ESP) values (Table 3). The ESP values ranged from 1.9 to 30.6 and 3.1 to 40.6 with mean values of 14.8 and 17.5 for the top soil and subsoil, respectively. Soil sodicity is therefore a potential problem in some parts of the project area. Sodic soils exhibit structural problems such as crusting, hardsetting and waterlogging associated with poor infiltration (Naidu and Rangasamy, 1993). Visual evidence of sodicity, such as crusting and waterlogging abound on many farmers' fields in KRIP. Values for Electrical Conductivity (EC) of the soil saturation extract were generally very low, indicating that the soils are generally non-saline. Soil pH (1:2.5, w/v) varied from 5.6 to 9.9 in the top soil and 4.8 to 9.8 in the subsoil.

Table 1: Exchangeable cations and CEC levels of KRIP soils

	Depth 0-20 cm			Depth 20-40 cm		
Parameters	Mean	SD*	Range	Mean	SD	Range
Exchangeable bases (cmol kg^{-1})						
Ca	4.5	1.96	2.3-9.4	4.9	1.96	2.3-10.9
Mg	1.7	0.69	0.5-3.2	2.1	0.95	0.5-4.2
K	0.4	0.27	0.1-1.1	0.3	0.26	0.1-1.1
Na	2.2	1.71	0.2-8.1	2.8	2.49	0.3-12.4
Exchange acidity	0.1	0.04	0.1-0.2	0.2	0.22	0.1-1.0
CEC	14.4	5.33	8.4-29.6	14.8	5.61	9.6-30.6

*Standard Deviation

Table 2: Soil pH, base saturation, ESP and EC levels of KRIP soils

	Depth 0-20 cm			Depth 20-40 cm		
Parameters	Mean	SD	Range	Mean	SD	Range
pH (H_2O)	7.1	1.4	5.6-9.9	7.1	1.6	4.8-9.8
pH (0.01M $CaCl_2$)	6.3	1.0	4.9-8.9	6.2	1.4	4.1-8.5
Base saturation (%)	62	13.5	36-92	66	11.2	37-86
ESP (%)	14.8	8.16	1.9-30.6	17.5	9.10	3.1-40.6
EC (dS m^{-1})	0.12	0.13	0.003-0.42	0.13	0.139	0.019-0.40

Table 3: Levels of soil separates, organic C, available P and total N

	Depth 0-20 cm			Depth 20-40 cm		
Soil separates	Mean	SD	Range	Mean	SD	Range
Sand (g kg^{-1})	639	73	490-750	659	68	490-750
Silt (g kg^{-1})	195	47	120-320	193	48	100-320
Clay (g kg^{-1})	156	57	90-310	150	60	90-310
Organic C (g kg^{-1})	4.9	1.18	3.1-7.1	2.5	0.49	1.5-2.2
Available P (mg kg^{-1})	13.2	7.11	4.5-31.0	12.1	5.02	5.5-25.2
Total N (g kg^{-1})	0.44	0.12	0.18-0.7	0.34	0.103	0.18-0.53

The soils are generally sandyloam in texture. Organic carbon levels were generally very low throughout the study area, ranging from 3.1 to 7.1 g kg^{-1} in the top soil and 1.5 to 2.2 g kg^{-1} in the subsoil (Table 3). The low levels of organic C is not surprising because of the continuous intensive cropping without much additions of organic matter in form of manures and crop residues. Also the high levels of sodium and high pH are not conducive for the accumulation and mineralization of organic matter (Rengasamy and Olsson, 1991; Naidu and Rangasamy, 1993). Organic matter-Na complexes are usually highly soluble and mobile. Total N levels were also low, with mean values of 0.44 and 0.34 g kg^{-1} for the topsoils and subsoils, respectively. The low levels of N in the soil could be partly associated with the low soil organic matter levels as well as the alternating oxic and anoxic conditions that prevail under rice cropping which results in losses of N through denitrification processes (Patrick and Wyatt, 1964). The availability of N to plants could also be reduced under high pH values when urea is the source of applied N because of the low activity of urease at high pH (Nitant and Bhumbla, 1974).

Levels of available P in the soil as determined by the Bray 1 method were moderate ranging from 4.5 to 31.0 mg kg^{-1} with a mean of 13.2 mg kg^{-1} and 5.5 to 25.2 mg kg^{-1} with a mean of 12.1 mg kg^{-1} in the topsoil and subsoil, respectively. Response to phosphate

Table 4: Levels of EDTA-extractable Mn, Cu and Zn and hot water soluble B in soils of KRIP

Levels of micronutrients ($mg\ kg^{-1}$)	Depth 0-20 cm			Depth 20-40 cm		
	Mean	SD	Range	Mean	SD	Range
B	1.540	0.250	1.18-2.12	1.39	0.350	0.93-2.54
Mn	27.300	13.280	6.0-53.0	16.20	5.880	10.0-31.00
Zn	7.800	6.520	1.3-30.0	6.35	5.160	1.30-20.0
Cu	0.048	0.218	0.0-1.00	0.14	0.358	0.0-1.0

Table 5: Farmers' soil management practices

Practice	Frequency	Percentage
Number of cropping seasons per year		
One	8	11.4
Two	53	75.7
Three	9	12.9
Crop rotation	48	68.6
Number of fertilizer applications		
Single dose	9	12.9
2 split	51	72.9
3 split	10	14.3
Use of inorganic manures	57	81.4
Cultivation on field drains	37	52.9
Evidence of waterlogging and/or sodicity noticed on field	51	72.9

fertilizers will be expected if heavy feeders like maize and rice are planted on these soils. Levels of some available micronutrients are shown in Table 4. EDTA-extractable Cu levels are generally low while EDTA-extractable Mn and Zn and hotwater extractable B levels are moderate.

Farmers' practices: The soil fertility management practices farmers employed in KRIP include crop rotation and the use of organic and inorganic fertilizers. Crop rotation is practiced by about 70% of the farmers (Table 5). The rotation sequences include: onion-tomato-maize, tomato-maize-onion-cowpea, Rice-tomato, sorghum-maize, maize-rice and pepper-maize-cowpea. Legumes were not incorporated much in the crop rotation sequences and there was no deliberate rotation of shallow-and deep-rooting crops, therefore the benefits of the rotation to soil fertility maintenance will be minimal. The use of organic manures and inorganic fertilizers are soil management practices that were well appreciated by the farmers in KRIP. All the farmers interviewed in this study used inorganic fertilizers on their farms and up to about 81% of them used organic manure. The types of manures included animal dung, domestic waste and plant ash. Incorporation of crop residues into the soil and green manuring were not practiced. Crop residues were usually fed to animals or burnt on the farm before land preparation. Inorganic fertilizers used by the farmers were urea and different formulations of NPK. Rate of fertilizer application was not based on soil or crop requirement but depends on the cost (affordability) of the product. Most of the farmers applied fertilizers in split doses, with majority of them applying by broadcast method.

Most of the shallow runoff drainage channels at the ends of the fields in KRIP were blocked. Similarly, the collector drains were poorly maintained and densely infested with weeds. Around 52.9% of the farmers interviewed in this survey cultivated on their field drains. The main reason was that if they left the drains free, cattle herders will pass with their animals along the drainage channels and cause damage to their crops. Almost 73% of the farmers interviewed had problems associated with waterlogging and salinity/sodicity. Ironically, over 80% of the farmers believed the drainages on their fields were adequate and functional.

CONCLUSION

Irrigated agriculture exerts a lot of pressure on land. Continuous intensive cultivation using high yielding crop varieties in KRIP leads to the depletion of soil nutrients resulting in nutrient deficiencies and imbalances and change in as well as breakdown of soil physical properties. Sodicity and soil fertility problems associated with sodic soils were widespread in KRIP. Under this situation crop yield and sustainability of production will decline unless deliberately chosen techniques oriented towards sustainability are incorporated into crop production system. Such techniques include the provision of adequate drainage, application of manures and fertilizers (including gypsum if necessary), crop rotation, return of crop residues, green manuring, use of cover crops and mulching.

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