Assessment of Soil Quality under Long-Term Rice-Based Cropping System in Paki, Kaduna State, Nigeria

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ABSTRACT--- ***The research was conducted to assess the long-term rice cropping effect on the quality of soils and to quantify thⁱe extent of degradation, aggradations and the sustainability of the soil for rice cultivation in the study area. Four farm plots were sampled from each of the three rice management regimes identified. Composite soil samples from top (0 - 15cm) were collected and analyzed for both macronutrients and micronutrients essential for rice growth. Using Larson and pears 1991 model, the result showed that micronutrients Cu, Zn, Mn, and Fe that are highly essential trace elements required for rice cropping, were found to be degrading and unsustainable and the trend in the degradation of these trace elements was that as the age of rice cultivation increases, the degree of degradation was also increasing. Other basic soil fertility parameters such as Organic Carbon (OC), Total Nitrogen (N), and Cation Exchange Capacity (CEC) were also found to be degrading. However, Available Phosphorus was found to be aggrading. For this reason, continuous rice cultivation on the same piece of land over a long period of time in the study area and similar environment is not encouraged. Hence, it is recommended that crop rotation and incorporation of farm-yard manure should be use for improving the soil fertility and its sustainability.***

Keywords--- cropping system, rice cropping, soil quality, sustainability

1. INTRODUCTION

Soil quality is defined as the capability of soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment [18]. However, soil quality affects and is affected by food, feed, and fiber production practices. It is also directly linked to environmental quality (i.e. water and air quality, global warming, and energy use for production practices) [1].

The long-term and intensive cultivation of rice can affect the dynamics of soil nutrient elements and their use efficiency which may lead to diminished soil quality and productivity [8, 19]. Loss of organic matter due to rice cultivation without restoration may initiate physical degradation processes. Very often, the process of depleting the soil of its natural resources when submitted to any given agricultural production system is put and what is taken out of the soil. It is well known that decline in crop yield are strongly related to soil quality degradation, particularly nutrient depletion [20, 11]. However, [3] highlighted that, there is very little information on soil changes and rice crop yields in long-term intensive rice cultivation in West Africa.

Rice is the most important food crop for about half of the human race and has traditionally been an important basic food commodity for certain populations in Sub-Saharan Africa and West Africa in particular. It has risen to a position of pre-eminence and enjoying a rapid growth in per-capital consumption in the sub-region. The regional demand of rice has grown at an annual rate of 6% driven by a combination of population growth and substitution away from traditional coarse grains such as sorghum and millet [15].

As the pressure to grow more rice from the limited agricultural land increases, the soils come under the threat of nutrient depletion and thus, the sustainability of the cropping systems under the present soil and crop management practices face a great challenge. However, [12], highlighted that agricultural sustainability is an important issue all over the world. It is particularly important in the tropical, arid and semi-arid zones of the globe where in addition to rapid population growth, environmental decay, water and air pollution is significantly contributing to the pressure on the cultivable land.

2. MATERIALS AND METHODS

2.1 Description of the Study Site

The study area is located within the latitude 11.00^{0}N to 11.30^{0}N and longitude 8.00^{0}E to 8.15^{0}E (figure 1). It lies at the north central margin of northern guinea savanna of Nigeria, where the rural population density is high by tropical African standard. The rural density as at November 2005 was estimated to be at least about 150 person/km^2 and the pressure on the agricultural land is annually increasing. The area experienced only one maximum (peak) of rainfall and this occurs in August with a mean annual rainfall of 1110mm. Rainfall intensities in most times are high and range from 25mm/hr and 125mm/hr [16] and usually higher at the beginning of the rainy season [14]. The temperature is high throughout the year with mean monthly raising from 22^{0}C in January and attaining the maximum 43^{0}C in April [22]. The atmospheric humidity is generally low with its lowest in dry season at 16.8% and highest in the wet season about 85.0% for most of the time in the day [9].

The area forms a part of the basement complex of pre-Cambrian origin. The rocks of the basement complex consist of metamorphic and igneous type, which have been in existence for millions of years and subjected to chemical and other forms of weathering in the past to produced clay rich regolith [28]. The area is extensive upland plain without grouped hills and believed to be the initial pediplain that are now covered by a layer of wind drift materials sometimes above three meters thick. The general slope angles in this area range between 0^0-1^0. Rock outcrops (hills) are generally few and scanty and ranges between 10 – 30 meters high above the plain and up to 30^0 steep.

The soils of the area are basically derived from the basement complex rocks and are usually described as ferruginous tropical soils on sandy parent material [27] and as leached ferruginous tropical soils[26].

2.2 Selection of Farmers and Plots

The sampling frame for this research includes the whole of Paki farming areas which is about 3km radius (figure 1). Snow ball method was applied as the technique in the selection of farmers while stratified simple random sampling was used in the selection of farm plots for the collection of primary data i.e. for interviewing the farmers and collection of soil samples respectively. To this end, the first interviewee was required to refer the researcher to another farmer who was also an expert or knowledgeable in the subject matter (rice cultivation). Four (4) farm plots were selected from each of the three management regimes (i.e continuous rice cultivation up to 10, 20 and 30years) and two control sites were identified within the study area, which are also plots of land with similar physiographic characteristics as the continuous rice cultivation farm plots. The first one is a piece of land identified to have never been cultivated and the second one is a farm plot identified to be under fallow for more than twenty (20) years. These were coded control 1 and control 2 respectively. Composite soil samples were collected from the top 0 - 15cm at the rate of twelve (12) samples per farm plot.

2.3 Laboratory Analyses

Each of the composite soil samples collected was air-dried, crushed and sieved with 2mm sieve and then prepared for the routing analysis of the following parameters: pH., Available Water Holding capacity (AWH), Particle Size Distribution (PSD), Organic Carbon (OC), Total Nitrogen (N), Available Phosphorus (P), Exchangeable Bases, CEC, and micronutrients which are assumed to be sensitive to rice cultivation such as Zn, Mn, Cu, and Fe. Soil pH was measured using the glass electrode method with 1:1 soil/water ratio. The total nitrogen (N) was determined using regular Micro-Kjeldahl Method [7]. Available soil phosphorus (P) was extracted using the Bray 2 method, and the content was determined calorimetrically by ascorbic acid molybdenum blue method [6]. Organic carbon was determined by Chronic-oxidation method by [23]. Particle Size Analysis was investigated through a hydrometer method [5]. Bulk density (Db) was determined by [4]. The Available Water Holding capacity (AWH) was determined by the method summarized by [10]. Exchangeable Na, K, Ca and Mg were determined using flame photometer. The double acid digestion technique [2], was used in sample extraction to digest the soils for metals determination. The concentration of the metals (Fe, Mn, Cu, and Zn) was determined using an Instrumentation Laboratory IL251 Atomic Absorption Spectrophotometer.

2.4 Statistical Analysis

Basic statistics such as mean, range and standard deviation and analysis of variance (ANOVA) via statistical computer package [21], were used for identification of trends and differences in soil qualities among the various categories of continuous rice cropping farm plots while Larson and Pierce (1991) model was used to determine the sustainability or otherwise of the entire management.

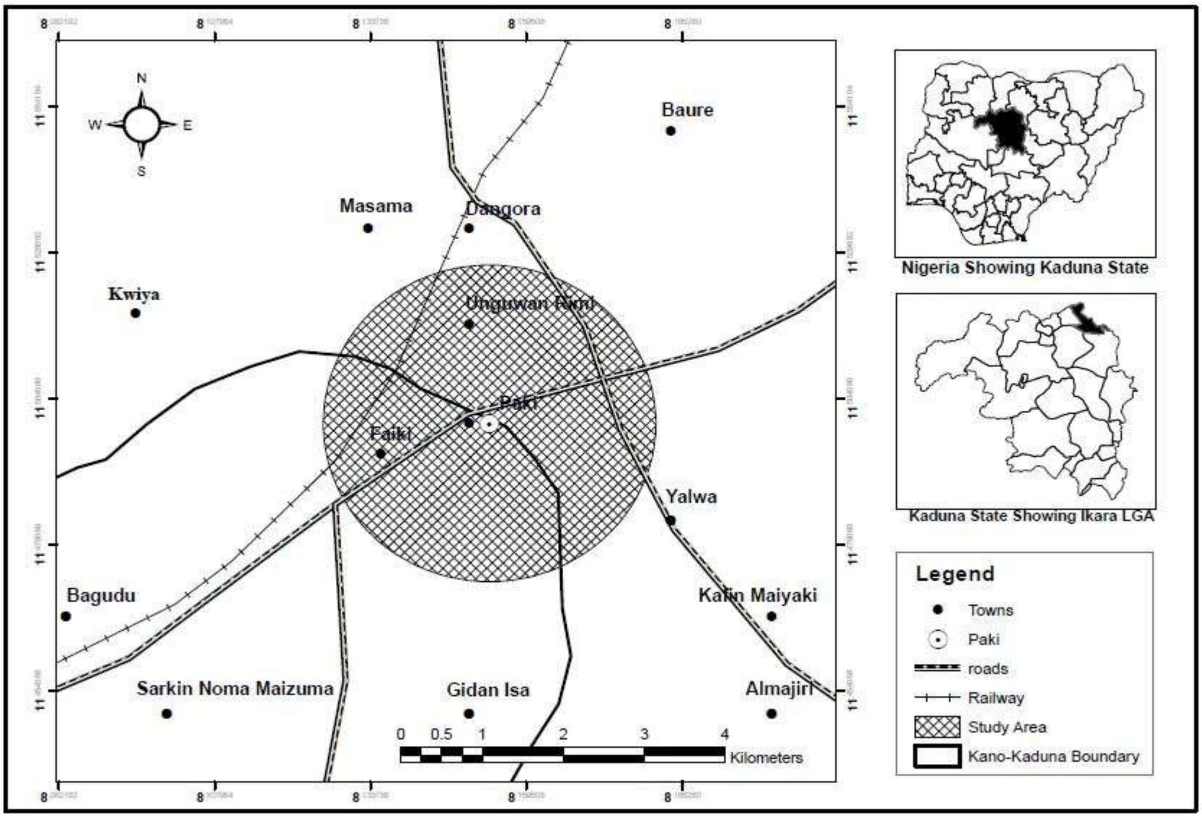

Figure 1: Study area Paki and its Environ in a Concentric of 3km Radius

3. RESULT AND DISCUSSION

The soil quality and sustainability of continuous rice cultivation management regimes was assessed with the aid of [17]. All the farms were quantitatively assessed based on the principles that a management is sustainable if that management practice maintains or improves the soil quality with age [24]. Hence a cumulative quality level of zero is acceptable on soil quality. While a negatively scored level management system is unacceptable and is termed as unsustainable because it is degrading. Table 1 Summarizes the sustainability level of the nineteen soils physical and chemical properties analyzed. However, the degree of degradation and sustainability among the nutrients varies with the nutrient type.

Table 1: Quality Level and Sustainability of the Individual Soil Properties under Three Management Regimes (Larson and Pierce, 1991)

S/N	Soil properties	Control site		Continuous rice cropping up to 10years		Continuous rice cropping up to 20years		Continuous rice cropping up to 30years	
		π	QL	π	QL	π	QL	π	QL
1.	pH (H_20)	6.80	0	7.00	+0.1177	6.55	-0.0367	6.425	-0.0551
2.	Organic Carbon (%)	0.768	0	0.662	-0.1382	0.645	-0.1607	0.764	-0.0055
3.	Organic Matter (%)	1.298	0	1.174	-0.0958	1.130	-0.1297	1.083	-0.1675
4.	Total Nitrogen (%)	0.055	0	0.220	+0.0000	0.052	-0.0454	0.055	+0.0000
5.	Av.Phosphorus (ppm)	18	0	21.25	+0.1183	19.00	+0.000	19.00	-0.00001
6.	Exch. Na (Cmol Kg^{-1})	0.21	0	0.155	-0.2619	0.165	-0.2143	0.185	-0.1190
7.	Exch. K (Cmol Kg^{-1})	0.35	0	0.362	+0.0357	0.367	+0.050	0.357	+0.0214
8.	Exch. Ca (Cmol Kg^{-1})	3.65	0	4.055	+0.1109	3.747	+0.027	3.645	-0.0013
9.	Exch.Mg (Cmol Kg^{-1})	1.97	0	2.235	+0.1345	1.990	+0.010	2.035	+0.0329
10	CEC (Meq./100g)	10.08	0	10.29	+0.0210	10.73	+0.064	10.17	+0.0092
11.	Sand (%)	68	0	63.25	-0.0193	62.75	-0.0291	61.75	-0.0426
12.	Silt (%)	23	0	26.25	+0.1169	27.00	+0.148	27.25	+0.1595
13.	Clay (%)	9	0	10.50	-0.0868	10.25	-0.1086	11.00	-0.0434
14.	Bulk Density (g/cm^3)	1.45	0	1.150	-0.2069	1.175	-0.1724	1.225	-0.1724
15.	Av. W.H.C	14	0	15.50	+0.0333	14.25	-0.1999	14.50	-0.0333
16.	Cu (ppm)	21.4	0	15.00	-1.1960	15.05	-1.1867	13.65	-1.4484
17.	Zn (ppm)	5.25	0	5.10	-0.1144	4.850	-0.3047	4.675	-0.4381
18.	Mn (ppm)	7.0	0	6.75	-0.1429	6.000	-0.5713	5.850	-0.6571
19.	Fe (ppm)	11.1	0	8.65	-0.8827	5.200	-1.2791	8.600	-0.9007
	Total Quality Level				-2.4561		-3.1392		-3.8596
	Time (years)				10years		20years		30years
	Relative Sustainability				-0.2456		-0.15696		-0.12865

π = mean, QL = Quality Level

3.1 Sustainability of Micronutrients

The results generally indicates that all the four micronutrients (Cu, Zn, Mn, and Fe) essential for rice growing assessed are not sustainable in the three continuous rice cropping management regimes. Control site 1, recorded highest micronutrients concentration followed by control site 2 which was under fallow for about 20 years. This was followed by continuous rice management regime up to 10 years while the management regime of continuous rice cropping up to 30 years recorded least in terms of quality level of most of these nutrients. This trend shows that as the age of continuous rice cropping increases the level of micronutrients are decreasing. This might have led to the decline in the rice yield experienced by farmers in the area despite their intensive application of inorganic fertilizers. However the level of the decrease of these nutrients with age of rice cultivation varies with nutrient type (Fig.2). Zn and Mn exhibits clear pattern of degradation across the three continuous rice cropping management regimes from 10years down to 30years of rice cultivation. However, Cu and Fe do not give a clear pattern of degradation across the three continuous rice cropping management regimes. This shows that the longer the age of continuous rice cultivation the less sustainable will be Zn and Mn. The degree of degradation of Fe is less from 10 years to 20 years but increases more down to 30 years of continuous rice cultivation.

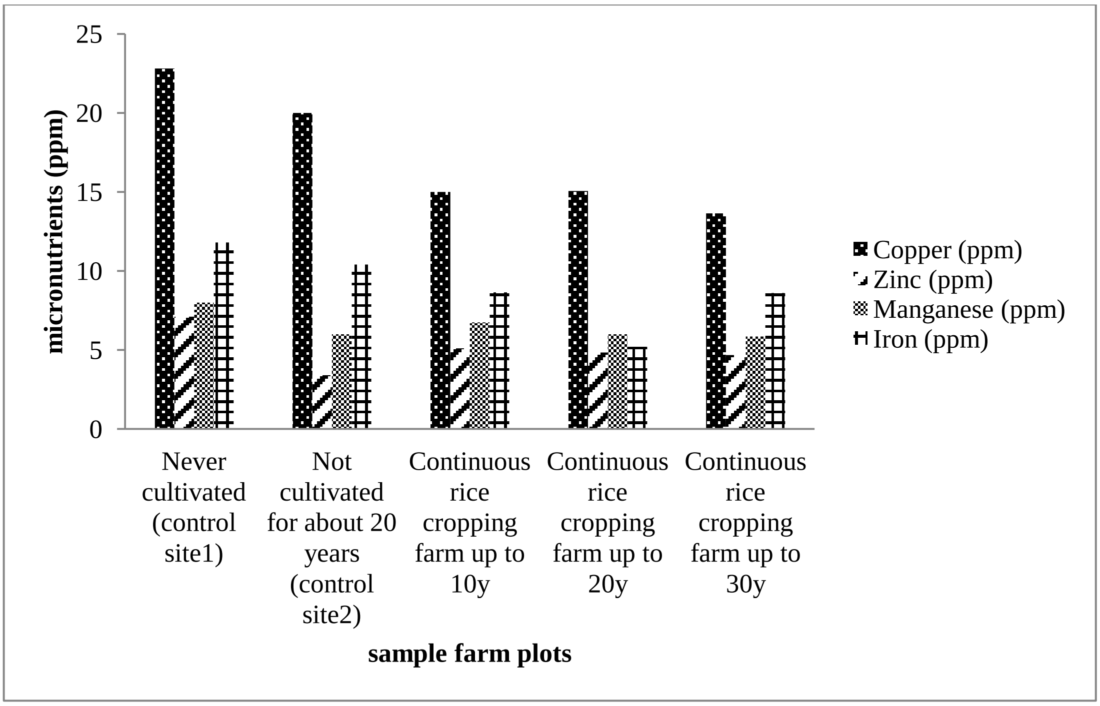

Figure 2: micronutrient level in the three rice cropping regimes

3.2 Sustainability of Exchangeable Bases (Na^+, K^+, Ca^{2+}, Mg^{2+})

The result of sustainability of four exchangeable bases (Na, K, Ca, and Mg) shows that exchangeable K, Ca, and Mg are sustainable when compared with control sites but their pattern of aggradation varies across the ages of continuous rice cultivation management regimes. The exchangeable calcium (Ca) aggrades more on the continuous rice cropping management regime up to 10 years and decreases a little down to continuous rice cultivation management regime up to 20 years and also degrades a little on the continuous rice cultivation management regime up to 30years. The exchangeable magnesium (Mg) also follows a similar trend as that of Ca but aggrades a little on the continuous rice cultivation management regime up to 30years. The trend in exchangeable potassium (K) is that it rises from the continuous rice cultivation management regime up to 10 years to the continuous rice cultivation management regime up to 20years but decreases down to the continuous rice cultivation management regime up to 30years. However, the exchangeable sodium (Na) shows a negative trend (figure 4.2) and this is because Na is one of the soil properties whose positive increment is detrimental to soil fertility improvement as cited by [25]. Hence, its negative decrease in [17] is rated as sustainable.

3.3 Other Macronutreint Essential for Rice Cultivation

The organic matter (OM) was found to be unsustainable in the three continuous rice cropping management regimes and the trend as shown in Table 1, is that the longer the period of continuous rice cropping the less is the sustainability. Similarly the organic carbon is also found to be unsustainable and its trend is that from continuous rice cropping management regime up to 10years it degrades to continuous rice cropping management regime up to 20 years it degraded but aggrades a little on continuous rice cropping management regime up to 30 years. While the trend in total nitrogen (TN) is that it is sustainable on the continuous rice cropping regime up to 10 years, it degrades on the continuous rice cropping management regime up to 20 years only to aggrades a little on the continuous rice cultivation management regime up to 30 years.

Moreover, the overall result is that all the three categories of continuous rice cultivation plots assessed are found to be degrading and not sustainable for continuous rice cropping. Management regime of continuous rice cropping up to 20years shows higher rate of degradation than rice cropping management regime of 10years. Reason for this degradation may be due to large amounts of nutrient uptake by the rice crop without sufficient addition of fertilizer or manure as highlighted by [19].

4. CONCLUSION

One conclusion that can be drawn from the results is that the model used in this study is suitable to measure the sustainability or otherwise of nutrients in the soils of cultivated fields. Secondly, it is clear that mono cropping of rice in a place like Paki and similar environments would not be sustainable unless soil improvement management that involves the application of farmyard manure (or organic fertilizer) is adopted. Finally, the reliance on chemical fertilizers alone is capable of causing negative imbalance in the properties of soils under 1continuous rice cropping thereby rendering the practice unsustainable.

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