Bayero Journal of Pure and Applied Sciences, 3(1): 255 - 259
Received: October, 2009
Accepted: June, 2010

EFFECTS OF SOME HEAVY METAL POLLUTANTS ON FERTILITY CHARACTERISTICS OF AN IRRIGATED SAVANNAH ALFISOL

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ABSTRACT
This research was conducted on the irrigated soils along the banks of the Jakara River within the metropolitan Kano and its suburb. Soil samples were collected between latitude 11°59' and 12° 08'N and longitude 8°34' and 8° 42'E at an altitude of 486.5m. The study investigated the effects of some heavy metals (Cd, Pb and Cu) on the fertility indices of the soil. Grid sampling was employed in which 100m² of land was randomly selected in each of two sampling areas and was divided into ten equally sized grid cells of 10m². Samples were analyzed for lead, cadmium and copper concentrations as well as fertility related parameters such as CEC and basic cations. Data obtained was subjected to correlation analysis using the Pearson moment correlation coefficient technique. The mean values of the heavy metals and the fertility indices are considered for the two sampling areas in bulk. Significantly positive correlation was found to exist between CEC, organic matter, nitrogen and phosphorus at P = 0.01. Significantly positive correlation was also found to exist between lead and potassium; lead and phosphorus; nitrogen and magnesium and copper and phosphorus. The quality of the soil for production is not immediately under threat especially with the very low mean values of the pollutants and the lack of significant effects they exert on many of the fertility indices determined.

Key words: Heavy metals, soil fertility, Jakara River, effect

INTRODUCTION

The metals that are considered as heavy are those with a "density greater than a certain value, usually 5 or 6gcm^{-3}" (Wild, 1996 p190). Heavy metals agreeably are one of the major pollutants that are encountered in the soil. Hill and Petrucci (1999) showed that these metals are among the transition metals, which fall in the d-group of the periodic table (which comprise of groups 1B, 2B and 8B) and periods 4 and 5 of the periodic table. They all have atomic weight greater than 50 and are capable of forming variety of complex ions. It is shown by Bingham (2004) that although some are essential for some biological processes as trace elements, all are toxic above certain tolerance level. Most readily cited examples of these substances as shown by Wild (1996) include Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn).

As Aydinalp and Marinova (2003) observe, a precise knowledge of heavy metals concentration and the forms in which they are found, their dependence on soil's physico-chemical properties provide a basis for careful soil management, which will limit as far as possible, the negative impact of heavy metals on the ecosystem. The concentrations of heavy metals in soil solution depend on the equilibrium between soil solution and the solid phase, with pH playing a decisive role (Lindsay, 1979). In addition to pH, other soil key parameters such as CEC, organic matter content, quantity and type of clay minerals, oxides of Fe, Al and Mn; and the redox potential of the soil, all play various roles in determining the soil's ability to retain and immobilize heavy metals.

To the concern of the soil however, the effects of heavy metals pollutants could be enormous. Major amongst which is their effects on microbial activities (Wyszkowska and Wyszkowska, 2002). Other negative effects of heavy metals, especially as they are being discharged through industrial effluents include negative effects on porosity and water holding capacity, CEC, mineral composition and seed germination as established on an Indian soil contaminated by discharges form fertilizer factory (Tripathi *et al*, 1990).

All heavy metals are toxic at soil concentrations above normal level (Ayolagha and Nleremchi, 2000). The CEC of the soil is a key factor in determining heavy metal concentration and even availability in the soil. As CEC is determined by organic matter content and clay type and quantity, one is invariably saying that organic matter content and clay content affect concentration of heavy metals in the soils. Aydinalp and Marinova (2003) explained the influence of these two factors on the concentration of heavy metals in the soil as follows; heavy metals tend to form complexes with organic matter in the soils which are different for each metal. In addition to forming complexes, organic matter also retain them in exchangeable forms. These two properties affect each heavy metal differently. For example copper is bound and made unavailable chiefly through the formation of complexes, while cadmium is retained in an exchangeable form and is more readily available.

The influence of clay is also in relation to its contribution to the CEC of the soil. In general, the higher the CEC of the soil, the higher the ability of the soil to retain heavy metals, and therefore the higher the concentrations of the metals. This research aimed at investigating the effects of some heavy metals (Cd, Pb and Cu) on the fertility indices of the soil. The objectives of the research included the determination of the concentrations of three heavy metals (Lead, Cadmium and Copper) in the soil, the fertility status of the soil in terms of the amounts of some of the exchangeable basic cations, the cation exchange capacity, (CEC) of the soil, organic carbon, available Nitrogen and Phosphorus and the effects of the metals on the fertility parameters.

MATERIALS AND METHODS

The Study Area

This research was conducted on the irrigated soils along the banks of the Jakara River within the metropolitan Kano and its suburb. Samples were collected between latitude 11^{o}59' and 12^o 08'N and longitude 8^{o}34' and 8^o 42'E at an altitude of 486.5m. The predominant soil type along the Jakara River basin is the Alfisol (Ahmad, 2009) which are the normal product of soil development on the acid crystalline rock. In the Jakara Plains, there is a pre-dominance of sand particles in some of the analytical works conducted (Foloronsho, 1998; Faruk, 1999). Hydromorphic soils tend to occur in areas where annual flooding occurs. These hydromorphic soils are dark-grayish in color and have a high content of clay. These hydromorphic soils are also called *fadama* and according to Nichol (1992), these soils are normally utilized in the production of crops under limited irrigation because of their high amount of residual moisture.

Sample Collection

Two irrigation sites were selected for this research; Hajj Camp and Magami. The selection was based on type of pollution source to the irrigation water. Hajj camp is suspectedly being polluted by domestic discharges from the city into the river while Magami suspectedly being polluted by discharges from the Bompai industrial estate into the river. Grid sampling (Adepetu *et al*, 2000) was employed in which 100m^2 of land was randomly selected in each of the two sampling areas and was divided into ten equally sized grid cells of 10m^2 that ran horizontally along the bank of the river and vertically to the edge of a settlement where there is one. Five samples were randomly collected from each grid, and the five were mixed up thoroughly to produce a composite sample. Sampling was done using steel augur, fabricated locally in the fashion of the Dutch augur and samples were collected from the surface to a depth of 20cm. Sampling was done in the period between late May and the first week of June when irrigation activities were winding up and the rains were just setting in so as to avoid the dilution and leaching effects rainfall might have on some of the parameters. Samples collected were put in polythene bags and labeled serially based on proximity to water source. Samples were taken to the laboratory, air-dried; crushed and sieved with 2mm sieve (Adepetu *et al*, 2000).

Laboratory Analyses

In the laboratory, six parameters affecting fertility were determined namely; organic carbon; available phosphorus; exchangeable bases (including sodium, potassium, calcium and Magnesium); CEC, total nitrogen and pH. In addition three heavy metals namely lead, copper and cadmium were analyzed for.

Organic carbon was determined using the Walkley-Black (1934) method. Phosphorus (P) content determination was done using the colorimeter method using sodium hydrogen carbonate extraction (Adepetu *et al*, 2000). Exchangeable bases were extracted by the ammonium acetate extraction technique and determined by Flame photometry (Adepetu *et al*, 2000). The CEC was determined using the ammonium acetate saturation method as described by Hesse (1971). The total nitrogen was determined using the Kjeldal Method while pH was determined using 1:2.5 $CaCl_2$ dilution method (Adepetu *et al*, 2000).

The double acid digestion technique (Anderson, 1974) was used in sample extraction using $HCl.HNO_3$ to digest the soils for heavy metals analysis. The concentration of the metals was determined using an Instrumentation Laboratory IL251 Atomic Absorption Spectrophotometer equipped with two hollow cathode lamp holders and Rank-Hilger slotted cathode lamps were used. The instrument is switched on and allowed to warm up for 15 minutes. The instrument was set up at a wavelength for each analyte; Cu (324.7nm); Cd (228.8nm) and Pb (217.0nm). The flame was switched on and allowed to stabilize for 10minutes. Adjustments were made to achieve the most sensitive line for the element being analyzed.

Statistical Techniques

The data obtained was subjected to correlation analysis using the Pearson moment correlation coefficient technique as is found in the Statistics for Physical and Social Sciences (SPSS 11) software package.

RESULTS AND DISCUSSION

The mean values for all the fertility parameters measured are as shown in Table 1. It could be said that the soil in all the respective areas sampled is only marginally fertile, especially as most of the parameters for which more is better (organic matter, CEC and nitrogen), are only within the low- medium range when compared with the standard values given by Landon (1990). Marginal fertility is a characteristic of many tropical soils (Young, 1981), mainly because of the high rate at which organic matter is lost, high rate of leaching, highly weathered mineral and low input agricultural practices.

The values recorded at Hajj Camp for most of the parameters may even be regarded as the only values that can be described as reasonably above marginal level probably due to the fact that higher levels of organic wastes are incorporated into the cultural practices of the areas as is clear from the difference in the organic matter values of the area compared to the other area. The phosphorus levels in the two areas are excessively higher than even the values suggested by Landon (1991) as high. This could be attributed to excessive use of phosphorus fertilizer during both rain-fed and irrigation periods with the consequent manifestation of the residual effects of phosphorus. Such high levels of phosphorus may lead to nutrient imbalance which would show up in nutrients deficiencies.

Table 1: Mean values of the fertility indices determined for the different areas

Parameter	Hajj Camp	Magami	Standard (Landon, 1990)		
			High	Medium	Low
Organic carbon (%)	1.87	0.63	3.35	2.00	0.75
*Organic matter (%)	3.22	1.09	5.57	3.45	1.29
CEC (cmol/kg)	14.50	6.82	30.00	15.00	6.00
Exchangeable K (cmol/kg)	5.52	4.54	15.00	5.00	2.00
Exchangeable Ca (cmol/kg)	2.30	2.16	8.00	3.00	0.50
Exchangeable Mg (cmol/kg)	1.68	1.54	1.20	0.60	0.20
Exchangeable Na (cmol/kg)	0.43	2.64	2.00	0.70	0.30
Total Nitrogen (%)	0.021	0.007	0.30	0.15	0.05
Available Phosphorus ($mgkg^{-1}$)	322.72	179.06	140	60	20
Mean pH (1:2.5$CaCl_2$)	6.6	7.26			

*% O.M calculated by multiplying % O.C with a constant, 1.724 (Brady and Weil, 1996)
Sources: Lab analytical data and Landon (1990)

Table 2 shows the comparison of the concentration of the metals in the sites investigated and the minimum approved values under European regulations and American literature. The result indicates that the mean values for both the sites studied and for all the three metals investigated were lower than both the Bowen (1979) in Aydinalp and marinova (2003) and the EU recommended means. Despite the variability, the results are in somewhat close agreement with the findings of Anonymous (2003) in the soils of the Jakara dam irrigation site in which case the concentration of lead and copper were found to be appreciably high (up to 27.9μgg^{-1} and 41.7μgg^{-1} respectively).

Table 2: Mean concentrations of the metals for the two studied sites

Sampling site	Metal Concentration (mg/kg)			Soil pH
	Cadmium (Cd)	Lead (Pb)	Copper (Cu)	
Hajj Camp	0.029	2.98	2.484	6.6
Magami	0.034	2.76	1.744	7.26
	Minimum allowable concentration in soils (mg/kg)			
Bowen (1979) (Aydinalp and Marinova, 2003)	0.35	35	20	
EU Values (Wild, 1996)	0.35	35	30	

Sources: - lab analytical data, Wild, (1996) and Bowen (1979) in Aydinalp and Marinova (2003).

Table 3 shows the correlation between some of the fertility indices and the heavy metals on one hand; and among the metals and fertility indices themselves on the other. Correlation was tested at two levels, P = 0.01 and P = 0.05. The values are considered for the two sampling areas in bulk. Significantly positive correlation was found to exist between CEC, organic matter, nitrogen and phosphorus at P = 0.01. Significantly positive correlation was also found to exist between lead and potassium; lead and phosphorus; nitrogen and magnesium and copper and phosphorus.

Correlation between CEC and organic matter, organic matter and nitrogen and phosphorus has been established by so many researches and documented works. Significantly positive relationship has been shown by the works of Alhassan (1996) and Dawaki (1996) at the Sokoto-Rima valley. It has also being asserted by Brady and Weil (1996) that organic matter is an important source of soil nitrogen and phosphorus while Donahue et al (1990) have shown that the contribution of organic matter to the CEC of soil is several times higher than that of clay, per unit weight.

The impact of the heavy metal concentration on the soil fertility has not been very significant, so far. The only correlation was found to exist between lead and potassium and phosphorus on one hand and copper and phosphorus on the other both at P = 0.05. The lesser impact could probably be attributed to the much lower concentration of the metals in the soil. The works of Kollender-Szych et al (1998) has shown that at much higher concentration (0.2 – 1.0mg/kg for Cd, 15 – 25 mg/kg for Pb and Cu) and much higher CEC (30 – 35cmol/kg); heavy metals such as copper and zinc have being shown to affect the concentration of beneficial metal such as calcium and magnesium. Their works also has however not established any relationship between lead and organic matter. The significant relations shown by lead to potassium is an indicator of the masking effect the former could have on the latter as shown by Wild (1996), much like the relationship shown by copper and lead to phosphorus. The ability of these metals to form complexes with other ions at certain pH has already being shown by various authors (e.g. Wild 1996; Calace et al 2002 and Aydinalp and Marinova 2003). The high concentration of phosphorus in the soil has encouraged presumably, the formation of phosphate of lead and copper which may probably explain the correlation shown by these two metals to phosphorus.

Table 3: Correlation between and among heavy metals and fertility indices

	O.M	**Ca**	**Mg**	**K**	**Na**	**Cd**	**Cu**	**Pb**	**CEC**	**N**	**P**
O.M		0.679**	0.596	0.040	-0.337	-0.004	-0.106	-0.112	0.812**	0.758**	0.474**
Ca	0.679**		0.875**	0.285	-0.042	0.154	-0.126	0.158	0.507**	0.518**	0.496**
Mg	0.596**	0.875**		0.285	-0.046	-0.088	-0.358	0.147	0.313	0.404*	0.329
K	0.040	0.285	0.254		.021	0.049	-0.008	0.371*	-0.046	0.006	0.154
Na	0.337	-0.046	-0.042	0.021		0.278	-0.166	-0.068	-0.282	-0.279	-0.175
Cd	0.004	0.154	0.088	0.049	0.278		-0.150	-0.160	0.011	-0.125	-0.278
Cu	-0.106	-0.126	-0.358	-0.008	-0.116	-0.150		0.259	0.287	-0.235	0.414*
Pb	-0.112	0.158	0.147	0.371*	-0.068	-0.160	0.295		0.003	0.134	0.362
CEC	0.812**	0.507**	0.313	-0.046	-0.282	0.011	0.287	-0.003		0.668**	0.565**
N	0.758**	0.518**	0.404*	0.006	-0.279	-0.125	0.235	0.134	0.668**		0.555**
P	0.474**	0.496**	0.329	0.154	-0.175	-0.278	0.414*	0.362*	0.565**	0.555**	

*Significant at 0.05 LSD ** Significant at 0.01 LSD
Source: Lab analytical data

CONCLUSION

It could safely be concluded that the quality of the soil for production although not immediately under threat especially with the very low mean values of the pollutants and the lack of significant effects they exert on many of the fertility indices determined. However such safety cannot be guaranteed forever. This is because the pollutants are gradually building up, because of their nature of forming complexes and not being easily leached out.

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