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Residual Effect of Long Term Application of Organic and Mineral Fertilizers on Selected Chemical Properties of a Savanna Alfisol

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Abstract: The residual effect of organic and mineral fertilizers on selected chemical properties of an Alfisol in the long term soil fertility trial established in 1950 at Samaru, Nigerian savanna was assessed. The trial was left fallow for fourteen years due to lack of funds. Topsoil was collected from plots that received three levels of cow dung (D), nitrogen (N) and phosphorus (P) in all possible combinations. The soils were analyzed for selected chemical properties. Except for significant effect of applied P on available P, sole application of cow dung, N or P had no significant effect on all the measured soil properties. The interaction of D and P significantly affected the mean values of exchangeable Ca, Mg, K and ECEC in the range of 1.12-1.96, 0.62-1.11, 0.37-0.64 and 2.82-4.11 cmol/kg respectively. The most important results were the ability of the plot that received neither D nor P to significantly increase these parameters than the plots that received only one of the treatments. The results show that the fallow period has changed the effects of application of organic and mineral fertilizers on the soil chemical properties under continuous cultivation by modifying them towards those of a native savanna Alfisol.

Key words: Alfisol, chemical properties, fallow, long-term, mineral fertilizer, organic fertilizer.

1. Introduction

The cropping systems in many parts of the West African savannas have witnessed a significant change in the last few decades with a shift from the traditional shifting cultivation to continuous cropping [1]. This is due to the burgeoning population and the associated pressure on the resource base, especially agricultural land. On the other hand, the introduction of higher yielding but also nutrient-demanding crop varieties could not allow farmers adapt to intensive cultivation on the inherently poor soils without the use of external inputs such as mineral fertilizers. Therefore, investigations into ways of increasing the productivity of agricultural lands under continuous cropping have become imperative. The soils are dominated by either Alfisol or Ultisol. These are characteristically low in organic matter (OM) and CEC, deficient in N and P and are largely coarse textured with clay fraction dominated by kaolinite. Under continuous cropping, soil fertility rapidly declines thus making it difficult to sustain crop yields at high enough levels to feed the expanding population [2].

The long term soil fertility trial at Samaru, northern Guinea savanna of Nigeria was established in 1950 to compare the effectiveness of organic and/or mineral fertilizers on soil properties, crop performance and yield under continuous cultivation. Forty five years later, combined application of organic (cow dung) and mineral fertilizers was reported to improve soil quality

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and crop productivity in the fragile agroecosystem [3, 4]. Studies at several other locations in the agro-ecological zone have also shown immediate benefits to maize yields with combined application of urea-N and an organic source of N [5]. However, nothing is known on the changes in ecosystem that have occurred in the Samaru site 14 years after it has been left under natural fallow. During a long-term natural fallow period, there is restoration of ecosystem biodiversity and productivity similar to that before the cropping period. The biomass usually consists of many plant species with different types of root systems that are considered to be most efficient for nutrient cycling. The biomass production and the rooting system modify soil properties over the years of fallowing and reach a conservative nutrient equilibrium characteristic of an old fallow or a savanna ecosystem [6].

In this study, the chemical properties of a kaolinitic Alfisol under natural fallow are measured 14 years after long-term application of organic and mineral fertilizers. The hypothesis tested is that soil chemical properties induced by cow dung addition to farm plots remain enhanced during fallow periods as long as fourteen years.

2. Materials and Methods

2.1 Materials and Site Description

The Samaru long-term soil fertility trial was started in 1950. Samaru (Lat. 11°11′N; Long. 7°38′E, altitude 686 m.a.s.l) is located in the northern Guinea savanna (NGS) of Nigeria and has a monomodal rainfall pattern with eighty years mean annual rainfall of 1011 ± 161 mm concentrated almost entirely in the five months (May/June-September/October) of the cropping season [7]. The main soil sub-group is Typic Haplustalf [8] or Chromic cambisols according to the FAO system of soil classification [9].

2.2 Treatment and Experimental Design

The treatments consist of three levels each of cow dung (D), N, P and K applied annually in all possible combinations. The 81 treatment combinations are arranged randomly in nine blocks. Each block contained nine plots and each plot size was 220 m^2 with adequate discard. Top soil (0-15 cm) was collected from 27 selected plots representing all combinations of D, N and P giving a 3 × 3 factorial combination. The K was deliberately omitted because previous studies on the site have shown no positive effect of K on soil and crop productivity [10]. The detailed description of the selected treatments is contained in Table 1. Fertilizer rates were increased substantially as from 1972 to correspond to the official recommendations for the crops grown on the site (Table 1). A three-course rotation of cotton, sorghum and groundnuts was followed from 1950 to 1960. From 1961 to 1970, the field was continuously cropped to cotton and from 1971 to 1975, to maize. A groundnut-maize rotation was introduced in 1976 and continued till 1995 after which the experimental field was left fallow. In this scenario, N was not applied and P rates were reduced to half whenever groundnut was grown as sole crop.

2.3 Soil Sampling and Analysis

A treatment plot was divided into three homogenous sub-plots of 72 m^2 using a stratified sampling procedure. Ten random soil samples were taken from each sub-plot and bulked. The soil samples were air-dried and screened through 2-mm sieve. The samples were analyzed for pH (H_2O). Sub-samples were fine-ground to 0.5 mm for the determination of

Table 1 Rates of organic and mineral fertilizers (kg/ha) used during the experimental period

Treatment	Level			Years
	0	1	2	
Cow dung (D)	0	2500	5000	1950-1995
[a]Nitrogen (N)	0	24	48	1950-1971
	0	67.5	135	1972-1995
Phosphorus (P)	0	9	18	1950-1971
	0	27	54	1972-1995

[a] N was applied as $(NH_4)_2SO_4$ from 1950 to 1968 and as $CaNH_4(NO_3)_3$ from 1969 to 1995, P was applied as single superphosphate, K was applied as muriate of potash (KCl). In all cases, level 1 rates were exactly half the rates of level 2 while 0 is "nil".

soil organic C (C_{org}) and total N (N_{tot}). Soil organic was determined by dichromate oxidation [11]. Total N was determined by the regular Kjeldahl distillation method [12] while available P was determined with an auto-analyzer following extraction with Mehlich III extraction solution [13]. Exchangeable bases (Ca, Mg, K and Na) were determined in the same extract by atomic absorption spectroscopy. The effective cation exchange capacity (ECEC) was calculated by summing the exchangeable bases and exchangeable acidity (EA). Data collected were analyzed using analysis of variance and treatment means were compared with the Fisher's least significant difference (LSD) test. All analyses were performed by the STATISTICA program (2007).

3. Results and Discussion

The main effects of long-term application of D or N were not significant ($P > 0.05$) on all the soil chemical properties measured (Table 2). Similar trend was observed with the application of P except for available P that was found to be significantly affected (Table 2). In this case, significantly higher value (7.76 mg/kg) was observed with the highest rate of P application (P_2) compared with P_0 and P_1. However, there was no significant difference between the lower rate (P_1 = 3.54 mg/kg) and nil (P_0 = 2.66 mg/kg). The interaction of D and P had a significant influence on soil pH, exchangeable Ca, Mg, K and ECEC (Table 2). On the other hand, the interaction of N and P had significant effect on available P only while D and N interaction and the second order interaction between D, N and P had no significant effect on any of the soil properties (Table 2).

The results of this study are in contrast to previous studies that have shown the beneficial effects of manure application on soil properties in the savanna Alfisol. Increased levels of soil C, N, P and CEC were reported with 45 years of annual application of farmyard manure [3, 14]. Although the residual effects of long-term application of manure on soil properties have been reported to last for several years [15], the magnitude of these effects diminishes or even disappears with time after application ceases depending on the rates of application [16]. It is believed that the fallow period after the last application of cow dung in the study site was sufficient to eliminate its beneficial effects on soil properties. Soil processes such as decomposition and rapid mineralization of organic matter in the savanna could be responsible for the decline in soil C, N and P. Reduction in soil organic matter means reduction in CEC because over 80% of CEC of savanna soils is contributed by OM. In this situation, there will be rapid leaching of basic cations because of the absence of exchange sites to adsorb them. This process is further exacerbated in the coarse textured soils. On the other hand, our study corroborates previous findings on the site that continuous application of N fertilizer had a negative effect on soil chemical properties. However, the residual effects of P fertilizer application on plant-available P could be said to have lasted up to 14 years since there was no addition after the site has been left fallow (Table 2). Phosphorus is relatively immobile in the soil and total plant P requirements are much lower than those of N. Although added P could be adsorbed on the surfaces of Fe and Al oxides in the P-fixing savanna soils, repeated additions have cumulative benefits. In acid P fixing soils, alkali-soluble inorganic-P fractions represent a sink for P during excess application, but also a P source under conditions of deficient supply [17]. This fraction could account for the residual effects of P application on plant-available P observed in this study.

The interaction between N and P has been found to be synergistic but the trend of our results seems to be controlled by P application suggesting smaller residual effect of N. In contrast, the interactive effect of D and P was not significant (Table 2). The presence of humic substances as a result of mineralization of dung manure could have prevented residual phosphate from direct bonding with soil surface [18]. On the other hand, exchangeable Ca, Mg and K were significantly influenced by the interaction of D and P. The values

Table 2 The F ratios of analyses of variance for the main and interaction effects of dung, nitrogen and phosphorus on soil chemical properties in the long-term soil fertility trial at Samaru, Nigeria.

Source	d.f.	pH (H_2O)	C_{org} /%	N_{tot} /%	Avail.P /mg/kg	Ca	Mg	K	Na	EA	ECEC
						----------/$cmol_c$/kg----------					
D	2	0.18	0.55	1.43	1.47	2.59	1.29	3.16	0.83	2.07	2.16
N	2	0.96	0.23	0.25	0.24	0.79	0.99	0.07	1.14	0.69	0.56
P	2	1.90	2.58	3.52	23.82**	1.67	0.59	0.20	1.08	0.16	0.53
D × N	4	0.30	0.09	0.46	1.32	1.60	1.72	2.18	0.45	0.76	1.95
D × P	4	3.57*	0.37	1.40	1.41	4.65*	4.79*	6.91*	1.72	0.38	4.51*
N × P	4	0.40	0.17	0.90	4.23*	1.14	0.72	1.24	1.77	0.79	1.49
D × N × P	8	1.38	1.07	0.45	0.92	1.49	2.04	2.71	1.81	1.13	2.39

* Significant at $P = 0.05$, ** Significant at $P = 0.01$.

were elevated with the combined application of the first level of D and the second level of P (D_1P_2) or combination of the second level of D and the first level of P (D_2P_1) but interestingly, the plot without application of either nutrients (D_0P_0) maintained values at par with these treatments (Table 3).

Similarly, the interaction of N and P fertilizers has a long-term residual effect on plant available P with the combination of lower N rate (24-67.5 kg N/ha) and the highest P rate (9-27 kg P_2O_5/ha) giving a significantly higher value compared to other treatments (Table 4).

Generally, the values are similar to those reported shortly after the commencement of the trial [10] and within the range reported for a native kaolinitic savanna Alfisol [19]. This suggests that the fallow period played significant role in modifying the fertility of the savanna soil but the levels of the soil chemical properties were not raised sufficiently enough to support continuous cultivation without addition of external inputs.

Table 3 The interaction effects of dung and phosphorus on soil pH, ECEC, exchangeable Ca, Mg and K.

Treatment	pH (H_2O)	Ca	Mg	K	ECEC
		----------/$cmol_c$/kg----------			
D_0P_0	5.30	1.67	0.97	0.56	3.80
D_0P_1	5.17	1.27	0.74	0.38	3.04
D_0P_2	5.23	1.41	0.78	0.37	3.23
D_1P_0	5.20	1.12	0.62	0.40	2.82
D_1P_1	5.23	1.37	0.80	0.46	3.34
D_1P_2	5.47	1.96	1.11	0.57	4.11
D_2P_0	5.33	1.62	0.93	0.48	3.64
D_2P_1	5.43	1.84	1.03	0.64	4.10
D_2P_2	5.37	1.65	0.86	0.47	3.58
LSD (P = 0.05)	0.23	0.47	0.28	0.14	0.83

Table 4 The interaction effects of nitrogen and phosphorus on available P.

Treatment	Avail. P/mg/kg
N_0P_0	2.13
N_0P_1	5.04
N_0P_2	6.29
N_1P_0	1.78
N_1P_1	2.80
N_1P_2	10.32
N_2P_0	2.79
N_2P_1	4.06
N_2P_2	6.67
LSD (P = 0.05)	3.03

4. Conclusions

The results of the study has revealed that the residual effects of organic and mineral fertilizers on the productivity of a savanna Alfisol disappear within a period of 14 years after application had ceased. The long-lasting effect of P fertilizer on available P shows that repeated additions have cumulative benefits which are proportional to the application rates. The implication of our results is that prolonged interval could disrupt the direct and residual benefits of organic and mineral fertilizers on soil fertility maintenance but large doses of P should be avoided to mitigate potential environmental pollution. While the fallow period was found to cause decline in some soil chemical properties, future studies may focus on the evaluation of the soil physical properties as these have been reported to

improve under fallow conditions as well as with the combined application of organic and mineral fertilizers. In addition, agronomic trials in the experimental site would enable us determine the overall effect of the long fallow period on crop productivity.

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