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CONSTITUENT COMPOSITION OF HARMATTAN DUST AND ITS INFLUENCE ON PROPERTIES OF *FADAMA* SOILS IN SEMI-ARID REGION, NORTH EAST NIGERIA

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Abstract

A study of the soils of the *fadama* around Gashua was carried out to assess the contribution of harmattan dust deposition on their genesis and characteristics. The surface horizons have medium coarse prismatic structure or strongly developed coarse subangular or angular blocky which becomes coarse prismatic with depth. The surface horizons typically have loam to sandy loam textures and low bulk density values (<1.17). The annual addition of the harmattan dust has the potential of improving the nutrient contents of *fadama* soils. This study shows that harmattan dust is an important soil-forming factor in *fadama* soil pedogenesis and represents a significant natural process in the fluvial ecosystems. The clay minerals of dust and soil were similar, being dominated by kaolinite and illite, with smaller amounts of vermiculite. It is concluded that harmattan dust contributes significantly to the fertility of *fadama* soils.

1. Introduction

Ecosystems acquire their soil nutrients from either unconsolidated sediments derived directly from *in situ* weathering or atmospheric deposition of mineral dust that commonly mixes with the soil and sacrificial deposits. Distinction between these two sources is important in understanding the geochemical characteristics of soils and the controls over supply of rock derived nutrients to plants (Wells *et al.* 1987, Vitousek *et al.* , 1999; Wang *et al.* 2004).

The distinction between substrate weathering and mineral-dust inputs can be made by integrating isotopic, mineralogical, textural, and geochemical analyses of soil. The nutrient input by dust may be an important factor for the maintenance of soil fertility. For example, dust geochemistry has been used to evaluate the long-term importance of atmospheric mineral-dust additions to the fertility of tropical forests on old, deeply weathered substrates in the Amazon basin (Swap *et al.*, 1992; Verecchia *et al.*, 1995). Similarly, Chadwick *et al.* (1999) have demonstrated the role of atmospheric inputs to ecosystems' fertility on older Hawaiian Islands using isotopic and mineralogical approaches.

Geochemical, isotopic, and mineralogical methods have also been used to identify the presence of aeolian dust in soils and superficial deposits in deserts (Shachak and Lovette, 1998). This body of work has improved understanding about interrelated aspects of dust content, soil composition and texture, and soil hydrology. Nevertheless, little is known about the relative contributions of harmattan dust and bedrock weathering to rock-derived nutrient content of most dry land environments in Nigeria.

Studies on aeolian dust and their influence on soil development in semi arid region of West Africa have indicated that the dust plays a significant role in improvement of the fertility of these soils (Stoorvogel *et al*., 1997; Stahr and Herrmann, 1996). Dust characteristics and their

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influence on genesis, texture ad nutrient status of soils have been examined in numerous studies (Moberg *et al*., 1991; McTainsh, 1984). The larger amounts of available phosphorus in the surface horizons as compared with the subsoil could partly be the consequence of the deposition of harmattan dust, which is known to contain up to 10 times the available phosphorus per unit weight of the surface horizons on which it is falling.

During the period between November to January each year, dry north easterly surface winds (harmattan) distribute dust in most parts of northern Nigeria (Moberg *et al*., 1991; McTainsh, 1984) and sometimes over most parts of the country. The presence of harmattan dust in the soils of north eastern part of the country has not received much attention. There is paucity of research on the extent, composition and contribution of harmattan dust deposition to the fertility of seasonally flooded *fadama* soils (Kundiri, 1995; Kundiri *et al.,* 1997). The conclusions by Moberg *et al.* (1991) which highlights the paucity of information on the influence of aeolian processes on soils in northern Nigeria serves as a stimulus for the paper.

The primary purpose of this paper was to determine the characteristics and constituent composition of the harmattan dust on *fadama* and also to compare these properties with *fadama* and nearby upland soils in which they are falling. The paper also attempts to estimate the abundance of far-travelled harmattan dust on the *fadama* soils as well as the relative importance of harmattan dust in providing potential plant nutrients.

2. Materials and method

The study was carried out on the alluvial floodplain of the Komadugu-Yobe which is situated in the semi arid region of Nigeria around Gashua in Yobe State, between latitude 12^o-13^o N and longitude 10^o-11^o E. The pattern of the rainy season is such that it starts in June or July, gradually increasing in amount and frequency, reaching a maximum in August and ceasing completely in September/October. The area has more or less flat topography. Geologically, the area is composed of recent and sub-recent alluvium. The floodplain area currently has a sparse vegetation cover. The natural vegetation consists mainly of *Acacias* with patchy short grasses. The grass species include *Cenchrus biflorus*, *Aristida stipoides*, *Schoenfeldia gracilis* and *Chloris prieurii*.

The soils were described using the terms, scales and codes in Soil Survey Field Handbook (Hodgson, 1974) and recorded on Soil Survey and Land Research Centre proforma data recording cards modified to suit fluvial environments (Kundiri, 1995). Eight representative soil profile pits were dug and the morphological characteristics of each surface horizon were also described. Soil samples were collected from the surface horizons and prepared for subsequent laboratory analysis.

Harmattan dust was also collected on the *fadama* around Gashua using 6 plates placed 1.5 m above the ground during the cool dry season between the months of November and June. The height was selected so that it was sufficient to prevent surface saltation of grains from entering the trap. Each plate was 1.5 m^2 in area and was screened with fine wire mesh to avoid contamination by birds and insects. The oven-dried weights of the harmattan dust were measured and the samples were ashed at 600 °C for 3 hours to obtain the weight of the mineral component. The sample weights were corrected for collector efficiencies, collector diameter, and length of sampling period to estimate the flux of dust.

The same laboratory methods used in analyzing the soil samples were also adopted for the analysis of the dust samples. The samples of *fadama* soil and harmattan dust were analysed for the following physical and chemical properties: Particle size distribution by pipette method using hydrogen peroxide to destroy organic matter and 5% Sodium hexametaphosphate (calgon) as dispersing agent (Bascomb, 1974). The pH was measured in a 1:2.5 soil:water suspension using a pH meter (MAFF, 1985). The electrical conductivity was determined in a 1:5 soil:water ratio using a conductivity meter (MAFF,1985). Exchangeable cations were determined by extraction with 1M NH_40AC (pH 7) solution.

Exchangeable K^+ and Na^+ were determined by flamephotometry and Ca^{++} and Mg^{++} by spectrophotometry. Organic carbon was determined by dichromate wet oxidation method (Bascomb, 1974) and total N by Kjeldhal digestion (MAFF, 1985). Phosphorus in the samples was extracted with 0.5 M $NaHC0_3$ (pH 8.5) (Olsen *et al.*, 1954). Cation exchange capacity was determined by $BaCl_2$ saturation and subsequent displacement of the adsorbed saturating cation (Rhodes, 1985).

The constituent compositions of the particle size fractions were determined using the method described by Moberg *et al.* (1988). The estimates of sand fractions were based on X-ray diffraction of non-oriented samples and microscopy (Klute, 1986) while the clay fraction was estimated by using a combination of X-ray diffraction analysis on both oriented and non-oriented samples as well as total elemental analysis and thermogrametric analysis (Ramsperger *et a*l., 1998). Clay-sized and silt-sized sub-surfaces from the two soil types were analysed to determine whether there were any differences in the clay and silt mineralogy of the surface 0-20 cm and 20-40 cm soil layers as well as the influence of harmattan dust.

3. Results and discussion

The texture of the *fadama* soil is closely related to the sediments in which it is formed (Table 1). The surface horizons have either strongly developed coarse prismatic structure or moderately developed subangular blocky. Analysis of field and laboratory data suggests that the surface horizons of the *fadama* soils are physically and chemically distinct from the soils of the surrounding uplands (Table 2). The surface horizons typically have loam to sandy loam textures and low bulk density values (<1.17 g/cm^3). The *fadama* soils also showed a difference, although less distinct, between the surface 0-20 cm and 20-40 cm layers, where they had considerably higher clay and lower sand content (Table 1). At some sites, these soils exhibited distinct bands of 0.5–1.5 cm thickness within the 0-20 cm depth with a distinctive reddish colour (Munsell 5YR 3/2) as shown in Table 3.

Table 1: Particle size analysis of soil samples from Gashua *fadama*

	Surface horizon (0-20cm)	Sub-surface horizon (20-40cm)	Upland soil (0-40cm)
Moisture content {%}	3.2	4.1	2.1
Organic matter content (%)	7.1	5.3	4.1
Clay (%)	39.1	32.5	23.1
Silt (%)	27.7	28.4	20.4
Fine sand (%)	23.3	20.3	18.3
Coarse sand (%)	9.9	18.8	38.2

Table 2: Chemical properties of soil samples taken from the *fadama* at Gashua

	Fadama	**Upland**	**Harmattan dust**
	Surface Horizon (0-20 cm)		
Ph	6.40	6.80	6.90
EC dS m^{-1}	7.00	5.80	6.00
Moisture content (%)	0.70	0.40	0.30
Organic carbon (%)	0.50	0.30	0.60
Bulk density kg m^{-3}	1.23	1.37	-
Nitrogen {mg/kg}	0.38	0.21	0.50
Phosphorus {mg/kg}	9.50	6.30	10.20
Calcium {mg/kg}	7.10	5.10	8.30
Potassium {mg/kg}	0.70	0.40	0.90
Magnesium {mg/kg}	5.90	2.30	6.20
Sodium {mg/kg}	0.60	0.40	0.70
CEC{mg/kg}	31.20	28.50	37.90
Percent Base Saturation	63.40	60.71	65.87
	Sub-surface horizon (20-40 cm)		
pH	6.80	5.70	-
EC (dS m^{-1})	6.40	5.20	-
Moisture content (%)	0.50	0.40	-
Organic carbon (%)	0.30	0.20	-
Bulk density (kg m^{-3})	1.32	1.34	-
Nitrogen {mg/kg}	0.21	0.11	-
Phosphorus {mg/kg}	7.60	6.30	-
Calcium {mg/kg}	5.30	4.70	-
Potassium {mg/kg}	0.40	0.30	-
Magnesium {mg/kg}	4.70	3.20	-
Sodium {mg/kg}	0.40	0.30	-
CEC{mg/kg}	29.62	25.40	-
Percent Base Saturation	59.68	54.86	

Table 3: Description of soil profile pit

Pit No 1 Horizon	**Depth (cm)**	**Texture**	**Structure**	**Moist matrix colour**	**Mottle colour**
Apg	0-13	Clay loam	Moderately developed coarse subangular blocky	Grayish brown 10YR4/2	Many fine and medium clear yellowish brown 10YR5/8
Bg1	14-41	Clay	Moderately developed medium prismatic	Gray 2.5Y 5/1	Many fine and medium diffused distinct yellowish brown 10YR5/4
Bcg	42-47	Clay loam	Moderately developed fine and medium subangular blocky	Grayish brown 10YR5/2	Light grayish brown 2.5Y5/2 Pale brown 10YR6/3
2Cg	48-73	Sand	Apedal single grained	Pale brown 10YR6/3	Many fine and medium prominent brownish ellow 10YR6/8
3Cg	74-78	Loamy sand	Very weak medium subangular blocky	Grayish brown 2.5YR6/1	Many fine and medium prominent strong brown 7.5YR4/6
3Cg2	79-114	Sand	Apedal single grained	Pale brown 10YR7/1	Common prominent and diffused reddish yellow 7.5YR7/8

Plot 2 **Horizon**	**Depth**	**Texture**	**Structure**	**Moist matrix colour**	**Mottle colour**
Apg	0-20	Clay	Strongly developed coarse prismatic	Dark grayish brown 2.5Y4/2	Common fine clear dark gray 5Y4/1
Bg1	21-50	Clay	Weakly developed coarse subangular blocky	Gray 2.5Y 5/1	Common fine diffused yellowish brown 10YR5/6 strong brown 7.5YR5/8
Bg2	51-94	Clay	Strongly and moderately developed medium angular and subangular blocky	Gray 2.5Y5/1	Common fine distinct diffused strong brown7.5YR5/8
Bcg	95-104	Sandy clay loam	Weakly developed medium subangular blocky	Grayish brown 2.5Y5/2	Many distinct clear strong brown 7.5YR5/8
2Cg	105-107	Sandy loam	Massive with weakly developed coarse subangular blocky in loamy layer	Pale brown 10YR6/3	Many medium and coarse prominent and diffused strong brown 7.5YR5/8

All the surface horizons had higher organic matter contents, EC, and nitrogen and phosphorus concentrations. The major exchangeable cations in these soils are Ca and Mg, with the amount of exchangeable Ca in the 0-20 cm layer of the *fadama* soils being conspicuously high. The pH of the 0-20 cm layer vary from slightly acidic to neutral soils and harmattan dust. The slightly acidic top soils may be due to the presence of strongly acidic functional groups in organic matter which were dissociated during organic matter mineralization.

The electrical conductivity of the soils (Table 2) fall within 5.20-7.0 ds/m which is greater than 4.0 ds/m threshold levels for salinity hazards to crops (Richards, 1969). The high EC values for *fadama* and upland soils as well as the harmattan dust suggests that additional increase in salts could have a tendency for salt build up which could have serious implications for sustainable crop production. The total nitrogen content of the soils varies from 0.11 to 0.38%. The moderate levels of nitrogen suggest that continuous cropping on these soils would require adequate fertilizer application.

Available phosphorus is low in all soils and was rarely above 9.5 ppm in any of the top soils. The larger amounts of available phosphorus in the surface horizons as compared with the subsoil could partly be the consequence of the deposition of harmattan dust, which is known to contain up to 10 times the available phosphorus per unit weight of the surface horizons on which it is falling (Moberg *et al.* 1991). From an agronomic point of view, the soils may be defined as high base status soils, since calcium and magnesium are the dominant exchangeable cations. The base saturation in it is above 50%. The relatively high base saturation is one of the noteworthy characteristics of these soils and could partly be responsible for their fairly high productivity under traditional agriculture (Tiessen *et al.*, 2003).

The cation exchange capacity (CEC) of the soils in all units is medium to highland satisfies minimum values of 3 meq/100g suggested by Dent and Young (1981) as satisfactory for arable cropping. The moderate level of CEC in the soils could be explained by the low organic matter content and the fact that clays are mainly kaolinitic, in nature, which is common with soils of north east Nigeria (Esu, 1989; Beavington, 1978). The *fadama* soils are more fertile than the adjacent upland soils partly because of the annual deposition of sediments and organic matter by the flood water from the Yobe River.

The surface 0-20 cm and 20-40 cm soil layers of the *fadama* soils were dominated by quartz, with feldspars, illite, kaolinite, chlorite and interstratified vermiculite, illite, or chlorite all present in reasonable proportions (Table 4). However, the amount of these clay minerals had all decreased in the 20-40 cm layer (Table 5). This is an indication of the contribution of harmattan dust to the surface of *fadama* soils. The differences between the 0-20 cm and 20-40 cm soil layers of the *fadama* soils in texture, structure, and chemistry support the theory that the surface layers are strongly influenced by aeolian-derived material, while the sub-surface horizons are the products of the weathering of the local bedrock.

Table 4: XRD analysis (%) of soil samples taken from *fadama* and upland at Gashua

Clay mineral	***Fadama***	**Upland**
	Surface horizon (0-20 cm)	
Illite	20.0	18.3
Kaolinite	18.1	17.2
Gibbsite	4.3	3.8
Vermiculite	6.2	5.7
Chlorite	2.1	2.0
Microcline	6.3	5.7
Orthocline	9.6	7.7
Quarrtz	47	44
	Sub-surface horizon (20-40 cm)	
Illite	16.3	15.1
Kaolinite	14.2	12.6
Gibbsite	4.0	3.8
Vermiculite	5.7	5.1
Chlorite	1.9	1.2
Microcline	5.3	4.9
Orthocline	7.2	6.3
Quarrtz	40.1	39.3

This study shows that harmattan dust is an important soil-forming factor in *fadama* soil pedogenesis and represents a significant natural process in the fluvial ecosystems. However, at this time we have no data on long-term rates of dust influx. The high deposition corresponds more frequently with the harmattan period. Sediment within the fine sand range dominated the trapped sediment (Table 5). A long-term monitoring program to measure influx rates and the effects of climate is needed to describe more completely the effects of harmattan dust influx in *fadama* ecosystems. This study reveals that the estimated contributions of dust to soil fertility of the soils on which the dust falls could be remarkable. The content of silts is much higher in the harmattan dust than the soils in which it falls (Reynolds *et al.,* 2006).

Table 5: XRD analysis of dust samples falling on the *Fadama* soils

	% of components
Silt 2-20μm	36
Clay <2 μm	40
	% <2 μm
Illite	48
Kaolinite	37
Vermiculite	21
Chlorite	5.3
Quarrtz	1.8

The samples trapped during periods of high deposition generally comprised of coarser material and contains higher percentage of quartz, suggesting that much of the sediment trapped was locally derived. The role of aeolian dust in ecosystem nutrient dynamics in these semi-arid ecosystems is likely to be significant (Drees *et al.*, 1993). Phosphorus can co-limit productivity (with N) in semi-arid environments (Snyman, 2002), particularly when water availability is high. Despite uncertainty regarding the total contribution of dust to surface P, this study shows that this contribution is significant.

In both *fadama* and upland soils, it is likely that aeolian dust inputs represent an important input of P to ecosystems. The more specific roles of these inputs, including their availability to biotic systems, remain unknown. Similar approaches reveal the importance of aeolian dust to dryland soil nutrient pools in other geologic settings (Stuart, 2001).

Atmospheric dust input varied during the period of collection as did particle size, being bigger in period of maximum fall. Dust deposition rates are highly variable but did not show any distinct seasonal pattern, although slightly higher amounts were recorded in November-January when maximum deposition occurs. The dry colour of the dust varied from light yellowish brown (10Y 6/5) to pale brown (10YR 6/4).

The study recorded dust accession rates of (1500 kg/ha), which is higher than the values reported by Moberg *et al.* (1991). But the absolute quantities of sediment trapped were comparable to those reported by previous studies. This can be explained by the proximity of the area to sand dunes around Kajimaram, Tolotulowa and Kaska. Any addition of soil material of this order of magnitude would certainly modify the nature of the soil profile.

However, as found in previous studies around the world, any monitoring of dust accession rates of 1 year or less is probably not representative of long-term dust deposition, since influx rates may vary annually especially when related to variance in climatic conditions (O'Hara *et al.*, 2006).

The clay minerals of dust and soil comprised of smectite and illite, with smaller amounts of kaolinite (Table 4). The dust samples showed higher amount of kaolinite (Table 5).

4. Conclusions

Increases in dust deposition generally coincided with increase in wind speed and with samples collected during this period having a higher proportion of coarse particles, suggesting an influx of locally derived material. The nutrient status of harmattan dust is substantially greater than the native soil and may serve as a nutrient renewal vector. Harmattan dust had clearly finer particle size distribution than dust collected during local storms, but the angularity and evidence of weathering on dust particles did not distinguish dust from different sources.

Comparing the dust with adjacent soil samples, a higher clay and organic matter content was found in dust, giving relatively high exchange capacities and available weatherable K, Ca, Mg and P were slightly higher in dust than in the soils. The EC, CEC, and water soluble ions in the dust were distinctly higher than at the soil surface, and dust therefore contributes ions to the soils. The enrichment with nutrients at the soil surface can be partly contributed by dust deposition.

This study shows that harmattan dust is an important soil-forming factor in *fadama* soil pedogenesis and represents a significant natural process in the function of *fadama* ecosystems. However, at this time we have no data on long-term rates of dust influx. A long-term monitoring program to measure influx rates and the effects of climate is needed to describe more completely the effects of harmattan dust influx in *fadama* ecosystems.

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