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Nutrient deposition during the harmattan dry season across the northern region of Ghana

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Abstract

The harmattan dry season (November to February) across West Africa is associated with dry nutrient deposits that are attributed to external dust sources and the redistribution of nutrients from local soils. Quantities of dry nutrient deposits are mostly estimated at single sites or in a single (North to south) direction; limiting data and knowledge on the two dimensional spatial nutrient deposits. In this study, the geospatial distribution of dry nutrient deposits across 15 (5 latitudinal zones and 3 longitudinal zones) sites of the entire northern region of Ghana is investigated through a modified stratified contiguous unit based spatial technique in order to ascertain the spatial variations and the mean dry nutrient inputs. Deposited nitrate-N showed no apparent trend in spatial distribution. However, quantity of deposited P, K, Ca, and Mg positively correlates with latitude ($P < 0.05$) and with longitude ($P > 0.05$): with latitude being the greater predictor of dry nutrient deposits. Negative correlations between Ca and Mg concentrations on one hand with Na and K concentrations on the other hand for all sites suggest that substantial amounts of deposited Na and K may not have come from same sources as Ca and Mg. Variation in mean nutrient concentration (mg kg^{-1}) with month (NO_3^--N: 24-640; P: 23-56; K: 2720-4150; Ca: 1680-2010; Mg: 740-930) and not space is attributed to temporal differences in nutrient sources. High nutrient concentrations of dry deposits compared to the concentrations of soils of harmattan dust sources and to concentrations of local soil nutrients (total N: 710; P: 12; K: 25; Ca: 610; Mg: 200) given similar chemical treatments as the dry deposition; suggest the return of burned vegetation debris to be a major contributor to dry nutrient deposits besides dust transport and redistribution from local soils. Given the relatively low amount of total annual dry deposits per unit area (95% confidence interval: 53 ~122 Mg km^{-2}), the total supply of plant nutrients (kg km^{-2}) by dry deposition (NO_3^--N: 3-40; P: 1-6; K: 100-620; Ca: 70-200; Mg: 40-90) is however minimal to the soils available nutrient pool.

Key words: Harmattan, geospatial distribution, burned ash, nutrient source, food security

Introduction

Dry atmospheric nutrient deposition is an essential source of soil nutrient replenishment in the northern region of Ghana during the harmattan dry season (Kugbe et al. 2012). The source of the nutrient is attributed to external dust, aerosols, and the redistribution of nutrients from local soils (Baker et al. 2006). The quantities of nutrient deposits are mostly estimated at single sites or in a single direction (e.g., north to south). Though such estimates are representatives of the sampled sites, there are no detailed studies on the two-dimensional-geospatial and temporal deposition of these nutrients. Given that dry nutrient deposition is a fundamental component of the underlying nutrient balance of the West African region, filling this knowledge gap is essential in understanding the holistic cycle of each nutrient element.

The aims in this study were to quantify the dry nutrient deposition (concentration, quantity), and how the deposition varies with month of deposition and geographical space, and relate these to the potential sources of the deposited nutrients.

Materials and Methods

A 24 cm surface-diameter dry-deposition sampler was used to collect the monthly deposits using the water-filled basin method. A complete description of the sampler, sampling sites and sampling process is provided in Kugbe et al. (2012). In summary, a modified stratified contiguous unit-based spatial sampling technique was used in this study, where the study area was stratified into 15 strata (three longitudinal zones and five latitudinal zones, Figure 1). Data collected from any point within a stratum were deemed representative of that stratum and different from data collected from any other strata. The technique is based on Tobler's First Law of Geography, which argues that for a given parameter, nearby units are more related to each other and hence share similar information compared to units that are far apart, especially so if the information is spatially correlated. There were three replications per sampling site. Nutrient extraction and chemical analyses follows the procedure described in Kugbe et al. (2012).

Statistical comparisons were made by the ANOVA and pair-wise t-testing procedure at alpha level of 0.05. Post hoc tests were run with the Duncan's multiple range test. Temporal and geospatial linear relations in nutrient concentrations and depositions were analyzed using Spearman's correlation.

Results and Discussion

Temporal nutrient concentration and deposition

The estimated average dust fall rate during the harmattan season was 0.4-1 g m^{-2} day^{-1}. This value is higher than the 0.25 g m^{-2} day^{-1} reported by Lyngsie et al. (2011) at a single location (Nyamkpala), and is attributed to the variations in geospatial dust fall rate across the study area.

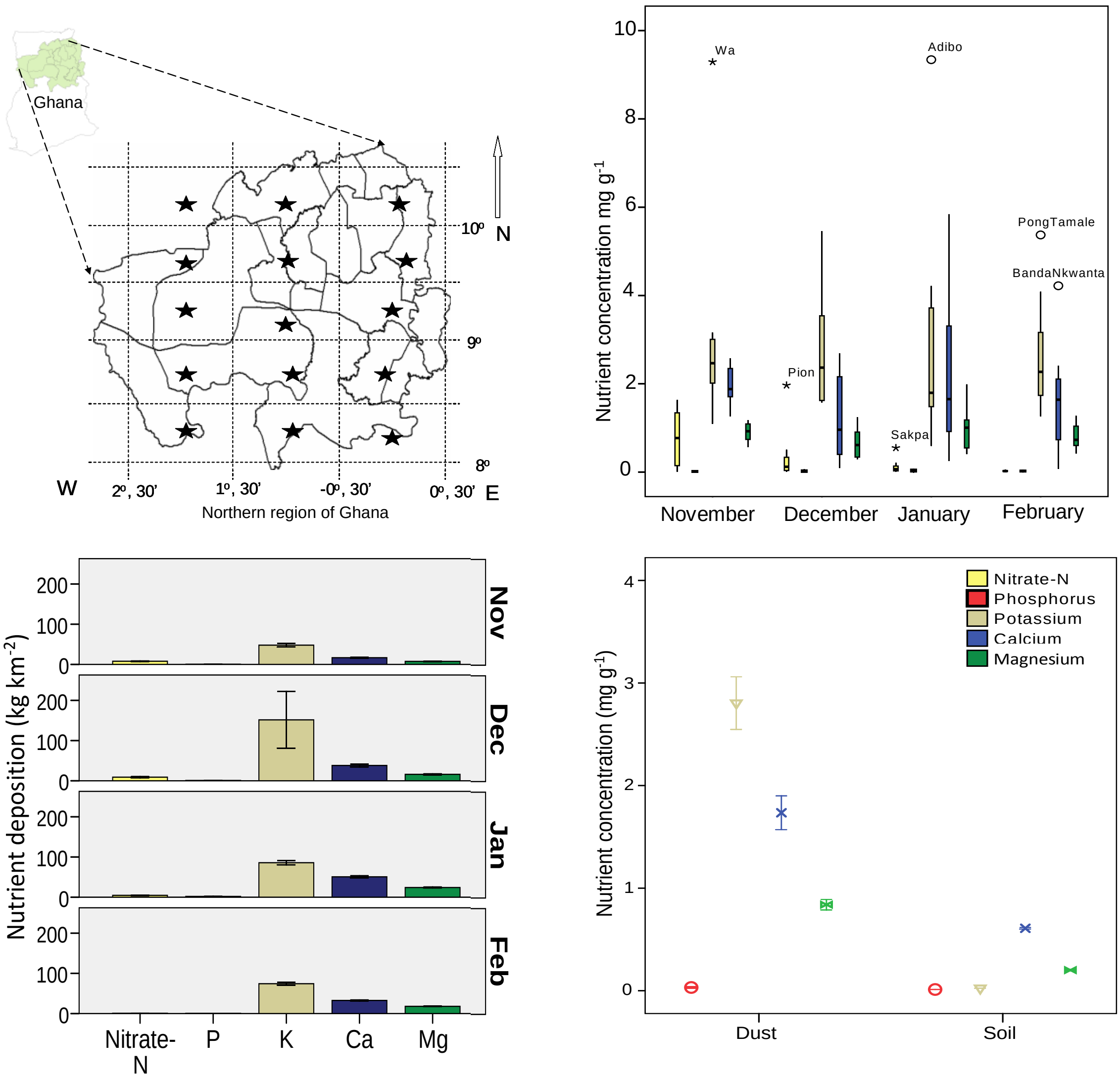

Figure 1: Study region showing the sites (*) for collection of deposited samples (upper left). The figure also shows the monthly concentration (upper right) and deposition (lower left) of nutrients in the dry deposits, and the comparison of nutrient concentration of the dry deposits with that of soils sampled at same site (lower right).

The concentration of individual nutrients varied from one month to another (Figure 1). Besides nitrate-N which showed significant ($P < 0.01$) differences in inter-monthly mean concentrations in the order November > December > January > February, there were no significant monthly differences ($P > 0.05$) in the mean nutrient concentrations for all other nutrients. Contrary to the results of Chineke and Chimeka (2009), who observed high Ca concentrations in harmattan-dust across Nigeria of magnitude ~21 times the concentration of K, this study shows that K concentration in the dry deposits was consistently higher than that of Ca. Elemental concentrations then followed the order Ca>Mg>nitrate-N>P as observed by Breuning-Madsen et al. 2012 (excluding nitrate-N). The mean nutrient concentrations of the dry deposits were multiples the concentration of soils sampled at same geographic site and extracted similarly. Unlike the soil-available nutrients, which did not show any wide variation or peculiar outliers in nutrient concentration, the dry deposits showed wide variations in elemental concentration, and suggest differences in the sources of the deposited nutrients. The high elemental concentrations compared to those of the soils (Figure 1), and to soils of harmattan dust sources (Goudie and Middleton 2001), suggest other sources for the elements than harmattan-dust and the redistribution from the local soils: or that harmattan picks up the finer particles of soil that are richer in nutrients than the bulk soil. An estimated area of 45-60% of total land of the northern region is annually burned during the harmattan dry season (Kugbe et al. 2012). The concentrations of all extracted nutrients of the dry deposits were consistently lower than the corresponding concentrations in ash of burned vegetation across the study area in the same period (Bagamsah 2005). This observation suggests the return of a mixture of fire-induced transferred-elements and low-nutrient source materials (probably external harmattan-dust) into the system. Though these high nutrient-concentrated materials are added to the soil, the net supply to the soil's available pool is minimal, given the low amounts of total dry deposits (53 -122 Mg km^{-2}).

Spatio-temporal distribution of dry deposits across northern Ghana

The month of deposition had higher influence on the concentration of dry deposits than the geospatial location of sample collection. Latitude was a greater geospatial predictor of deposited dust/nutrients, with more dust falling closer to the Saharan dust source in the north due to the influence of gravity, and less dust as one approaches the equator (Table 1).

Table 1: Pearson's correlation matrix for the spatial distribution of dry atmospheric nutrient concentrations in the northern region of Ghana during the 2010-2011 harmattan dry season. N = 60, ^{3}n = 44. Values are coefficients, significant level (two-tail) in brackets.

	Ca	Mg	K	Na	NO_3^-	PO_4^{3-}	Longitude	Latitude
Dust (Mg km^{-2})	-0.26	-0.21	-0.045	**0.40	-0.22	0.13	0.22	**0.66
	(0.05)	(0.11)	(0.72)	(0.00)	(0.13)	(0.32)	(0.09)	(0.00)
Ca	1	**0.77	-0.05	*-0.31	0.01	0.03	-0.24	-0.15
		(0.00)	(0.73)	(0.05)	(0.97)	(0.83)	(0.06)	(0.27)
Mg		1	-0.08	-0.18	-0.03	0.02	-0.22	-0.10
			(0.55)	(0.27)	(0.82)	(0.99)	(0.09)	(0.44)
K			1	*0.31	0.08	0.10	0.07	0.12
				(0.05)	(0.58)	(0.47)	(0.61)	(0.35)
^{3}Na				1	-0.17	-0.05	*0.30	0.14
					(0.34)	(0.70)	(0.02)	(0.39)
NO_3^-					1	-0.03	0.08	-0.12
						(0.86)	(0.58)	(0.40)
PO_4^{3-}						1	-0.20	*0.23
							(0.15)	(0.04)

The total dry deposits and the concentration of phosphate (PO_4^{3-}) increased with increasing latitude, while potassium (K) magnesium (Mg), calcium (Ca) and nitrate (NO_3^-) concentrations were not significantly affected by geographical space (Table 1). The positive inter-nutrient concentration correlation between Ca and Mg suggests a potentially common source for these

nutrient elements. So, also was the relation between Na and K. The negative relations between Ca and Mg concentrations on the one hand with that of Na and K on the other for all sites suggest that substantial amounts of Na and K may not have come from same sources as Ca and Mg.
The deposit of individual nutrients should follow similar temporal trends as those of total dry deposition (January> February> December> November) if the nutrients come from the same source. Nutrient concentration should be about the same if the source is same while they may vary for different nutrient sources (e.g., burned debris, aeolian transport from external sources, local dust redistribution). If the bulk of nutrients deposited in a given month is from different sources, then the concentration of the various nutrients in the different sources will be the predominant determining factor of the quantity of each nutrient deposited as well as the total dust deposit collected in that month. In this case, the relative fraction of total dry deposits from the different nutrient sources will be a predictive factor for the quantity of each nutrient deposited in the given month. The period of dominance for the different sources of nutrients during the harmattan dry season subsequently defines the major nutrients that are deposited across the region in a given month. For instance, fire activity is highest during the last week of December (Kugbe et al. 2012). One would expect that redistribution of fire-transferred particulate elements (N, P, K, Ca, Mg and Na) and the debris from burned vegetation will contribute to high nutrient deposition between December and January. On the other hand, local dust redistribution and external aerosol deposits will be the major sources of nutrient deposits in early November and late February when there are relatively fewer fires.

Conclusions and Outlook

The differences in order of monthly dry-deposits for different nutrients compared to the trend in total dry deposition show that all nutrients were not from the same source, and that the different sources of nutrients dominate deposition at different periods during the harmattan dry season. Redistribution of nutrients transferred into the atmosphere during vegetation burning might be the major source of the high nutrient concentrations of dry atmospheric deposits.

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