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Effect of original vegetation on nutrient loss patterns from Oxisol cropland in forests and adjacent savannas of Cameroon

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ABSTRACT

Forest-savanna mosaic is widespread in tropical Africa mainly occurring on nutrient-poor Oxisols. Though sustainable agriculture is a major concern in this region, little is known about the effects of original vegetation (i.e., forest vs savanna) on nutrient losses from cropland. Hence, we evaluated basic cation losses and nutrient balance of Oxisol cropland cultivated over two years in the Cameroonian forest-savanna mosaic. Solute fluxes at 30-cm depth in maize croplands derived from forest (CR_{FR}) and savanna (CR_{SV}) were compared with those in adjacent forest (FR) and savanna (SV) ecosystems. Nutrient inputs by rainfall, outputs from solute leaching and cropland grain removal, and soil nutrient stocks measured at depths between 0 and 30 cm were investigated. The main anion present in FR soil solutions was NO_3^- (0.16–0.19 $mmol_c\,L^{-1}$), while it was present in negligible amounts in SV. The 2-year NO_3^- flux in CR_{FR} (156 kg N ha^{-1}) was double that in CR_{SV} (78 kg N ha^{-1}), leading to greater 2-year K^+ leaching in CR_{FR} (118 kg K ha^{-1}) than in CR_{SV} (37 kg K ha^{-1}). The ratio of 2-year nutrient losses to total soil stocks was the greatest for Ca both in CR_{FR} (5%) and CR_{SV} (4%), while K loss also reached 5% in combination with lower solution pH in CR_{FR}. In conclusion, cultivation of former forest land substantially increased NO_3^- leaching, resulting in depletion of both K and Ca; whereas, cultivation of former savanna results in mainly Ca depletion.

1. Introduction

In West and Central Africa, the transitory ecotone between the Congo basin forest and the Guinea savanna, known as the forest-savanna mosaic, is widely distributed to the north and south of the forest belt (Mitchard et al., 2011). The area of African forest-savanna mosaic accounts for more than half of that of dense forest (Mayaux et al., 2004). In sub-Saharan Africa, the population is predicted to double over the next 2 decades to approach numbers nearly equal that of China (Lutz et al., 2001). Such rapid population growth and a large dependence on natural resources, owing to the small gross national product per capita (Khasa et al., 1995), result in vulnerable populations putting increasing agricultural pressure on local ecosystems, e.g., forests and savannas (Gaston et al., 1998). Therefore, sustainable food production to meet the demands of such rising populations is a major concern as forests and savannas in West Africa are converted to agricultural land (Smith et al., 1994).

The most abundant soil type in this region is Oxisols (Ferralsols), which are characterized by limited availability and retention capacity of basic cations owing to extreme weathering (Jones et al., 2013; Van Wambeke, 1992). Oxisols have a high macroporosity and hydraulic conductivity, which contribute to a large rate of downward solute movement (Anamosa et al., 1990; Melgar et al., 1992). The combination of a large soil permeability and flat topography results in leaching as the primary cause of soil nutrient (mainly basic cations) losses from croplands in equatorial Africa. The nitrogen (N) cycle is a key process to control the loss of basic cations; export of those ions from the rooting zone has been positively correlated with NO_3^- leaching (Currie et al., 1999; Johnson and Cole, 1980). As plant macronutrients, the dominant basic cations, Ca^{2+}, Mg^{2+} and K^+, and N are important for the stability of ecosystems (Lucas et al., 2011).

Highly weathered kaolinitic soils have cation selectivity and prefer K^+ over Ca^{2+} due to kaolinite's relatively high surface charge density, allowing it to dehydrate weakly hydrated cations, such as K^+ (Agbenin and Yakubu, 2006 from Nigeria; Alves and Lavorenti, 2003 from Brazil; Appel et al., 2003 from Puerto Rico). These findings are consistent with

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field measurements of nutrient loss in West African Oxisol cropland (Poss et al., 1996; Poss and Saragoni, 1992; Uyovbisere and Lombin, 1990) and in the Brazilian Cerrado (Wilcke and Lilienfein, 2000), all of which showed mainly Ca^{2+}, but not K^{+}, to be leached. These field measurements listed above were conducted under relatively dry conditions (ustic moisture regime), where savanna-type vegetation dominated, and leaching was less intense (Uyovbisere and Lombin, 1990). Information on ecosystem dynamics in African forests (udic moisture regime), where leaching is expected to be more intense, is lacking (Working Group II of the IPCC, 2001). Very little quantitative data on nutrient budgets of cropland in Central Africa is available (Cobo et al., 2010), especially concerning Oxisols, which are widely distributed on the continent (Jones et al., 2013).

The forest-savanna mosaic of Cameroon has sufficient rainfall (ca. 1500 mm year^{-1} with an udic moisture regime) to support forest growth, and its savanna vegetation is maintained by some disturbances, such as fire (Sankaran et al., 2005; Staver et al., 2011). Many studies conducted in these mosaic concluded that forest progresses on savanna without savanna burning, indicating the difference of vegetation is not caused by edaphic reasons (Guillet et al., 2001). In these forest and savanna Oxisols, Sugihara et al. (2014) reported that the surface soil (0–20 cm) carbon/nitrogen (C/N) ratio was smaller in the forest (11.0–12.0) than in the savanna (15.3–15.7) and that the total soil K stock through the forest soil profile (0–80 cm) was significantly less than in the savanna. Potentially greater N release rates in the forest due to smaller soil C/N ratio, which may promote basic cation leaching (Bowen et al., 1988), indicate that nutrient leaching on newly cultivated ex-forest cropland could be more intense than ex-savanna cropland. Furthermore, depletion of K in formerly forested cropland may be critical owing to smaller starting stock amounts. To assess nutrient dynamics of shifting cultivation practices, it is important to consider the total nutrient stock of an entire ecosystem (Cobo et al., 2010; Juo and Manu, 1996).

Human-induced change is difficult to detect, predict, or manage without thorough knowledge of the causes and rates of baseline nutrient cycling in ecosystems (Bormann et al., 1995). In an effort to establish this baseline, we quantified soil nutrient fluxes in the East Cameroon forest and adjacent savanna plots through an in situ soil solution study. Then, nutrient leaching fluxes and grain removal were compared over a period of two years in each adjacent cropland plot to reveal the effects of cultivation on soil nutrient losses. These data were then used to address the following questions: 1) How does soil nutrient flux differ in the forest compared with that in the savanna? 2) Does the original vegetation affect nutrient-leaching patterns that follow cultivation under an udic moisture regime? 3) Is it sustainable to cultivate Oxisols croplands of forest-savanna mosaic in terms of the sustainability of soil basic cation?

2. Materials and methods

2.1. Study sites

This study was carried out in the village of Andom, East Region, Cameroon (4°35′N, 13°16′E) in a forest-savanna transition area on the north side of the South Cameroon Plateau, the dominant geographical feature of Cameroon. The average elevation of the plateau is ~650–700 m above sea level with even terrain and homogeneous soil type distribution. Field experiments were conducted from April 2010 to March 2012. The mean annual precipitation and air temperature at the field sites were 1512 mm and 23.1°C, respectively. Experimental plots consisted of a forested plot (FR) and a savanna plot (SV), each with an adjacent cropland plot, cleared in March 2010 and located < 50 m from each original vegetation plot (designated CR_{FR} and CR_{SV}, respectively). The size of each plot was 20 m × 20 m. The FR and SV plots were located ~5 km apart on nearly level topography within the same soil color and texture. Most of the soils under both vegetation were classified as Typic Kandiudox (Soil Survey Staff, 2014) developed on Neoproterozoic (Pan-African) granitoids (Toteu et al., 2006). Results from preliminary plot soil surveys (> five pits for each vegetation type), showed that each plot represented a typical regional soil profile (Sugihara et al., 2014). The dominant FR vegetation was *Albizia zygia* J.F.Macbr. (Fabaceae; N-fixing species) and in the SV, it was *Chromolaena odorata* (L.) R.M.King & H.Rob. (Asteraceae) as reported by (Sugihara et al., 2014). Maize (*Zea mays*) was cultivated in both croplands during each wet season (twice a year) in 2010 and 2011. We followed the practice of the local farmers without any fertilizers, soil amendments, nor irrigation.

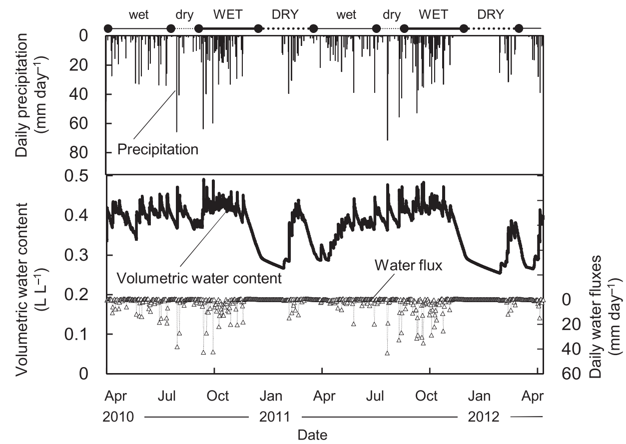

Fig. 1. The upper graph shows daily precipitation. The lower graph shows seasonal fluctuations in volumetric water content and daily water fluxes 15 cm below the soil surface as calculated by HYDRUS for FR. Seasonal water fluxes for the remaining plots are shown in Appendix Fig. A1. because their tendency was similar for all the plots. (wet, minor wet season; dry, minor dry season; WET, major wet season; DRY, major dry season).

Table 1
Estimated water fluxes for two years

	FR (mm 2 yrs^{-1})	CR_{FR}	SV	CR_{SV}
Precipitation	3024	3024	3024	3024
Throughfall	2534	–	–	–
15 cm	1401	1930	1807	1693
30 cm	1027	1643	1575	1416
Evapotaranspiration	2390[a]	1478	1872	1637

[a] Evapotranspiration in FR includes canopy interception of 490 mm.

2.2. Soil analysis

Prior to the start of the experiment, samples were taken from each soil horizon at each site in March 2010 after the original vegetation was cleared in the cropland plots, then air dried, and crushed so as to pass through a 2-mm sieve. Soil pH was measured with a glass electrode meter (pH/ion meter 225; Iwaki Glass) using a soil to solution (H_2O or 1 M KCl) ratio of 1:5 after shaking for 1 h. Total C and N soil contents were determined using a dry combustion method with a CN analyzer (VarioMax CHN, Elementar, Germany). Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) were determined by analyzing an ammonium