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Seasonal patterns in decomposition and nutrient release from East African savanna grasses grown under contrasting nutrient conditions

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ABSTRACT

Litter decomposition and nutrient release is one of the key biogeochemical processes that regulate plant productivity and nutrient cycling in African savanna ecosystems. We examined the influence of nitrogen and phosphorus additions on grass decomposition and nutrient release rates in an *Acacia* savanna ecosystem in central Kenya. Grass was clipped from a factorial nitrogen × phosphorus experiment and decomposed in a common plot that had not received fertilizer. After 20 weeks, including one dry season and one wet season, 50–65% of carbon, 68–75% of nitrogen and 73–83% of phosphorus had been released from the litter. Decomposition was slow in the dry season (mass loss 1–2% wk^{-1}) compared to the wet season (7–11% wk^{-1}). Wet season decomposition was more rapid for grasses that had been fertilized with nitrogen, even though tissue nitrogen was not significantly different from the control grass, indicating that factors other than litter nitrogen concentration influenced decomposition rates under nitrogen enrichment. Surprisingly, nutrient loss from decomposing litter was relatively high during the dry season, suggesting a role for dew in leaching nutrients from dry litter. We conclude that seasonal rain and nitrogen addition (but not phosphorus addition) accelerate decomposition of grass litter, but that nutrient leaching during the dry season can be considerable.

1. Introduction

The balance between net primary productivity and decomposition of organic matter determines carbon (C) stocks in savannas and other terrestrial ecosystems (Valentini et al., 2000). The decomposition of annual litter fall contributes approximately half of the CO_2 released from soils (soil + litter CO_2) (Couteaux et al., 1995) and recycles nutrients for plant uptake (Aerts et al., 1992). Understanding the factors controlling litter decomposition is therefore important to determine the influence on greenhouse gases emission and global warming (Fearnside, 2000).

Both abiotic and biotic processes regulate litter decomposition, including photodegradation, and microbial breakdown (Facelli and Pickett, 1991) and also physical fragmentation (leaching of soluble C) during rainfall events (Ferreira et al., 2006). Decomposition rates are controlled primarily by extrinsic drivers such as climate (Aerts, 2006; Austin and Vitousek, 2000; Gill and Burke, 2002) and soil properties (Gill and Burke, 2002). Intrinsic drivers include plant litter quality (Aerts, 2006; Gindaba et al., 2004; Mugendi and Nair, 1997) and litter physical properties (Meentemeyer, 1978). Temperature is considered to be a major regulator of litter decomposition in cold climates, while litter quality is more important under warmer conditions (Couteaux et al., 1995).

Moisture content is a major regulator of decomposition and nutrient leaching in the arid environments. Rain and irrigation are considered to be the main sources of moisture in agricultural areas, while rain is considered to be the main source in natural ecosystems. In these places other sources of water namely fog, mist and dew are often overlooked (Went, 1955). Dew is mainly deposited in the dry season when the sky is clear and hence an important source of moisture in the semi-arid areas during the dry season compared to other climates (Went, 1955). Duvdevani (1953) conducting an experiment in the coastal plains of Israel, where dew

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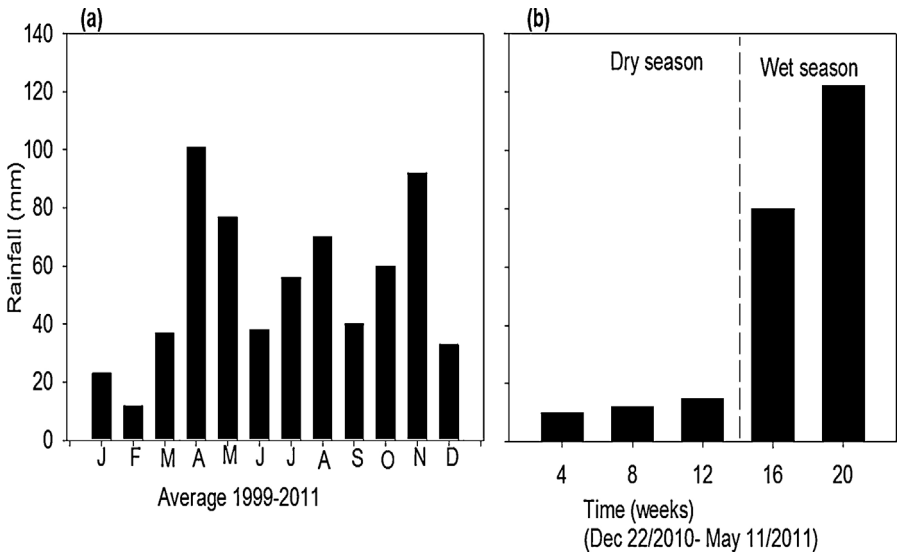

Fig. 1. Rainfall at the Mpala Research Centre, Laikipia, Kenya. Records are presented for a) the long-term rainfall average (1999–2011) and b) during the study period from 12/22/2010 to 5/11/2011. In (b) the data are presented in 4 weeks intervals to emulate the field litter incubation period. The litter was incubated for 20 weeks and the samples were collected from the field after every 4 weeks without replacement.

occurred frequently indicated that most plants grew about twice as much when they received dew during the night. The dew water could run off the leaves and collect in the soil on which it drips (Duvdevani, 1953; Ruinen, 1961). The dripping dew contains both mineral and organic constituents in varying composition, making dew a leaching agent (Ruinen, 1961).

In African savannas, most litterfall occurs in the dry season, yet most decomposition studies have been initiated at the onset of the wet season (Deshmukh, 1985; Jama and Nair, 1996; Mafongoya et al., 1997; Mugendi and Nair, 1997; Mugendi et al., 1999) with few in the dry season (e.g., Fornara and Du Toit, 2008). In addition, most studies involved leguminous forbs and trees (Fornara and Du Toit, 2008; Fosu et al., 2007; Jama and Nair, 1996; Mafongoya et al., 1997; Mugendi and Nair, 1997; Mugendi et al., 1999; Oladoye et al., 2008), and few included grasses (Deshmukh, 1985; Ohiagu and Wood, 1979), even though grasses dominate the aboveground biomass of savanna ecosystems (Bond, 2008). Finally, few studies have examined the role of nutrients in determining the decomposition rates of tropical savanna grasses, yet foliar nutrients can have a marked impact on litter decomposition in other ecosystems such as temperate grassland (Kochy and Wilson, 1997; Moretto et al., 2001), tundra (Bryant et al., 1997; Hobbie and Gough, 2004), temperate forest (Melillo et al., 1982), montane forests (Hobbie and Vitousek, 2000) and tropical forests (Gonzalez and Seastedt, 2001; Kaspari et al., 2008).

The objectives of our study were to determine the influence of N and P addition on plant litter decomposition, N and P release in savanna ecosystem. To do this, we decomposed grasses from a factorial N × P fertilization experiment in a common unenriched site throughout one dry season and one wet season. We hypothesized that decomposition rate, N and P release would be greater in the wet season than in the dry season, and that grasses that had been fertilized with N and P would decompose faster than untreated grasses.

2. Methods

2.1. Site description

The study was conducted in 2010 and 2011 at Mpala Research Centre, Kenya, which encompasses 190 km^2 of semi-arid savanna within the Laikipia County of the Rift Valley Province (37°53′E, 0°17′N). The site is a conservancy where wildlife and livestock co-exist and share resources. The dominant woody vegetation includes *Senegalia (Acacia) brevispica*, *Vachellia (Acacia) etbaica*, *S. (Acacia) mellifera*, *V. (Acacia) nilotica* and *V. (Acacia) gerrardii*, *Croton dichogamus*, *Grewia* spp. and *Rhus vulgaris* (Young et al., 1995). The herbaceous vegetation consists of a discontinuous layer of mostly perennial grasses, which include *Pennisetum mezianum*, *Pennisetum stramineum*, *Digitaria milanjiana*, and *Cynodon dactylon*.

The soils are red sandy loams (Typic Haplustalfs in Soil Taxonomy) derived from metamorphic basement rock (Ahn and Geiger, 1987; Goheen et al., 2013). Prior to fertilization, soil pH was 6.3 (measured in water), total soil P was 230 mg kg^{-1} and available P was 11 mg kg^{-1} (determined by resin bags as outlined by Kouno et al. (1995)). Total soil C and N contents were 10 and 1.1 g kg^{-1}, respectively and the mean annual rainfall was approximately 640 mm over a 13 years period (Fig. 1a) (Goheen et al., 2013). Monthly maximum temperatures range from 25 to 33 °C, while minimum temperatures range from 12 to 17 °C (Young et al., 1998).

This study was conducted in the Ungulate Herbivory Under Rainfall Uncertainty (UHURU) experiment, established in 2008 at the Mpala Research Centre (Goheen et al., 2013). The study was conducted in the southern (wettest) site of the UHURU experiment, which received an average of 638 mm rain $year^{-1}$ from 2009 to 2011.

2.2. Experimental design

Four fertilizer addition plots (16 m^2 each; hereafter "plots") were established in February 2010 in each of three replicate exclosures (1 ha each) which fenced out all herbivores larger than *Lepus spp.* (~2–3 kg). Thus, there were a total of 12 plots arranged across the three exclosures. The 12 plots entailed four fertilizer treatments and three replications of each fertilizer treatment. Within each of the 12 plots, grass was clipped to ground level in a 1 m^2 patch and discarded and fertilizers were applied to the entire 16 m^2 plot on the onset of rainfall (March 2010). This allowed regrowth standing dead grass from the 1 m^2 plot to be used for the decomposition experiment. The fertilizer treatments included: (1) N only, (2) P only, (3) a mixture of N and P, and (4) unfertilized