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Water and nutrient inputs in rainfall into natural and managed forest ecosystems in south-eastern highlands of Ethiopia

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Abstract

The input of rain water to the forest floor and the composition of rainfall and throughfall water were monitored between October 2001 and September 2002 in a natural and two plantation (*Eucalyptus globulus* and *Cupressus lusitanica*) forests at Munesa, south-eastern highlands of Ethiopia. The proportions of throughfall to annual incident rainfall that passed through the different forest canopies were 53% under *Cupressus* and the natural forest and 82% under *Eucalyptus*. Annual nutrients deposition by rainfall varied from 0.08 kg ha^{-1} yr^{-1} for Mg to 3.79 kg ha^{-1} yr^{-1} for Na. Wash-off of materials deposited on the canopy surface and leaching of intracellular solutes from the canopy resulted in an enrichment of throughfall fluxes in K, Mg, Ca and Cl relative to rainfall and varied among forest types, being highest under natural and *Eucalyptus* forests and lowest under *Cupressus*. Sodium, NO_3–N, NH_4–N, SO_4–S and PO_4–P fluxes in throughfall were depleted relative to rainfall, but the magnitude of net depletion was different for the different elements; highest for Na (3.87 kg ha^{-1} yr^{-1}) followed by NH_4–N (2.85 kg ha^{-1} yr^{-1}) and lowest for PO_4–P (0.42 kg ha^{-1} yr^{-1}). The amount of canopy uptake and leaching were generally low in the dry season and increased sharply towards the wet season.

Key words: *Cupressus*, *Eucalyptus*, Ethiopia, throughfall, rainfall.

1. Introduction

Nutrient fluxes and ecosystem productivity are driven to a large extent by the landscape water balance because water is both a limiting natural resource in most landscapes and the driving fluid of most nutrient fluxes. Water and nutrient cycles are two of the most important biogeochemical processes directly affected by land use and land cover. Human-induced land use changes are known to affect the spatial and temporal patterns of landscape water fluxes (Bosch, Hewlett 1982). Increasing concern on the ecological status of water resources has resulted in physical processes based studies that examine the influence of vegetation on precipitation water quantity and quality. The quantity of incident gross precipitation passing through the forest canopy has a significant hydrological importance because it is responsible for the recharge of groundwater and streamflow, and influences runoff and distribution of understorey vegetation. Forest stands of different tree species differ in their above ground vegetation surface area, stand structure and morphology, and can have a differential impact on rain water interception and evapotranspiration losses, hence, on soil water regimes (Pritchett 1979; Cape *et al.* 1991). For example Swank and Douglass (1974) in the United States found that streamflow was reduced by 20% by converting a deciduous hardwood stand to *Pinus strobus* L.

Precipitation also plays an important role in ecosystem nutrient cycles. Rainfall contains dissolved and particulate constituents; almost all of the pool of nitrogen and sulphur including important quantities of inorganic nitrogen necessary for forest growth are derived from the atmosphere (Waring, Schlesinger 1985). Forests are particularly effective in scavenging and retaining atmospheric particles and gases that contain nutrients due to their high surface area and aerodynamic resistance (Howsam *et al.* 2000; Levia, Frost 2003). Throughfall and stemflow are the two hydrological processes responsible for the transfer of precipitation and solutes from vegetative canopy to the soil (Levia, Frost 2003) and have been documented to significantly impact forest geochemical cycles (Parker 1983). The chemistry of precipitation can be changed as it passes through the forest canopy resulting from wash-off of dry depositions and leaching of leaves and branches, and uptake of nutrients by the canopy (Jordan *et al.* 1980; Veneklaas 1990). Ions such as Na^+, Cl^-, SO_4^{2-} and PO_4^{3-} usually flow passively through the canopies (Lindberg, Lovett 1992; Ragsdale *et al.* 1992; Hultberg, Ferm 1995). On the other hand, it has been documented that nitrogen can be absorbed by tree canopies from the atmospheric inputs, and this process relates to both ammonium and nitrate ions (Potter *et al.* 1991; Lovett 1992; Shubzda *et al.* 1995; Stachurski, Zimka 2000).

Many studies that have been carried out on the effects of atmospheric deposition on forest ecosystems have concentrated on countries with greater risk of air pollution (Krupa 2002). However, even in the absence of air pollution risks, such studies are also of critical importance because of the potential ecological significance of atmospheric depositions in forest ecosystems nutrient cycling and the need for such information to make reliable forest management decisions. Such studies are also useful in understanding the level of atmospheric deposition in the country and, in comparing deposition measurements with different networks, and evaluating air quality to undertake sound environmental management practices. The objectives of this study were to (1) assess the relative importance of atmospheric deposition in the nutrient cycle and (2) determine the effects of land use and land cover change on the hydrologic and nutrient cycles in the Munesa forest.

2. Materials and methods

2.1. Study site and experimental design

The experimental site was located at the Munesa/Shashemene forest enterprise site (7° 34′ N and 38° 53′ E), 240 km south-east of Addis Ababa. The long term average annual precipitation of the area is about 1250 mm (Solomon *et al.* 2002) and shows seasonal pattern: main rainy season (June to September) and small rainy seasons (February to May) with a relatively dry season from October to January (NMSA 1996). The soils parent materials are volcanic origin and are classified as Nitisols (FAO 1997). A natural forest and two plantation forests (*Eucalyptus globulus* and *Cupressus lusitanica*) situated side by side were selected for this study. The natural forest was a montane tropical forest mainly dominated by old growth *Podocarpus falcatus* trees. The two plantations were established in 1980 after clearing of part of the natural forest. *Eucalyptus globulus* had 595 stems ha^{-1} with a mean diameter at breast height (dbh) of 19-39 cm and a height of 30-40 m. Tree density in *Cupressus* was 672 ha^{-1} with mean dbh of 29 cm and height of 18-20 m. In each forest type, three replicated 0.06 ha plots were located and within each plot about 20-25 m^2 area was fenced for throughfall collector installation.

2.2. Field equipment and sampling

An automatic weather data-logger was installed at the site to record the daily weather data including rainfall. We also kept a deep freezer in a nearby town for sample storage. Rainfall and throughfall were collected using plastic funnels of 12 cm diameter and 2 l capacity mounted 1 m above the ground. Rainfall was collected at three spots, each with three collectors, in a large opening between the plantation and natural forests. Throughfall was collected in three replicated plots with five collectors per plot. The collectors were placed randomly under the canopy of the sample trees. Table tennis balls were put inside each collector to prevent loss of water by evaporation. The sampling period commenced in October 2001 and concluded in September 2002. Water was collected on a weekly basis. During sample collection the volume of water was registered. After each collection, the collectors were washed with deionized water or with a portion of the sample water. On each sampling day, water samples were transported to the storage facility and kept frozen until they were transported to Germany

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