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Harvest residue effects on soil organic matter, nutrients and microbial biomass in eucalypt plantations in Kerala, India

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ABSTRACT

Conservative site management practices such as harvest residue retention can potentially convey long term benefits for site sustainability, but they are only practiced to a limited extent in many *Eucalyptus* plantations in the tropical regions. Burning and/or removal of harvest residues can remove substantial quantities of nutrients, but it is still common practice in many parts of India. We explored the effect of harvest residue retention or removal on soil properties at 4 multi-rotation *Eucalyptus* plantations in Kerala, India. Soil carbon, N and P content were little influenced by differing harvest residue treatments. Interestingly, soil N mineralization rates were affected only minimally by harvest residue retention at individual sites, however, laboratory incubations demonstrated a significant increase in soil N-mineralization potential with increasing harvest residue additions. Soil microbial biomass was influenced to a lesser extent by harvest residue retention. We conclude that harvest residue retention can help to sustain the soil fertility in subsequent rotations and minimize the loss of nutrients from the sites, but fertilizers are still likely to be an important part of the nutrient management regime for productive plantations.

1. Introduction

The area of forest plantations is increasing in both the tropical and subtropical parts of the world (FAO, 2010). New plantations are being established on different soil types, and under different climatic and management conditions. The productive capacity of any given site depends on its inherent fertility status and the management strategies adopted by the plantation growers (Tiarks et al., 1998). Poor site management practices have, in part, resulted in declining productivity of plantations over multiple rotations and gradual loss of soil fertility at many sites (Tiarks et al., 1998; Powers, 1999).

Eucalyptus is a common plantation forest species grown in tropical countries (including India) on soil types with a range of fertility status (Gonçalves et al., 1997; Sankaran et al.,1999; Laclau et al., 2010). *Eucalyptus* is often the preferred species because it has a good capacity to grow productively under many conditions. However, lower productivity levels in 2nd and subsequent rotations have often been observed, and are typically attributed to poor site management practices such as extensive removal and/or burning of harvest residues (Gonçalves et al., 1997; Corbeels et al., 2005; Laclau et al., 2005) which results in the export of large amounts of nutrients from site in plant biomass at harvest of each rotation (Madeira and Pereira, 1991; Hopmans et al., 1993; Ludwig et al., 1997; Khanna, 1997; Sankaran et al., 2005; Corbeels et al., 2005). Such practices result in decline in soil fertility over multiple rotations and increase in rotation length to achieve economically harvestable stands. Retention of harvest residues in subsequent rotation crops potentially has advantages for sustaining and controlled release of nutrients during the plant growth period (Schaefer and Krieger, 1994; Johnson, 1995; Tiessen et al., 1994). Previous studies in Kerala have shown that there is potential for a large quantity of nutrients to be exported from *Eucalyptus* plantations at harvest, especially if key harvest residue fractions are substantially removed (Sankaran et al., 2005).

There has recently been increasing importance placed on maximizing the economic returns from short-rotation plantations. High input management is considered as an economic imperative (Herbert, 1996; Gonçalves et al., 2004; Smethurst et al., 2004), but it is not commonly practiced in plantation forestry across *Eucalyptus* growing areas in India because of high fertilizer cost and delayed return on investment (Gonçalves et al., 2004). Potential on-site options like harvest residue management are gaining increased prominence for soil fertility maintenance and

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supplementing the soil N (Mendham et al., 2003; Tiarks and Ranger, 2008). Introduction of leguminous plant species is one of the potential options for increasing the system N (Gadgil, 1983; Mendham et al., 2004), while retention of harvest residues may be important for conserving site nutrient capital. The benefits of harvest residue retention and/or manipulation of organic matter have been well recognized in other plantation forestry systems (Jones et al., 1999; Saint-Andre et al., 2008; Laclau et al., 2010a, 2010b; McKay, 2011; Voigtlaender et al., 2012; Mareschal et al., 2013).

Assessment of the impact of harvest residue manipulation on the rate of N-mineralization can be used to understand the potential effect on soil fertility and plantation productivity. Nitrogen deficiency is the most common nutritional limitation to many non-leguminous plantation species. Potentially available N, as determined through anaerobic incubation (Keeney and Bremmner, 1966) and sequential soil core incubation studies under field conditions (Raison et al., 1987) have been used for assessing the soil N availability. Likewise, long term laboratory incubation studies (Mendham et al., 2004; María et al., 2007; Sánchez et al., 2010; Mareschal et al., 2013) have provided insight into the N-mineralization pattern in different soils, harvest residue loads, and under variable climatic conditions. Models that account for changes in N mineralization with soil temperature and moisture also have been used to predict the pattern of N-mineralization under various soil–plant–climatic conditions (O'Connell et al., 2004; Mendham et al., 2009). The impact of retaining harvest residues on soil N mineralization, or on soil microbial biomass has not been previously reported for many tropical *Eucalyptus* plantations. The aim of this study was to understand the impact that harvest residue retention has on (i) the pools of soil carbon and nutrients, (ii) the dynamics of nitrogen and (iii) microbial biomass in tropical *Eucalyptus* plantations. We tested the hypothesis that residue retention would increase these soil attributes at four sites planted to *E. grandis* (2 sites) and *E. tereticornis* (2 sites) in Kerala, India. The study was part of a CIFOR network collaborative research initiative to explore the options for sustainable management of productive capacity of soils in multi-rotation plantations (Nambiar, 2008).

2. Materials and methods

2.1. Experimental sites and soils

Details of the study sites are provided in Table 1, and have been described in previous publications (Sankaran et al., 2004; Mendham et al., 2004). In summary, the study sites comprised 2 lowland (*E. tereticornis*) sites, and 2 upland (*E. grandis*) sites on Ferralsol soils in Kerala, India. The plantations were established on sites where *Eucalyptus* had been grown for 2 rotations since 1977 (*E. tereticornis* sites), and 3 rotations since 1968 (Surianelli), and 1958 (Vattavada). The 4 sites represented contrasting environmental conditions and soil fertility status, which was useful for interpreting the response of tree growth and N mineralization to residue manipulation.

2.2. Harvest residue manipulation in the field

Four treatments were studied at each of the sites, comprising Zero residues (all residues, leaf litter, twigs and bark, removed from the plots), Burn (all residues redistributed evenly and burnt in the plot), Single residues (harvest residues retained and spread evenly) and Double residues (normal residue load plus all harvest originally removed from the Zero residues treatment). The treatments were established in a randomised block design with 4 replications. The gross treated plots were 20 m × 20 m size, with an inner measure-plot of 10 m × 10 m. Due to space restrictions at the Kayampoovam site, the gross plots there were 18 m × 18 m size. All treatments had a starter fertiliser at establishment, added at rate of 100 g/tree N:P:K, 17:7:14. The fertilizer was placed at 10-cm depth. The nutrient content of the harvest residues was reported in Sankaran et al. (2005), but briefly, the above-ground biomass in the tree crop across the sites contained of 94–174 kg N ha^{-1}, 8–40 kg P ha^{-1}, 83–266 kg K ha^{-1},166–715 kg Ca ha^{-1}, and 21–75 kg Mg ha^{-1}. More details on the nutrient contents and distribution within the tree and understorey components are presented in Sankaran et al., 2005.

2.3. Soil sampling

Soil samples were collected at 1 and 2 years after establishment of the plantation, from the inner measure plots (10 m × 10 m). Sampling was carried out in the first half of September of the years 1999 and 2000, during the rainy season in Kerala. At this time of the year the soil moisture level was at field capacity. A total of 9 soil cores were collected from each plot, from the 0–5 and 5–10 cm depth ranges. The 9 cores from each plot were bulked within depths to produce a single sample for each depth range from each of the experimental plots. N mineralization was assessed on the 1999 samples, while other soil chemistry was assessed on the samples collected in the year 2000. A sample processing error meant that we could not use the samples collected in 1999 for soil chemical analysis other than N mineralization.

2.3.1. N-mineralization studies

To collect soil samples for N mineralization assessment, the mineral soil was firstly exposed by removing surface litter deposits, and then steel cores (18 cores per plot, 4 cm diameter) were driven in pairs into the soil to 20 cm depth and extracted with care so as to not disturb soil inside the core. The cores with soil were maintained upright in polyethylene bags and transported to laboratory under cold conditions in insulated containers. One set of cores (the 'initial' samples) was extracted immediately after transportation to laboratory. The soil cores were sectioned into 0–5 cm, 5–10 and 10–20 cm intervals, the 9 cores per plot were

Table 1
Selected properties of the sites and soils (0–10 cm depth) prior to the start of the experiment.

	Kayampoovam (*E. tereticornis*)	Punnala (*E. tereticornis*)	Vattavada (*E. grandis*)	Surianelli (*E. grandis*)
Latitude	10.68	9.10	10.13	10.03
Longitude	76.38	76.90	77.25	77.17
Rainfall (mm y^{-1})	2700	2000	1800	3000
Altitude (m)	120	150	1800	1280
Previous land use	Moist deciduous forest	Moist deciduous forest	Semi-evergreen forest	Grassland
Soil texture	Light to medium clay	Sandy loam to clay loam	Clay loam to medium clay	Medium clay to sandy loam
pH	5.3	5.1	5.3	4.8
Total C (mg g^{-1})	16.0	43.0	50.4	37.2
Total N (mg g^{-1})	1.23	2.43	3.61	2.15