HAYATI Journal of Biosciences, December 2007, p 127-132 Vol. 14, No. 4
ISSN: 1978-3019

Nitrogen Resorption and Nitrogen Use Efficiency in Cacao Agroforestry Systems Managed Differently in Central Sulawesi

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Received September 24, 2007/Accepted December 27, 2007

Cacao agroforestry is a traditional form of agriculture practiced by the people of Central Sulawesi. These agroforestry systems vary from a simple system following selective cutting of forest trees, to a more sophisticated planting design. The cacao was planted under remaining forest covers (CF1), under planted trees (CF2), and between shade trees *Gliricidia sepium* (CP). The objectives of this study were to quantify nitrogen use efficiency (N NUE) and nitrogen resorption in cacao agroforestry systems. The N NUE at the ecosystem scale (N NUE_{ES}) for the cacao agroforestry systems were compared with the natural forest. The results showed that CP produced the highest litterfall and cacao foliar nitrogen. CP and CF1 produced litterfall and the nitrogen resorption that not were significantly different. In contrast, CF2 produced the lowest litterfall, hence required lower nitrogen supply. The nitrogen resorption of CF2 was less than that of CF1 and CP. However, N NUE in cacao plant (N NUE_C) of CF2 was higher than that of the CP. The N NUE_{ES} of either CF1 or CF2 were similar to that of the natural forest, but higher than that of the CP. Using shade trees in cacao plantations increased foliar nitrogen concentration, nitrogen resorption, N NUE_C and N NUE_{ES}; thus, might be one reason for a higher productivity of cacao in unshaded systems.

Key words: cacao agroforestry system, cacao foliar nitrogen, nitrogen resorption, N NUE

INTRODUCTION

Agricultural and forest lands in the tropics have been subjected to unprecendented development pressures for the past several decades (Collier *et al*. 1994; Janzen 1998). Millions of hectares of primary forest have been degraded by logging (Putz *et al*. 2000) and millions more were converted into intensively used agricultural areas (Lenne & Wood 1999). At the same time, traditional agroforestry, perennial, and long-fallow shifting cultivation systems (i.e. forest farming) have been displaced by monocultures techniques (Thrupp 1998). The role and importance of agricultural lands, particularly traditional forest farming systems, have been neglected in global biodiversity conservation efforts (Thrupp 1998; Fox *et al*. 2000).

In closed-canopy forests, both external micro-climatological factors and plant metabolic processes vary from the top of the canopy to the forest floor. As a consequence, pronounced vertical gradients occurred in the physiology of foliage in the forest canopies (Ishii *et al*. 2000; Lewis *et al*. 2000). The foliage also responds to factors that vary through the canopy, such as foliar nitrogen (N) and N translocation or resorption efficiency (Ishii *et al*. 2000; McDowell *et al*. 2000).

An agroforestry system such as shade-grown cacao (*Theobroma cacao*) is one alternative land use such as in slash-and-burn agriculture and is recommended for sustainable development in the humid tropics (Johns 1999). Cacao is shade-tolerant and can grow under a canopy of trees maintained, regenerated, or replanted from the traditional tropical forest (Beer *et al*. 1998). Hence, its inclusion into a forest agro-ecosystem can maintain biodiversity and ecological services provided by the native forests (Rice & Greenberg 2000; Glor *et al*. 2001).

Nitrogen is a major constituent of chlorophyll and is involved in the carboxylating enzymes of the photosynthesis, especially Rubisco (Waring & Schlesinger 1985). The difference in N concentration of foliage tissue generally reflects the differences in enzyme concentration (McGuire *et al*. 1995). Foliar N concentration depends on many variables, including soil N mineralization and nitrification rates, soil C/N ratio, plant species, temperature, and irradiance (Yin 1994; MaGill *et al*. 1996; Ollinger *et al*. 2002). Species traits, N availability, and climate are the three controlling factors that likely determine canopy foliar N concentration (Pan *et al*. 2004).

Nutrient resorption is a process in which nutrients are withdrawn from leaves prior to abscission and redeployed in developing tissues. Nutrients resorption prior to abscission is one of key processe by which plants conserve them. Resorption may occur throughout leaf's life, particularly as they become progressively shaded (Ackerly & Bazzaz 1995; Hikosaka 1996). This process reduces the likelihood of nutrient loss in litter dropped on the forest floor (Bormann *et al*. 1977). Subsequently, the withdrawn nutrients are redeployed in new tissue, such as leaves and reproductive structures, or stored for later use (Wright & Westoby 2003). On average, plants withdraw about 5-80% of leaf nitrogen via resorption. The

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proportion of nutrients withdrawn from leaves (the resorption efficiency) varies widely between species and environmental condition. For example, less than 5 up to 80% of leaf N, and 0 up to 95% of leaf P may be resorbed (Aerts 1996; Lambers *et al*. 1998; Aerts & Chapin 2000). In infertile habitats, nitrogen in senescent leaf is reduced to lower levels than in fertile habitats (Wright & Westoby 2003).

Nutrient or fertilizer use efficiency concepts generally describe how well does plants or a production system use nutrients. The efficiency of plant nutrient use is simply the inverse of nutrient concentration in senescent leaf. Consequently, plants from nutrient-poor habitats are typically more efficient in their N use than plants from nutrient-rich habitats (Vitousek 1982; Tateno & Kawaguchi 2002). Nutrient use efficiency (NUE) as an index may help explain species distributions across landscapes that vary in soil fertility and other resources (Vitousek 1982; Schlesinger *et al*. 1989).

The objective of this study was to quantify N NUE and nitrogen resorption in cacao leaf from three types of cacao agroforestry systems over one year. In this study, we collected fully-developed and senescent cacao leaf, soil samples, and litterfall.

MATERIALS AND METHODS

Study Sites. The studies were conducted in three different types of cacao agroforestry systems at the northeastern margin of Lore Lindu National Park (LLNP), located in Central Sulawesi, Indonesia ca. 75 km southeast of Palu. The whole sites were located between 120º1' - 120º3'30"E and 1º29'30" - 1º32'S at an elevation of 800 m to 1100 m in Toro village, Kulawi district, Central Sulawesi, Indonesia. The average of relative humidity at Toro village is 87.2%, the mean of monthly temperature was 22.9 ^{o}C, the average annual global radiation was 17.48 MJ m^{-2}, and the total annual precipitation in 2005 recorded in the study sites was 2055.6 mm.

Three different cacao agroforestry systems were selected in the buffer zone of LLNP. They were (i) the system under a remaining forest cover (CF1), (ii) the system under local shade trees (CF2), (iii) the system without forest cover, but with planted shade srees, *Glyricidia sepium* (CP). The natural forest (NF) was used as the undisturbed ecosystem compared to N NUE_{ES} cacao agroforestry systems. Environmental characteristics of study sites were presented in Table 1. The CF1 was dominated by *T. cacao, Coffea robusta, Arthocarpus vrieseanus, Turpinia sphaerocarpa,* and *Horsfieldia costulata*. The species that dominated CF2 were *T. cacao, Erythrina subumbrans, Syzigium aromaticum, Arenga pinnata,* and *Bischofia javanica,* while CP was dominated by *E. subumbrans, T. cacao, G. sepium, Mellochia umbellate, Piper aduncum* (Ramadhanil 2006). Topography of study sites was relatively flat with different slope (Table 1). Planting distance in the CF1 and CF2 was unregulated, but not the CP. Planting distance in CP was 3 x 3 m. Plot size was 30 x 50 m in every study site. In the study area, cacao trees were mainly hybrids ("Trinitario" type) between the "Criollo" and "Forastero" varieties. The age of cacao trees were 5-15 years old.

Table 1. Environmental characteristics of the natural forest (NF) and three cacao agroforestry systems (CF1, CF2, and CP) in Toro village, Central Sulawesi, Indonesia

Environmental characteristics	NF	CF1	CF2	CP
Tree density (sum of trees/0.5 ha)*	592	304	244	604
Basal area* (m^2)	58.4	31.5	6.6	13.2
Exposition	95º E	110º E	100º E	100º E
Air humidity (%)**	95.7	92	91.4	86.3
Temperature (^{o}C)**	20.4	21.5	21.8	22.9
Canopy cover (%)**	89.7	72.1	69.4	49.8
Altitude (m asl)	1006	832	802	799
Slope (%)	80	70	35	20

*Ramadhanil (2006), **Bos *et al*. (2007)

Experimental Set-Up. The experiment was began in March 2005 and ended in March 2006. Ten litter traps (1 x 1 m, 50 cm above the ground) were installed at 20 subplots on each plot. Litter was collected at monthly intervals for one year (March 2005 to February 2006). The litter was taken to the laboratory and dried to constant dry weight at 80 ^{o}C. The total litterfall was obtained by weighing the samples. Nitrogen content in litterfall was determined with Kjeldahl method.

Leaves were collected at three-monthly intervals over one year (March 2005 to March 2006) from the three types of cacao agroforestry systems. At each collecting time, three to five leaves samples (fully-developed leaves and senescent leaves) were collected from five cacao trees from each plot. The senescent leaves were yellowish and easily dropped by shaking the branch. Fully-developed leaves and senescent leaves from each sampling period were thoroughly washed and air dried then kept in oven at 60 ^{o}C for 48 hours. Grounded dried leaves were stored in paper bags for chemical analyses. Leaf nitrogen concentration was determined with Kjeldahl method.

Soil samples were also collected at three-monthly intervals over one year using a soil core down to 15-20 cm depth. At each collecting time, twenty five soil samples were collected randomly in each plot. Soil samples for soil nitrogen content determination, were stored in sealed plastic bags at 4 ^{o}C until analysis. The total soil N content was determined with Kjeldahl method.

The nitrogen use efficiency of the cacao plants (N NUE_C) in the agroforestry system was calculated according to Vitousek (1982) and Tateno and Kawaguchi (2002):

$$\text{N NUE}_C = 1 / \text{nitrogen concentration in senescent leaf (\%)}$$

The nitrogen use efficiency at the ecosystem scale (N NUE_{ES}) in the cacao agroforestry system and in the natural forest as a control was calculated according to Vitousek (1982):

$$\text{N NUE}_{ES} = \frac{\text{Litterfall production (g m}^{-2}\text{ y}^{-1})}{\text{N content in litterfall (g m}^{-2}\text{ y}^{-1})}$$

The proportional nitrogen resorption was calculated according to Sharma and Pande (1986):

$$\text{Resorption (\%)} = \frac{\text{Nd} - \text{Ns}}{\text{Nd}} \times 100\%$$

where Nd: N in fully-developed leaf, Ns: N in senescent leaf