VII. GENERAL DISCUSSIONS

Under the increasing population growth, and an extensive unemployment, it has been a common issue that large areas of natural forest are modified and converted into agricultural land-use; this is also the case for Central Sulawesi; particularly for the Lore Lindu National Park (LLNP). For many years, parts of natural forest in this National park have been transformed into several land-use types including cacao agroforestry systems, annual agriculture, and even secondary forest (Schulze et al. 2004).

Land–use change from natural forest into cacao agroforestry systems in LLNP has the impact to decreasing annual litterfall production, due to changes of vegetation diversity, structure, and composition. Among the sites studied, the natural forest had the greatest litterfall production, because it had a greater basal area, high tree density, and vegetation cover than cacao agroforestry systems. Variation in monthly litterfall production was affected by climatic factors, mainly air humidity and temperature. Besides that, one mechanism through which aboveground diversity may influence belowground function is through the diversity of leaf-litter inputs (Madritch and Cardinale 2007). The type of plant litter may affect the type of SOM formed. Hence, the impact of trees on soil fertility depends on their litter chemical quality and decomposition (Singh et al. 1999). Changes in land-use influence SOM quality and quantity (Craswell and Lefroy 2001, Mendham et al. 2002), because plant litter is the main input of organic matter and energy to soil, and is important for nutrient cycling (Fioretto et al. 2003). The rate of decomposition in natural forest was higher than that in the cacao agroforestry systems. Thus, the amount and quality of soil macro-organic matter in cacao agroforestry systems were lower than that of natural forest. These research in line with Singh et al. (2004) that accumulation of soil macro-organic matter in forest systems depend upon the input of litter and its decomposition.

Soil organic matter plays an important role in nutrient cycling in tropical ecosystems (Barrios et al. 1996) and SOM content has long been closely linked to the capacity of soils to sustain crop growth (Biederbeck et al. 1994). Methods commonly used for measuring and characterizing SOM, such as organic carbon and humic acids, they might limit the understanding in the link between SOM dynamics and nutrient availability because they do not measure biologically active SOM fractions (Motavalli et al. 1994). On the other hand, size and density fractionation method show certainty for physical division of SOM into pools differing in composition and biological function (Barrios et al. 1996). From density perspective, soil macro-organic matter can be divided into light fraction (active fraction), intermediate fraction, and heavy fraction (Meijboom et al. 1995). The light fraction (LF-SOM), regarded is highly labile and reported to be a major nitrogen source in various agricultural soils, is composed principally of partially decomposed fragments of roots and aboveground litter (Boone 1994).

The total fractions of soil macro-organic matter decreased with increasing of land-use change from NF, CF1, CF2, and CP (6.1, 3.1, 3.9, 2.7 g kg^{-1} dry weight soil), respectively however, that LF-SOM value were similar. Although the LF-SOM represent only a small proportions of the total, they are very dynamics and account for much of the organic matter fluctuations over time and land-use change (Cambardella and Elliot 1992). The quality of LF-SOM can be represented by organic carbon, nitrogen content (Barrios et al. 1996). The quality of LF-SOM in this study varied among land-use types. The organic carbon and nitrogen content in LF-SOM decreased with increasing intensity of land-use change. The decreasing quality of LF-SOM in cacao agroforestry system indicated the decreasing of soil fertility, because light fraction or active fraction is an indicator for soil fertility than total SOM (Maroko et al. 1999).

Soil nitrogen content was not different among cacao agroforestry systems. On the other hand, N NUE_{Es} of cacao agroforestry under CF1 and CF2 were similar to that of natural forest and differed from that cacao agroforesry under CP. The similarity of N NUE_{Es} in CF1 and CF2 with NF was due to the fact that cacao in both study sites were planted under forest canopy cover, whereas cacao in CP was planted under shade trees. Nitrogen use efficiency at ecosystem scale (N NUE_{Es}) represents how the ecosystems utilize nitrogen for plants growth in this ecosystem.

Canopy cover decreased with increasing of land-use change. It was understood that canopy cover was related to light radiation, which affected the nitrogen resorption and N NUE_{C}. Cacao trees growing under CP agroforestry systems showed a nitrogen resorption only 14.4% which was less than that of CF1. Cacao agroforestry under CF1 was located in a foothill with about 80% inclination. In this steeply sloping condition surface runoff was considerable with the consequence that nutrients were washed out into the river below thereby reducing soil nutrient content in the cacao plantation. This situation apparently forced cacao plants under CF1 agroforestry system to rely more on a higher resorption of nitrogen (17.6%).

Cacao trees in the study sites were planted under shade trees. Cacao trees under CF1 had higher canopy cover (72.1%) than those under CF2 (69.4%) and CP (49.8%). As mentioned earlier that the soil nitrogen content in cacao agroforestry systems was similar. On the other site, the highest yield was under CP, but under CF1 was the lowest one. It means that the limiting factor for yield is light intensity. The effect of shade tree on cacao is very complex. It involves reduction in light intensity, temperature and air movement and it affects relative humidity and soil moisture. Reduction in light intensity, or rather radiation, is a very important effect, as radiation is one of the main factors governing photosynthesis. Therefore, light was the main factor limiting yields. When this limitation was removed the supply of nutrients from the soil became the next limiting factor which was in turn amended by application of fertilizers. The shade is not only needed to reduce light intensity but also to buffer the micro-environment for young cacao trees. When the trees grow older and their canopies are sufficiently developed to provide some self-shading, and when later on the canopies of neighboring trees meet, the need for shade decreases and yields are usually higher when trees are grown with little or no shade. The larger leaf area and the higher photosynthetic activity of unshaded cacao, which results in higher pod production, can only be maintained when trees are well provided with nutrients. For this reason fertilizer application is usually needed in lightly shaded or unshaded cacao.

The Figure 7.1 showed hierarchical cluster analysis from all variables, which separates cacao agroforestry systems from the natural forest. Both cacao agroforestry under CF1 and CF2 showed a high degree of similarity. The cacao agroforestry under CP represented a relatively distinct group. In ecological scale seemed that cacao agroforestry under CF1 and CF2 had similar condition. Apparently, the separation group between cacao agroforestry under CF1, CF2 and CP was caused by a kind of shade trees. In the cacao agroforestry under CF1 and CF2, cacao was planted under natural and mixed shade trees, whereas in the cacao agroforestry system under CP, cacao was planted under leguminous trees. Siebert (2002) in his research conducted in Moa, Central Sulawesi, stated that a traditional shade-cacao farms has the biodiversity is due to the high canopy tree species, multilayered forest structure, and the presence of lianas and epiphytes. Cacao cultivated beneath primary or secondary forest vegetation may maintain soil organic matter levels and help retain soil productivity, because shade plants can increase organic matter levels and thereby reduce soil moisture losses and increase soil water-holding capacity.

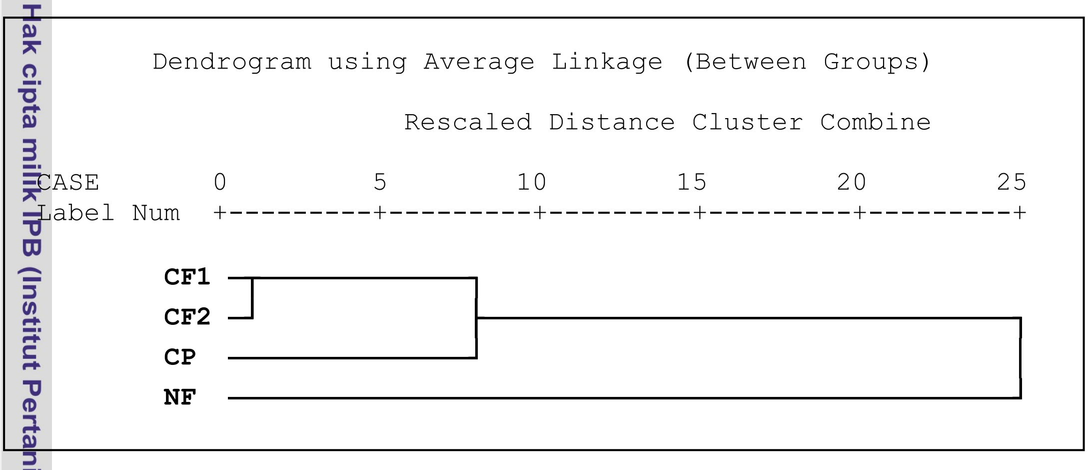

Figure 7.1. Hierarchical cluster analysis of among four land-use type in Toro village.

In fact, the cacao farmers would be burning soil surface litter periodically, whereas, litter is an input for soil organic matter. Therefore, it is important increase the input of organic matter to the soil to maintain soil fertility.

VIII. GENERAL CONCLUSIONS

1. Litterfall production varied in land-use type. Cacao agroforestry systems had lower litterfall than that of natural forest. Cacao agroforestry system CP had the highest litterfall production among cacao agroforestry system in LLNP. Natural forest exhibited the highest annual litterfall production compared with other cacao agroforestry systems studied.
2. The highest monthly litterfall production coincided with low air humidity, high wind speed, and high temperature.
3. In the first period leaf-litter decomposed (March to June) faster under natural forest than those under the cacao agroforestry systems. It seems due to a high microbial activity. During the second period (September to December), however, the rate of decomposition was lower. This period was relatively dry and probably with low microbial activity.
4. Fine root biomass under natural forest went down with time and the value was lowest in December, explaining the fact that litterfall production was highest. It seems that when a substantial amount of leaves being shaded, not enough photosynthate to support the growth of fine root underground under CF2, however, showed a different phenomenon, due to weed infestation.
5. The amount and quality of soil macro-organic matter varied in land-use types. The total of soil macro-organic matter fractions in natural forest was higher than that those cacao agroforestry systems. Land use change from natural forest into cacao agroforestry systems decreased organic carbon and nitrogen in soil macro-organic matter fractions.
6. Soil nitrogen content, nitrogen resorption, and N NUE_C were not differently significant in all study sites. However, nitrogen resorption in cacao agroforestry system under CF1 was higher than that of CF2 and CP. Nitrogen use efficiency in ecosystem CF1 and CF2 similar with that of NF, and the lowest under cacao agroforestry system CP.
7. It seems that cacao agroforestry system under CF1 and CF2 is able to maintain biodiversity and ecology performance similar to natural forest

RECOMMENDATION

It is important to evaluate the function of ecosystem component of cacao agroforestry systems periodically in the future. The conservation of tropical rainforest margin ecosystem particularly in Toro village is related to the knowledge of local people in using and managing their ecosystem in forest margin for cacao agroforestry systems. In order to increase soil organic matter in cacao agroforestry systems, it is necessary to increase the input of organic residues to the soil, particularly in the land with steep slope. It is of importance to manage land conform to its characterizations for cacao agroforestry systems in the future.

REFERENCES