

Soil degradation due to the conversion of forests to secondary land uses

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Abstract

The conversion of forests to secondary land uses particularly agriculture is believed to be the major cause of soil degradation in the humid tropics. Degraded soils particularly in upland areas have very low productivity for agriculture. In addition, they contribute to ecological problems such as siltation of surface waters, occurrence of floods and others. However, very little data have been published concerning the nature of degraded soils as well as the role of secondary land uses on the process of soil degradation. This paper discusses the concept of soil degradation and then presents some data about degraded soils in the Philippines. It then presents some highlights of the results of our detailed pedological study on soil degradation due to forest conversion in two sites in Leyte. The paper concludes, among others, that the conversion of forest to secondary land uses enhances soil degradation. However, such degradation is probably the direct effect of vegetation removal and the subsequent cultivation in the past and not necessarily the direct effect of the present secondary land uses. In fact, some secondary land uses improved the organic matter content and nutrient availability of the soil.

Introduction

The conversion of forests to secondary land uses is widely considered as the major cause of the widespread occurrence of degraded lands in the humid tropics such as the Philippines. Because of the adverse ecological effects of soil degradation particularly in upland areas (e.g. siltation of water bodies like rivers, lakes and seas), reforestation and rehabilitation efforts are strongly needed. Schulte (1997) reported for instance that in view of the extent of severely

eroding, hydrologically and ecologically disrupted lands in Southeast Asia, calls for massive reforestation and rehabilitation programs are becoming more frequent. Likewise, because of the increasing population and food demand, many of these degraded lands need to be utilized for crop production. Both efforts require detailed information about the nature and characteristics of the soil. This paper presents some highlights of our pedologic-ecological research in Leyte, the first of such kind in the Philippines particularly the part concerning soil degradation.

The term *soil degradation* was coined by the Russian pedologists Kostychiev and Korchinski in 1888 to mean the natural deterioration of the soil. The modern meaning of soil degradation according to the Global Assessment of Soil Degradation or GLASOD (UNEP, 1992) is that it is a human induced phenomena which lowers the soil's capacity to support human life. It is one of the most serious ecological problems in the Philippines today (Asio, 1997 and 1998).

Theoretical basis of soil degradation

Soil is a four-dimensional natural body (Stahr, 1984 and 1996). This implies that the soil is dynamic and its properties change with time according to the soil model of V.V. Dokuchaiev and H. Jenny which is given as $S=f(c_l, p, r, o, t, \dots)$. The equation means that the soil or any soil property (S) is a function of climate (cl), parent material (p), relief (r), organism including vegetation and land uses (o) and time (t). Soil degradation occurs because of drastic changes in vegetation or land uses due to human activities. It is possible to investigate the processes of soil degradation by selecting sites where only the organism factor (vegetation and land uses) varies while the other factors are more or less the same as expressed by the equation $S=f(o)_{cl, p, r, t}$. The most common approach of studying soil degradation is by

artificially changing the land use or vegetation for instance of a forest and then monitoring the temporal changes in soil properties. The major limitation of this approach is that many soil properties change slowly (10 to 30 years). An alternative approach is the space-for-time substitution (adjacent area approach) wherein adjacent areas differing in vegetation or land uses are compared with the fundamental assumption that the original vegetation and other site factors were similar and therefore also the original soil.

The thermodynamics of soil processes has been traditionally investigated using the Second Law of Thermodynamics which states that natural processes always lead to an overall increase in disorder or entropy (Krauskopf, 1969). Accordingly, soil degradation results in an increase in entropy. In recent years, however, the use of the Second Law of Thermodynamics in soils has been criticized since it is for closed systems and soils are open systems (Hoosbeek and Bryant, 1992; Addiscott, 1995). The Principle of Minimum Entropy Production (Prigogine, 1947; Ulrich, 1987) is considered more appropriate for soil-plant systems (Addiscott, 1995). According to this principle, soil formation results in decreased entropy production because of increased ordering processes such as development of structure, aggregation, horizonation and others. Perturbations such as changes in land use or vegetation could enhance soil degradation and thus increase entropy. But with time, the soil system will regenerate and restore itself to the steady state resulting in minimum entropy production. This concept is clearly illustrated by the regeneration of the soil as a result of fallowing.

Nature of degraded upland soils

Many tropical soils already have several constraints inherent in them (Jahn, 1998). Land use-induced soil degradation aggravates the soil-related problems. In our survey of

degraded upland soils in the Philippines, the following were the soil constraints to crop production identified (Asio and Tulin, 1997): For physical constraints, the most common were the heavy clay texture, high stickiness, low porosity (compaction), low water holding capacity, low aggregate stability and shallow depth. Chemical constraints included acidity (and alkalinity in Karst landscapes), low organic matter content, poor nutrient availability and reserve particularly of N, P, K, Ca and Mg, nutrient/element toxicity (e.g. Al, Fe and Mn) and low nutrient holding capacity. Although no quantitative data were gathered, low soil animal activity was also commonly observed in the degraded upland areas surveyed.

In terms of site or landscape characteristics, the degraded upland areas are commonly located in volcanic (andesite and basalt) and sedimentary (sandstone, limestone and shale) hills and mountains often with rolling to steep slopes. These landscapes are mostly of Tertiary and Quaternary origin and thus are geologically young. Spatial variability of soil properties in them is generally high due to high variation of soil-forming factors particularly organism (e.g. vegetation), parent rock, relief, age of surface (due to erosion, deposition, slides, etc.), microclimate and human impact. In many areas the degraded upland soils are covered by *Imperata cylindrica*, *Saccharum spontaneum*, *Paspalum conjugatum*, *Axonopus compressus*, *Cyrtococcum accrescens* and others. The shrubs *Mimosa pudica*, *Melastoma affine* and native guava (*Psidium guajava*) are also commonly observed.

Soil degradation due to forest conversion: Example from Leyte Island

In order to evaluate the contribution of the conversion of forest into secondary land uses on volcanic soils in Leyte, we

conducted a study using the space-for-time substitution approach. We selected two sites, one in Milagro, Ormoc with a young volcanic soil classified as Andisol (Andosol) and another in Mt. Pangasugan in Baybay with an older volcanic soil classified as Ultisol (Alisol). For the Ormoc site, the different land uses selected included forest, grassland, pasture and bushland. For the Baybay site, the land uses were forest, reforestation, coconut+bushes, shifting cultivation and coconut+kudzu. Details of the pedological and geological characteristics of the soils studied as well as the history of the land uses are found in Asio (1996), Asio et al. (1998a and 1998b) and Jahn and Asio (1995 and 1998).

Results of the study revealed that conversion of the forest into secondary land uses resulted in increased bulk density (decreased porosity), decreased available water and aggregate stability (Table 1). The changes in the said properties depended on the characteristics and age of the soil. Thus, the changes in the Ormoc soil were different from

TABLE 1. Effects of forest conversion to secondary land uses on Soil physics.

Land Use	Bulk Density (g/cm ³)	Porosity (%)	Available Water (%)	Aggregate Stability (%)
Ormoc Site (Andosol)				
Forest	0.51	76	26	76
Grassland	0.90	63	20	58
Pasture	0.75	67	23	62
Bushland	0.71	70	24	68
Baybay Site (Alisol)				
Forest	0.80	70	13	86
Reforestation	1.00	63	13	82
Coconut + bushes	1.20	57	12	67
Shifting cultivation	1.10	58	10	75
Coconut + Kudzu	0.86	68	14	87

that of the Baybay soil. It was also clear from the result that the nature of the secondary land use had some influence on the degree of changes in soil properties.

In terms of organic matter status and nutrient availability especially in the root zone (0-50 cm depth), our data (Fig. 1) showed that organic matter was decreased by the change in land use. Available nitrogen (NO_3^- and NH_4^+) was decreased by some secondary land uses but was increased by others. Available phosphorus remained unaffected primarily because it was present in very low amount due to the very high phosphate fixing capacity of the soils (a property directly related to soil mineralogy). Contrary to what is commonly reported in the literature, we found that available K, Ca and Mg (extracted by ammonium lactate) were increased by some secondary land uses particularly in the Baybay site. We hypothesized that cultivation, burning and other human disturbances increased weathering of rock fragments in the solum resulting in the release of K, Ca and Mg into the soil. In addition, erosion of the highly weathered and nutrient-poor topsoil resulted in the exposure of the less weathered and relatively base-rich subsoil.

Our results also showed that soil erosion varied with land use (Table 2). In the Ormoc site, bushland produced the lowest erosion rate among the secondary land uses. Grassland and pasture had much higher soil erosion rates. If we accept the critical limit of 11 t/ha/year suggested by some researchers, then all the secondary land uses in this site are acceptable as far as erosion is concerned. However, we believe that assessment of soil erosion rates should take into account the rate of soil formation. Thus, our calculations showed that the acceptable rate of soil erosion in the site based on the rate of soil formation is only 1 to 2 t/ha/year. For the Baybay site, shifting cultivation gave the highest soil erosion rate of 100 t/ha/year. Among the secondary land

TABLE 2. Effects of forest conversion to secondary land uses on soil erosion rate.

Land Use	Erosion rate (t/ha/year)
Ormoc Site	
Forest	0
Grassland	11
Pasture	13
Bushland	2
Baybay site	
Forest	1
Reforestation	23
Coconut + bushes	23
Shifting cultivation	100
Coconut + Kudzu	6

uses coconut+kudzu produced the lowest soil erosion rate.

Because of the importance of carbon dioxide evolution data not only as indicator of biological activity in the soil but also since soil is a major source of this greenhouse gas, we also measured it in the field using the soda-lime method. Results showed that forest land use generally produced more carbon dioxide due to a higher organic matter content and higher biological activity in the soil compared to most secondary land uses (Table 3).

Summary and conclusion

Soil degradation due to forest conversion is one of the most serious ecological problems in the humid tropics including the Philippines. Degraded uplands contribute to several ecological problems and therefore need to be rehabilitated. On the other hand, they are potential areas for agriculture provided proper management strategies are given. Unfortu-

TABLE 3. Carbon dioxide evolution in different land uses.

Land Use	CO ₂ (g/m ² /day)	
	July 1994	January 1995
Ormoc site		
Forest	14.3	16.8
Grassland	12.3	9.7
Pasture	15.3	14.2
Bushland	10.9	5.8
Baybay site		
Forest	16.6	14.9
Reforestation	13.2	14.2
Coconut + bushes	14.8	10.5
Shifting cultivation	13.5	13.1
Coconut + Kudzu	16.5	17.0

nately, very little detailed information is available about the nature of degraded soils and their management requirements. Moreover, the contribution of secondary land uses to soil degradation is not well understood in many countries in the humid tropics like the Philippines. Our data from Leyte showed that the conversion of forest resulted in the degradation of many soil properties but were probably the direct effect of forest removal and not necessarily the effect of the present secondary land uses. In fact, it was shown that in some secondary land uses, there was improvement in soil properties particularly organic matter status and nutrient availability.

References

- ASIO, V.B., 1996. Characteristics, weathering, formation and degradation of soils from volcanic rocks in Leyte, Philippines. *Hohenheimer Bodenkundliche Hefte* Vol. 33, Stuttgart, 209 pp.
- ASIO, V.B., 1997. A review of upland agriculture, population pressure and environmental degradation in the Philippines. *Annals of Tropical Research* 19:1-18.
- ASIO, V.B., 1998. Degraded upland soils in the Philippines: research needs. *PLITS*, Stuttgart, 16(2): 275-278.
- ASIO, V.B. and A.B. TULIN, 1997. The characteristics of degraded soils and the ameliorative effect of vegetation. Paper presented during the International Conference on Reforestation in the Philippine Species, 3-6 March 1997, Tacloban, Leyte, Philippines, 15 pp.
- ASIO, V.B., R. JAHN and K. STAHR, 1998a. Changes in the properties of a volcanic soil (Andisol) in Leyte due to conversion of forest to other land uses. *Philippine Journal of Science* (accepted for publication).
- ASIO, V.B., R. JAHN, K. STAHR and J. MARGRAF, 1998b. Soils of the tropical forests of Leyte, Philippines. II: Impact of different land uses on status of organic matter and nutrient availability. In: *Soils of Tropical Forest Ecosystems* (A. Schulte and D. Ruhiyat, eds.) Springer-Verlag, Berlin-Heidelberg-New York, 37-44.
- ADDISCOTT, T.M., 1995. Entropy and sustainability. *European Journal of Soil Science* 46: 161-168.
- HOOSBEEK, M.R. and R.B. BRYANT, 1992. Towards the quantitative modelling of pedogenesis—a review. *Geoderma* 55: 183-210.
- JAHN, R. and V.B. ASIO, 1995. Verwitterung und Mineralneubildung in Boeden aus intermediären bis basischen Vulkaniten im tropischen Klima von Leyte, Philippinen. *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft* 76: 1437-1440.
- JAHN, R. and V.B. ASIO, 1998. Soils of the tropical forests of Leyte, Philippines. I: Weathering, soil characteristics, classification and site qualities. In: *Soils of Tropical Forest Ecosystems* (A. Schulte and D. Ruhiyat, eds.), Springer-Verlag, Berlin-Heidelberg-New York, 29-36.

- JAHN, R., 1998. The soil resource of the tropics- the necessity of intensified nutrient cycling within ecological land use systems. Paper presented during the International Conference on Applied Tropical Ecology, 8-10 September 1998, ViSCA, Baybay, Leyte, Philippines, 10 pp.
- KRAUSKOPF, K.B., 1969. Thermodynamics used in geochemistry. In: Handbook of Geochemistry (K.H. Wedepohl, ed.), Vol 1. Springer-Verlag, Berlin, 37-77.
- PRIGOGINE, I., 1947. Etude Thermodynamique des Processus Irreversibles. Desoer, Liege.
- SCHLICHTING, E., H.P. BLUME and K. STAHR, 1995. Bodenkundliches Praktikum (2nd ed.) Blackwell, Berlin-Vienna, 295 pp.
- SCHULTE, A., 1997. Reforestation with fast-growing exotics versus rehabilitation of forest ecosystems with native tree species in Southeast Asia. I: Theoretical aspects. Paper presented during the International Conference on Reforestation with Philippine Species, 3-6 March 1997, Tacloban, Leyte, Philippines, 28 pp.
- STAHR, K., 1984. Der Bodenkundliche Beitrag zu einer oekosystemorientierten Landschaftplanung-Struktur einer Wissenschaft. In: Oekosystemorientierte Landschaftplanung. Landschaftsentwicklung und Umweltforschung 22, Berlin, 229-241.
- STAHR, K., 1996. In: Handbuch der Bodenkunde (by Blume, Felix-Henningsen, Fischer, Frede, Horn and Stahr). Ecomed, Landsberg/Lech.
- ULRICH, B., 1987. Stability, elasticity and resilience of terrestrial ecosystems with respect to matter balance. Ecological Studies 61: 11-49, Springer-Verlag, Berlin-Heidelberg.
- UNITED NATIONS ENVIRONMENTAL PROGRAMME (UNEP), 1992. World Atlas of Desertification. Edward Arnold, London, 69 pp.