ORGANIC MATTER DYNAMICS AFTER CONVERSION OF FORESTS TO FOOD CROPS OR SUGARCANE: PREDICTIONS OF THE CENTURY MODEL

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ABSTRACT

The major constraints of acid upland soils such as ultisols when used for agricultural purposes are the rapid degradation in its fertility and the limited and highly variable supply of water. Slash and burn methods for land clearing are used both in the traditional cropping system with low-input management on such soils and for conversion of forests to perennial crop plantations. The primary objective of the present study was to simulate soil organic matter (SOM) dynamics after converion of forest by slash and burn methods to food crops or to a sugarcane estate. A comparison is made between sugarcane as managed by of Bungamayang Sugar Plantation (BSP) in Lampung applying high-input management and by smallholders in the area, who often do not use fertilizer. The CENTURY model version 3.0 was used to simulate the SOM dynamics on the basis of site files for shifting cultivation in Sumatra. The results of simulation were compared with observations on SOM dynamics on an Ultisol in the study area.

Predicted SOM dynamics vary substantially between vegetation, crop management and fractions of SOM. Forest removal followed by rice or sugarcane cultivation causes a considerable decrease in active (SOM1C), slow (SOM2C) and total soil carbon (SOMTC) particularly with farmer management. When BSP management is followed by the application of straw, the decrease in SOM is markedly reduced. Nearly similar results are found when biological management (zero tillage + P fertilizer + straw) is applied. The most sensitive SOM pool in response to changes in vegetation and soil is SOM1C followed by SOM2C, whereas SOM3C (passive soil C) declines only slightly with time in all cases. The dynamic of SOMTC, the most frequently measured SOM pool, can be used in most cases to represent changes in SOM2C, but not SOM1C or SOM3C. Crop yield declines drastically in the second year with farmer management. Sufficiently high yields can be expected for sugarcane in the first ten years with BSP or biological and particularly BSP + straw management, but declines are to be expected thereafter. The model predicts a clear role for SOM in the maintenance of cane productivity on the Ultisol in Lampung, acting directly as well as through N and P supply.

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is widely cultivated now on acid soils in Indonesia. For instance, the total area of sugarcane in Lampung, where soils are dominated by Ultisols, was estimated to be more than 100,000 hectares (Ismail, 1990). Some of this area was under primary (logged-over) or secondary forest vegetation prior to its conversion to sugarcane plantation by slash and burn techniques. After ten years of cultivation following forest removal, sufficiently high cane yields were still reported in the sugarcane estate of Bungamayang sugar plantation (BSP). This suggests that declining soil fertility, the central issue on acid soils, is not (yet) a constraint to sugarcane production. The sugarcane estate operates with high-input management involving lime and high fertilizer rates, while sugarcane is highly tolerant to aluminium and low pH. Sugar cane has a sufficiently dense canopy during the last one-third of the growing season. Successful plantation of sugarcane on acid soils was also reported in Australia without serious problems, except deficiencies in calcium and magnesium which were corrected with application lime (dolomite) and Mg-fertilizer (Edwards and Bell, 1989).

The application of lime and fertilizers alone, which have been found to be effective to tackle the infertility of acid soils in many cases (McIntosh & Effendi, 1979; Setijono & Soepardi, 1985; Ismunadji & Makarim, 1989), will not be able to alleviate the deteriotation of soil fertility due to decline in SOM and erosion. Sanchez (1983) reported that frequent lime application was needed (every one to three years) to maintain high yields of upland rice, maize, soybean and peanut on an acid soil at Yurimaguas. He also found that the quantity of fertilizers and lime required to eliminate soil constraints varied between adjacent fields having the same previous vegetation, geomorphic position and soil classification at family level. Smallholder farmers in North Lampung often do not use fertilizer on their sugar cane (partly due to logistical problems in fertilizer supply via BSP) and many farmers do not continue growing sugarcane after the first crop cycle. Serious difficulties exist for the adoption of high-input technologies for small farmers.

Actually, the poor inherent fertility of acid soils, includes not only chemical conditions, e.g. low pH, nutrient elements such as N, Ca, Mg, P, K & Mo, and CEC and high Al and Mn concentration, but also soil physical properties, e.g. low water holding capacity (Edwards & Bell, 1989; Uexkull & Bosshart, 1989; Arya, 1990; Van der Heide *et al*., 1992; Van Noordwijk *et al*., 1992). This is, however, not expressed until the original vegetation of rainforest is replaced with agricultural crops which is followed by dramatic reduction in the supply of soil organic matter and substantial loss of soil organic matter. Perennial cropping systems involving particularly acid and Al-tolerant species such as rubber and oil palm (Pushparajah, 1983) are considered to be the best systems in the use of acid soils for agriculture purposes (Notohadiprawiro, 1989).

In parts of the BSP sugarcane plantation in Lampung degradation of soil fertility by erosion can easily be spotted. This is very likely the consequence of intensive tillage with tractors combined with the instability and susceptibility to erosion and sensitivity to compaction of Ultisols (Von Uexkull & Bosshart, 1989). If this soil management is maintained, continued removal of top soil through erosion will end up with the abandonment of sugarcane fields as they can no longer support adequate yields. This would create a new form of shifting cultivation. Even at present, poor growth of crops may be found on certain plots which are then left fallow for one or more growing seasons. For production to be sustainable, erosion has to be minimized which may be achieved through minimum tillage. Efforts to improve soil physical properties allowing, for instance, high infiltration and aggregate stability are desirable. It is thus of great importance to have a good understanding on factors and processes operating in the formation of good physical properties of Ultisols.

Many studies have demonstrated that increased supply of organic matter in addition to residues from cultivated crops, achieved by growing cover crops during fallow period or hedgerow trees, in combination with zero tillage was able to maintain sufficiently high yield of food crops such as cassava, rice, maize and soybean on an Ultisol in Lampung receiving no lime and nitrogen fertilizer (Sitompul *et al*., 1992a,b; Utomo *et al*., 1992). The best cropping system among the examined cassava-based cropping systems produced the highest soil organic matter contents (Sitompul & Listyarini, 1992). Scholes *et al*. (1994) considered that the sustainability of agroecosystem is a function of surface hydrology, soil organic matter dynamics and the synchronization of nutrient supply & demand. On upland soils, crop water requirement is entirely dependent upon rainfall, and crops during the absence of rainfall would rely on water stored in the soil. This soil water storage is determined by rate of infiltration or surface water flow and soil water holding which is closely related to soil organic matter. McIntosh *et al*. (1979) reported on long-term research on an Ultisol in Lampung showing that yields of several food crops were higher with mulch than without mulch.

Thus, SOM appears to be a key control of sustainability on acid upland soils through its function as protective material of soil (from rain drops, exposure to solar radiation and excessive surface water flow), source of nutrients and as agent creating favourable physical and chemical soil conditions for root development (Woomer *et al*., 1994). It is expected that any (semi) permanent cropping system as alternative to slash and burn, such as a sugarcane plantation, will be eventually unsustainable unless proper management is applied to avoid the depletion in SOM. As SOM continues to change from fresh SOM to relatively stable SOM through various decomposition stages which each may have different functions, a good understanding on the effect of particular management on SOM dynamics is important.

The primary objective of the present study was to simulate SOM dynamics in sugarcane systems derived from forest by slash and burn techniques, by taking the case of the sugarcane estate of Bungamayang Sugar Plantation in Lampung with its high-input management. The results of simulation with the Century Model, were compared with field observations to test the model predictions of SOM and cane yield.

MATERIALS AND METHODS

Model. CENTURY model version 3.0 (Parton *et al*., 1992) was used to simulate SOM dynamics during forest growth and after forest removal by slash and burn, followed by sugarcane plantation in the sugarcane estate of Bungamayang Sugar Plantation, Lampung. Model routines were used which were developed for shifting cultivation (forest regrowth and upland rice production) in Jambi province (Sumatra), partly on the basis of data from Yurimaguas (Peru) by Woomer (1994). Site-specific files for Lampung were made for climate data and some soil characteritics (Van der Heide *et al*., 1992; Van Noordwijk *et al*., 1992).

The simulated SOM consisted of RLWODC (carbon in large wood live component in forest system), SOM1C (C in active pool with fast turnover rate), SOM2C (C in slow pool with slow turnover, approximately corresponding to the 50 m - 2 mm size fraction), SOM3C (C in passive with very slow turnover rate, corresponding to organo-mineral associated humic substances) and SOMTC (total soil carbon including litter, and structural and metabolic components). Nitrogen and phosphorus in top soil (0-20 cm layer) were also simulated; crop files for sugarcane were derived from the one for upland rice. The highest yield of each crop that could be achieved in the area of study based on experimental results (Van Noordwijk *et al.*, 1992; Ismail *et al.*, 1990), 5 Mg of rice grain and 90 Mg of cane yield were used as a basis for this conversion.

Field Study. A field study was conducted in 1995 at Sugarcane estate of Bungamayang Sugar Plantation, Lampung and in forest areas (at least 30 years old) surrounding the area of sugarcane. This site is, within the same location as the experimental site of the N-Management project (Van der Heide *et al.*, 1992), with a soil classified as Ultisol (Grossarenic Kandiudult). Geographic location, soil characteristics and climate description of the experimental site of N-Management were reported previously (Van der Heide *et al.*, 1992; Van Noordwijk *et al.*, 1992), and detail soil characteristics at the site of present study were reported by Mahabrata (1996). The site originated from secondary forest and was converted by slash and burn technique combined with heavy machinery to remove large woods and trunks, leaving about 10 % of organic matter in the field.

After forest removal, the fields for the plantation were ploughed by tractor and cultivated with sugarcane var. Triton, Div or Q 90 supplied with about 70 kg N (Urea), 160 kg P_2O_5 (TSP), 60 kg K_2O (KCl) and 100 kg lime (Dolomite) per hectare every year. For the model, a rate of fertilizer use was tested of 100 kg N and 60 kg P_2O_5. The cane and ratoon cane are maintained for 3-5 years and (manually) harvested every year. All cane residues left in the field are burnt before soil tillage, which is combined with the application of fertilizers and lime. Sugar cane plots opened from forest 2, 3, 4, 6 or 10 years ago were selected, and triplicate soil samples were taken from sample are of 10 m2 to a depth of 0-15 cm, and soil organic matter was analyzed. Soil samples were also taken from a forest area, recently cleared area with slash and burn technnique and in farmers' field as controls. The fraction of soil organic matter with a size of 150 m - 2mm was determined with the Ludox method (Meijboom *et al.*, 1995; Hariah *et al.*, *this issue*).

RESULTS AND DISCUSION

Forest Growth and Removal

Tree biomass (about 100 Mg ha^{-1} of C) is the main part of total organic carbon in the forest (about 150 Mg ha^{-1} of C, taking a depth of 15 cm as baseline), with a minor role for under storey biomass (Table 1).

Table 1. Organic matter pools and SOM resources before and after forest removal on an Ultisol in Lampung.

	Weight	C content	Total C
	(Mg.ha^{-1})	(%)	(Mg.ha^{-1})
I. BEFORE BURNING			
Under Storey			
Green Biomass	0.94	40a	0.38
Roots (0-5 cm depth)	0.743	40a	0.02
Brown Biomass	7.95	40a	2.54
Tree Biomass			
Living trees	249	40a	99.6
Dead standing trees	11.0	40a	4.40
Dead material on forest floor	19.5	40a	7.80
Stumps left after logging	9.18	40a	3.67
Total Soil Organic Carbon			
0-5 cm depth	600	2.44	14.6
5-15 cm depth	1200	2.12	25.4
Total (I)	154.0		
II. AFTER BURNING			
Ash (0-3 cm)	10.6	7.55	0.80
(3-5 cm)	21.6	4.23	0.91
Brown Litter	0.45	40a	0.18
Roots (0-5 cm depth)	1.40	40a	0.56
Small Branches	8.08	40a	3.23
Stumps left after clearing	0.16	40a	0.06
Total Soil Organic Carbon 5-15 cm depth)	1200	1.94	23.2
Total (II)	28.9		
Difference (I-II) (81.2%)	125.1		

Note: a = estimated

The amount of above-ground biomass carbon (AGBC) of living trees was estimated on the basis of tree basal diameters. The model predicts an exponential increase in RLWODC and FROOTC for the first 10 years, followed by a linear increase (Fig. 1A). A similar growth pattern is found in AGBC (RLWODC + FBRCHC + RLEAVC, referring to wood, branches and leaves, respectively) which reaches 100 Mg ha^{-1} (or 10 kg m^{-2}) in year 31 (Fig. 1A) which is close to the field observation. FBRCHC increases very slowly after a rapid initial growth (FBRCHC), while RLEAVC and FROOTC re-

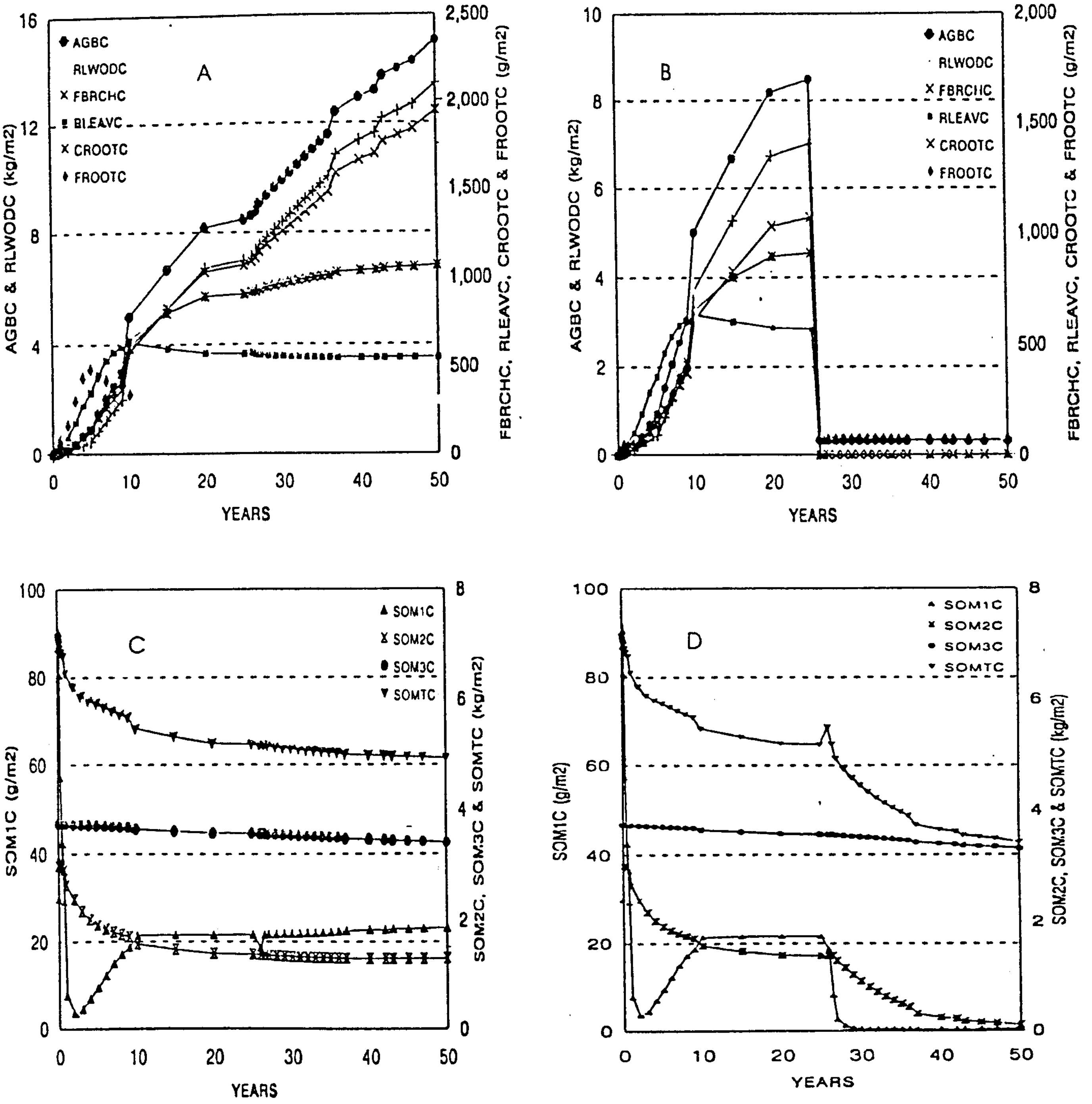

Figure 1. Biomass/Som of forest & forest removal.

main relatively constant after rapid intial growth (years 0-10 and 0-5, respectively) and a slight decline (years 10-20 and 5-10, respectively).

The mean growth rate of simulated AGBC up to 6, 20 and 50 years old is 2.6, 4.1 and 3.0 Mg ha^{-1} $year^{-1}$, and the ratio of AGBC/total biomass in these years is 0.70, 0.86 and 0.87. These results are close to field observations in Zaire where the production of total biomass was found to be 47.8 Mg ha^{-1} for 6-year old secondary forest (80% above-ground biomass), 175 Mg ha^{-1} for 18-year old secondary forest and 523 Mg ha^{-1} for forest of at least 50 year old (Bebwa & Lejoly, 1993). This is equivalent to 3.2, 3.9, 4.2 Mg (C) ha^{-1} $year^{-1}$, by assuming C content to be 50% of forest biomass (Bebwa & Lejoly, 1993). Woomer *et al.* (1994) reported that the annual production of shoot observed in 16 tropical sites rages varies from 2.04 to 32.8 kg (C) m^{-2}.

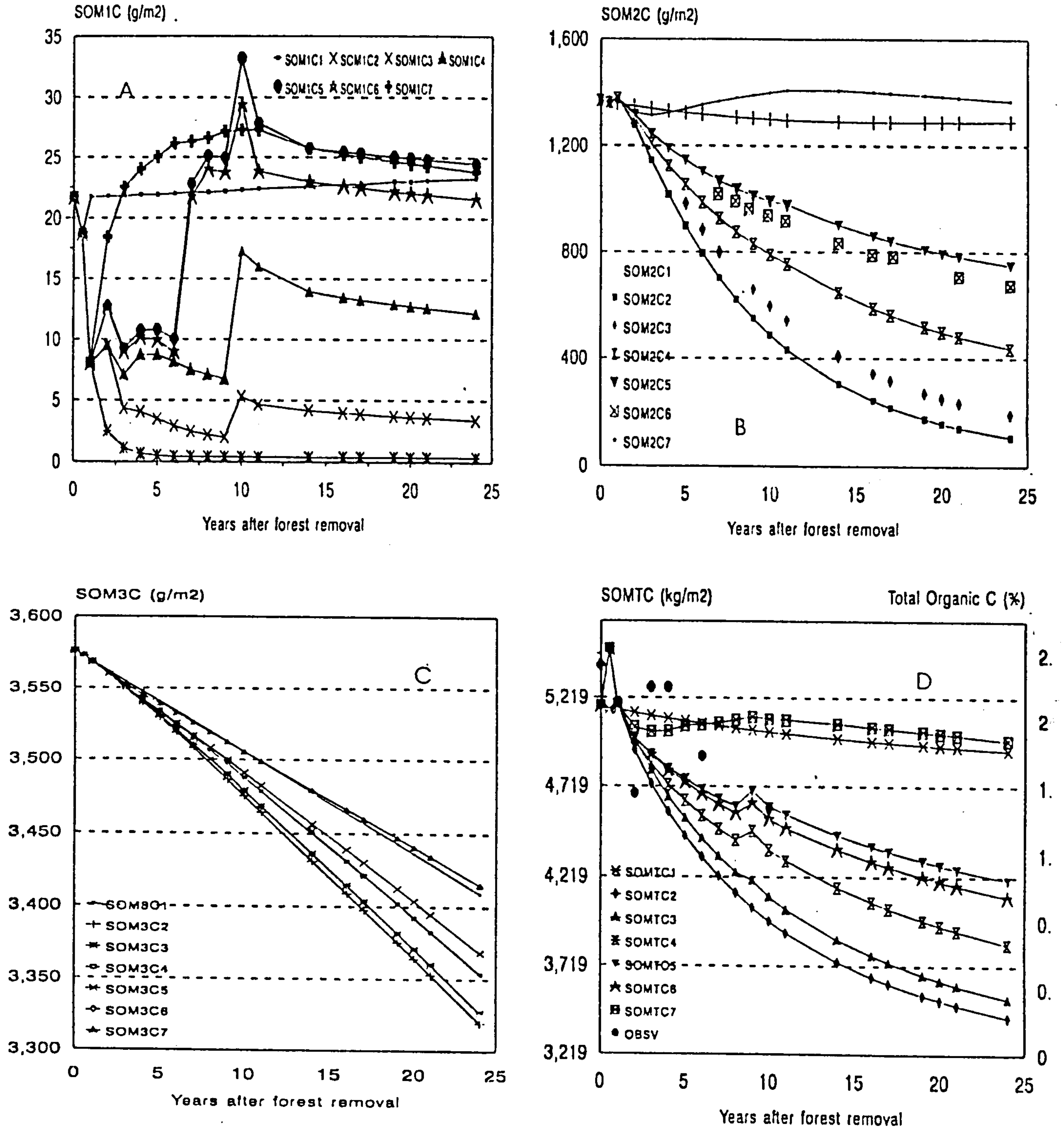

Figure 2. All som of different system.

The average age of trees at the time of forest conversion was set in the model to be 26 years old, as the year of conversion of forest to sugarcane area ranged from 0 to 10 years before 1995. From field obsevations, the amount of AGBC left after forest clearance with slash and burn technique was estimated to be less than 5% (Table 1) for the plantation management. In the cas of small farmers, the amount of forest materials left al ter clearing is generally more than 5%. In the model, th amount of AGBC left in the field is set to be 5%, an this is confined only to RLWODC, the most likely pai of AGBC left in the field. All roots are also set to die i

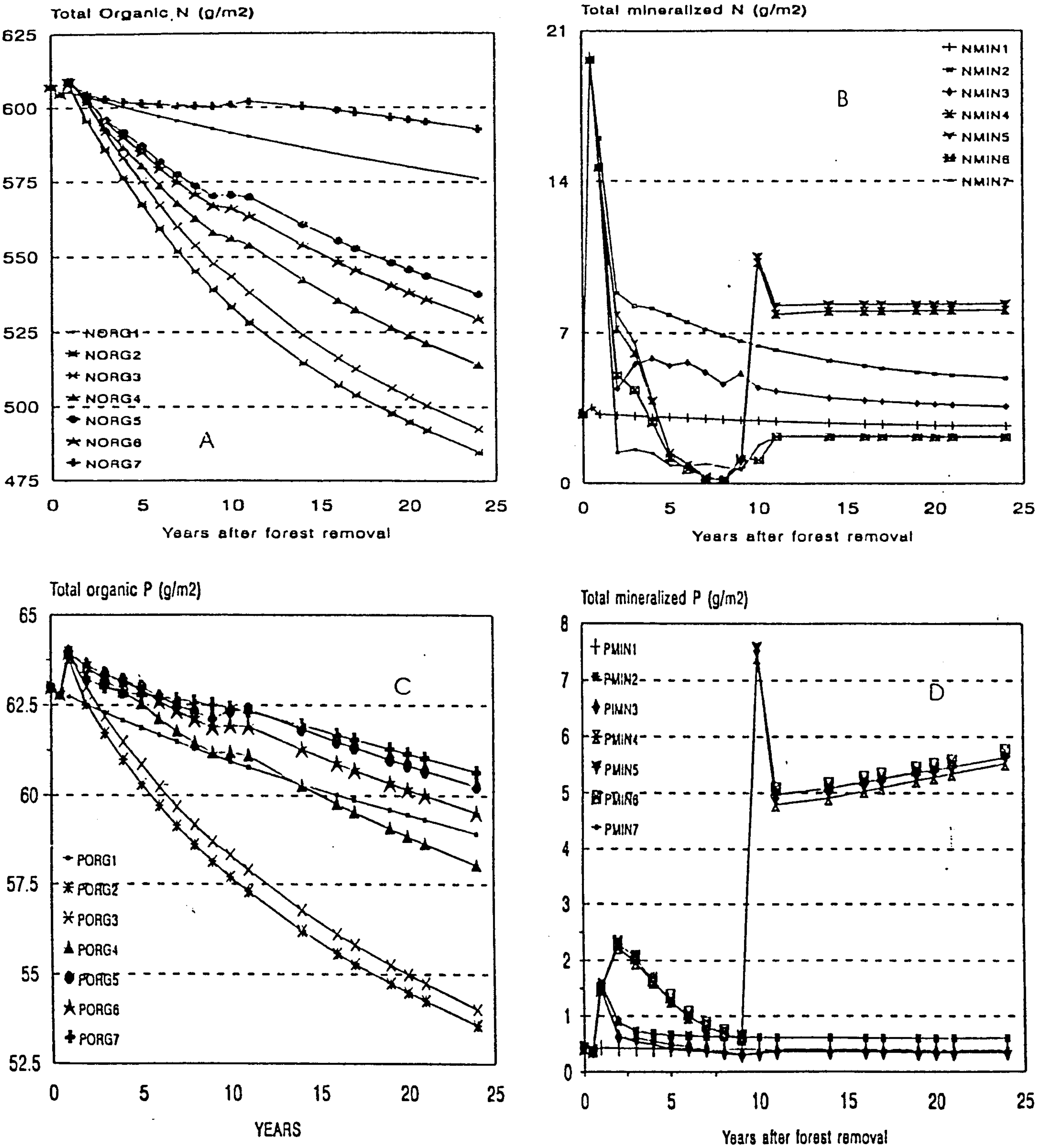

Figure 3. N & P at different system.

the model and thus there is no regrowth of forest after slash-and-burn (Fig. 1B).

SOM Dynamics

SOM dynamics was simulated for several cropping systems (see legend in figures) and a bare soil system, in which the area is left bare after forest removal (Fig 2). The cropping systems consist of crops with a traditional management applied by farmers (with soil cultivation but without fertilizer and straw application), a management applied by the Bungamayang Sugarcane Plantation, BSP, (soil cultivation + fertilizers without straw application), a high external-input (HEI) management (soil cultivation + fertilizers + straw) and biological managament investigated by BMSF (Biological managament of soil fertility) project in Bungamayang, Lampung (zero tillage with P ferilizer and straw application). In brief, these situations are referred to as forest (legend 1), bare (legend 2), farmer (legend 3), BSP (legend 4), HEI (legend 5), and Biological (legend 6) management respectively. A further comparison was made with a fallow regrowth (savanna) (legend 7).

Under forest systems (Figs. 1C & 2), all SOM fractions decline with time from the initial parameter estimates. SOM1C looses almost 90% in the first two years, but recovers rapidly after 3 years of forest growth and increases very slowly after year 10. For the last 40 years; SOM1C increases by only 1.8 g m^{-2}, thus it would take nearly 200 years to reach the initial value (30 g m^{-2}). This suggests that a marked increase in SOM1C would not be expected under a growing forest in 'long term fallows'. SOM2C also shows a considerable decrease from the initial estimates and is reduced by almost 50% for the first 10 years; it declines slowly thereafter. SOM3C declines very slowly following a linear trend throughout the simulation time. SOMTC declines significantly at the initial stage of forest growth then slowly during the rest of simulation time.

If the area is left bare after removal of forest (killsom), SOM1C shows an immediate and considerable reduction, and is almost completely lost within 5 years. SOM2C also declines considerably following an exponetial decay model and less than 10% is left after 24 years. This substantiates the sensitivity of SOM1C and SOM2C pools to organic matter inputs. In turn, SOM3C is not affected by the removal of forest and is reduced by less than 10% after 24 years, with a dynamic similar to that under forest. SOMTC is reduced by about 34% for 24 years and its changes are dominated by those in SOM2C. Maintenance of all SOM fractions appears to be better with a fallow (savannah) regrowth following forest removal than for the undisturbed forest system.

When forest is replaced by a crop vegetation (rice or sugarcane), the model outputs show that SOM2C, SOM3C and SOMTC all decline with patterns similar to those found under bare soil. However, the rate of decrease is lower than that under bare soil and varies between crop management. From high to low maintenance of SOM2C and SOM3C, the management systems rank as HEI > biological > BSP > farmer management. In turn, the dynamics of SOM1C change with the presence of crop and are characterized by a considerable decrease in the initial years of crop cultivation followed by an increase, different from that found under bare soil. This increase is lowest with farmer management and highest with HEI management. The biological management produces a slightly lower SOM1C than that found under HEI management. The soil SOM1C content with this management is higher for some years and only slightly lower after the year 16 than that found under forest. SOM1C with BSP is lower than that with biological management but higher than that with farmer management.

N and P Nutrients

Total organic N (NORG) and P (PORG) as well as total mineralized N (NMIN) and P (PMIN) were also simulated and both show a decrease with time independent of systems (Fig. 3). The decrease in NORG follows a pattern close to an exponential decay model. A similar pattern is also shown by the decrease in PORG under bare soil and crop with farmer management, but the decrease in PORG under other systems is close to linear. The maintenance of total organic N and P appears to be better with undistubed fallow than with forest which causes succesively a decrease of about 2% and 5% in NORG and 4% and 6% in PORG. Bare soil causes the largest decrease, and total organic N and P falls to about 80% and 85% after 24 years under this system.

When crops are grown after forest removal, the rate of decrease in NORG and PORG is reduced in comparison with bare soil and varies with crop management. In the case of N, the maintenance of N is better with forest than with crop even with high-input management. The best crop managements in term of N maintenance after high-input management is the biological management which is followed by BSP and farmer managements. In the case of P, the biological management as well as HEI management lead to higher PORG than in forest soils. A similar picture appears during initial years with BSP management. Farmer management causes considerable loss of PORG being almost similar to bare soil.

Total mineralized N (NMIN) shows not much change under forest throughout the simulation time (Fig. 3B). In other systems, it is characterized by a period with a dramatic increase and decrease in the first two years. After this period, NMIN is relatively high and declines slowly with time when the field is left bare or used for crop with farmer management. NMIN with BSP and HI management increases suddenly to more than 7 g m-2 (70 kg ha^{-1}) after a very low value between year 5 and 10. With the biological management, NMIN shows a

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VERTEBRATE PESTS, CROP AND SOIL: THE CASE FOR AN AGROFORESTRY APPROACH TO AGRICULTURE ON RECENTLY DEFORESTED LAND IN NORTH LAMPUNG

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ABSTRACT

With the influx of both spontaneous and government sponsored transmigrants into North Lampung, the once abundant forest has been widely cleared for conversion to new agricultural land. This ex-forest soil is rapidly degraded. In the study area the farmers have to deal not only with the low fertility of this soil, but also with heavy vertebrate pest depredation. This paper explores the interaction between cropping systems, soil conservation measures and vertebrate pests. Comparisons are drawn between the indigenous rubber-based agroforestry systems and the food crop based system also found in the area. Farm level control options include choice of crops (and varieties), poisoning and synchronized planting. At a landscape level the present of forest remnants may influence natural enemies.