SUGGESTIONS FOR THE MANAGEMENT OF "PROBLEM SOILS" FOR FOOD CROPS IN THE HUMID TROPICS

H. R. von UEXKULL*

Summary

A fast-growing population and the resulting need for more food is putting increasing stress on our land resources. One of the biggest pools in terms of potential agricultural land is found in the belt of the tropical rain forests.

The highly weathered, low CEC, acid Ulti- and Oxisols in the tropics can maintain a good forest vegetation, but lose rapidly their fertility when planted to arable food crops.

A management system is suggested that may significantly improve the continued productivity of many "problem soils" in the tropics.

Introduction

While almost all land areas in tropical Asia that lend themselves to rice cultivation have been densely settled, vast tracts of land exist that may have a potential for agriculture.

It is estimated that in order to meet mankind's food needs, food production has to be increased by 60% over the next 20 years. While a great part of the needed increase is expected to come from intensification efforts on existing (good) land, as much as 200 million ha of new land – mostly "problem soils" will have to be opened up (Table 1) (Dudal, 1980).

It is estimated that Indonesia alone has over 40 million ha of "potential" agricultural land. Smaller, but still very significant acreages exist in Malaysia, Thailand, the Philippines and the three Indo-China states.

The "problem" nature of these soils is indicated by the fact that in Java and Bali, the population density is over 600 persons/km^2, whereas in Kalimantan – where most of the land reserves are located – population density is less than 10 persons/km^2.

Over the past 3 decades considerable efforts have been made to "transmigrate" farmers from the densely populated areas of Java into the empty lands of Sumatra and Kalimantan.

While the transformation of the tropical rain forest into highly productive tree crop (rubber, oil palm) plantations has met with little difficulty, no good answer has yet been found as to how to manage the "problem soils"for food crops.

A great many of the transmigration schemes have therefore failed or have resulted in the transformation of good, productive forests into poor subsistence agriculture and wasteland.

Unless a low cost technology is offered that permits continued cropping on problem soils, they should be left untouched, that is under forest cover.

In this paper, suggestions are made that could offer a way for a better and more efficient utilization of some of the tropical soils.

Definition of "problem soils"

In the context of this paper we refer to "problem soils" as to "soils that after removal of their forest cover cannot be permanently cropped with annual crops by smallholder farmers with the financial and technological means currently available to them."

The "problem" is largely seen as a man-made one. Nature has little problem in maintaining some of the world most productive forests on soils that every soil scientist would classify as ex-

* Regional Director, E. and S.E. Asia Program of the Potash Institute. 126 Watten Estate Road, Singapore 1128.

Table 1 World soil resources and their major limitations for agriculture (Dent, 1980)

Region	Percent of total land area with limitation					
	Drought	Mineral stress*	Shallow depth	Water excess	Permanent frost	No serious limitations
North America	20	22	10	10	16	22
Central america	32	16	17	10	–	25
South America	17	47	11	10	–	15
Europe	8	33	12	8	3	36
Africa	44	18	13	9	–	16
South Asia	43	5	23	11	–	18
N. and C. Asia	17	9	38	13	13	10
S.E.Asia	2	59	6	19	–	14
Australia	55	6	8	16	–	15
World	28	23	22	10	6	11

* Nutritional deficiencies or toxicities related to chemical composition of origin.

tremely poor. The "problem" begins when man starts to clear the forest. With the forest cover removed, the almost closed nutrient cycle broken and the soil surface directly exposed to the elements, many of the chemical and physical defects of the soils come to the open.

For the farmer tilling such soil, problems of mineral stress (mineral deficiencies and toxicities) temperature, alternate water and oxygen stress are compounded by a climate that favours the growth of weeds, *Imperata cylindrica* in particular.

Taxonomy of the "problem soils"

The majority of the soils that are still potentially available in Southeast Asia for food production and that are currently covered by virgin tropical rain forest or a secondary vegetation belong to the order of Ultisols (Acrisols), Oxisols (Ferrasols), and Spodosols (Podzols).

A profile description of an Ultisol and an Oxisol, including some data on physical and chemical characteristics is given in Annex A and B.

Soil-related constraints of Ultisols, Oxisols and Spodosols

As the soil-related constraints of tropical soils have recently been subject to detailed discussions (IRRI, 1980, MSSS, 1981) we will limit ourselves to mentioning the most commonly found factors.

They are:

(1) A low pH.
(2) A low cation exchange capacity.
(3) A low level of total and available nutrients.
(4) A very low base saturation percentage.

(5) A high to very high aluminum saturation percentage.
(6) A high phosphate fixation capacity.
(7) A clay fraction consisting of rather surface inactive minerals (kaoline, quartz, aluminum oxides, etc.).
(8) A very low level of microbiological activity, especially in the subsoil.
(9) An organic matter fraction that consists largely of coarse, purely dispersed material.
(10) Sensitivity to compaction (especially on Ultisols) and very slow recovery from compaction.
(11) A weak retention for water and nutrients.

Mineral stress, usually in association with low pH is the major limiting factor, affecting 59% of the total land area in Southeast Asia (Dent, 1980). Only 14% of the soils are without serious limitation and on above 14% of the land area over 70% of the population is concentrated.

Forest growth on "problem soils"

As mentioned earlier, a flourishing forest vegetation can be found on most of the "problem soils" – as long as man is not interfering. The total biomass contained in a tropical rain forest is estimated to range between 350 – 450 tdm and the amount of nutrients contained in this dry matter is considerable (see Table 2).

With rainwash included, it is estimated that about 1/4 to 1/3 of the above nutrients is re-cycled every year. The annual nutrient additions from a mature forest to an Alfisol in Ghana are shown in Table 3.

This shows that very considerable amounts of nutrients are in constant and rapid circulation in the rain forest. With water hardly ever limiting, the shallow rooting forest vegetation can largely depend on the nutrients in the cycle and is therefore rather independent of the poor (sub) soil as long as the topsoil remains shaded, moist and undisturbed.

Table 2 Estimated biomass (and nutrients contained) of a tropical rain forest grown on an Ultisol in Kalimantan

Component	Dry matter (ton/ha)	Nutrient content (kg/ha)				
		N	P	K	Ca	Mg
Leaves and twigs	26	468	31	312	130	65
Litter	6	72	1	18	60	9
Dead wood	18	16	2	9	26	11
Live wood	285	513	71	712	855	132
Roots	50	150	22	150	223	33
Total	385	1,219	127	1,201	1,294	250

Table 3 **Annual nutrient additions from a mature forest to an Alfisol in Ghana**

Transfer pathway	Dry matter (kg/ha)	Nutrient content (kg/ha)				
		N	P	K	Ca	Mg
Rainwash	–	12	3.7	220	29	18
Litter fall	10,528	199	7.3	68	206	45
Timber fall	11,200	36	2.9	6	82	8
Root decomposition	2,576	21	1.1	9	15	4
Total	24,304	268	15.0	303	332	75
Annual turnover (%)	7	13	11	33	12	19

Source : Sanchez, 1976. Calculated from data by Nye (1961).

Effects of forest clearing on nutrient cycle and soil properties

As most of the effects of forest clearing have been discussed in detail by Sanchez (1976), we limit ourselves to mentioning the major factors affected, without going into further details.

Factors affected and permanently changed by cutting (and burning) the forest are:

	Before cutting	After cutting
(1) Soil surface temperature	Uniform 24 – 28°C	Big variation 23 – 42°C
(2) Soil surface moisture	Uniform moist	Extreme
(3) Leaching and surface erosion	Minimal	Considerable to severe
(4) Microbiological activity	High	Low very high very low
(5) Soil structure	Stable	Variable
(6) Nutrient cycle	Closed	Broken
(7) Organic matter cycle	Closed	Broken
(8) Organic matter content	Constant	Declining
(9) Co_2-production and release	High and uniform	Low and irregular

Temporary or one-time changes in connection with forest clearing and burning are:

(1) A one-time, large addition of plant nutrients that can range from kg/ha (Nye and Greenland, 1964, Brickmann and Nascimento, 1973, Sanchez, 1976.)

N	P	K	Ca	Mg
150 – 250	30 – 120	300 – 800	250 – 1000	30 – 180

(2) A temporary increase in pH and base saturation.
(3) A very irregular distribution of nutrients as a result of burning, re-stacking and re-burning.
(4) A localized irreversible dehydration of soil colloids as a result of high temperature during burning.
(5) A steep decrease in microbial activity due to partial "sterilization" after burning, followed by a short "flush" and a gradual decline in population (Landelot, 1961).

Crop yields after clearing and burning the forest

From the above it is clear that for a short time after clearing and burning the forest, soil fertility is improved but that such improvement is very short-lived. Increasing nutrient stress, increasing water stress and increasing competition from weeds (grasses) all contribute to a very rapid decline in crop yields unless effective counter-measures are taken.

Changes in soil fertility after 2 respective 4 years of cropping on an Ultisol (Acrisol) in Lampung (S. Sumatra) are shown in Table 4.

It has to be pointed out that soils shown in Table 4 are of "above average" quality, as their pH is relatively high and consequently exchangeable aluminum is low and the base saturation in high.

The trend in maize grain yield over a 4-year period on an African Alfisol as affected by fertilizer application and weeding is shown in Fig. 1.

In most cases in Southeast Asia on Ultisols or Oxisols the original yield level is much lower and the yield decline is much steeper than shown in Fig. 1. In many cases shifting cultivators give up their field already after the first crop, or they grow cassava, the only crop that can tolerate high levels of aluminum.

Table 4 Soil test results from cassava plantations in Central Lampung, Indonesia, Cropping Systems Research, 1978

Test		Plantation I		Plantation II	
		New	4th yr	New	2nd yr
pH H_2O		5.5	5.4	5.7	5.6
pH KCl		4.4	4.1	4.4	4.2
Extr. Al	meq(in KCl)	0.09	0.30	0.17	0.32
Exch. bases					
Ca	meq	3.1	1.3	0.5	0.8
Mg		1.1	0.4	0.5	0.5
K		0.5	0.3	0.3	0.1
CEC	meq	10.1	10.8	7.6	8.9
% Base sat		25	19	18	17
Organic matter					
C – %		4.37	2.80	2.00	2.45
N – %		0.31	0.21	0.18	0.17
C/N		14	13	16	14
$Bray_1$ – ppm		32.1	13.3	10.1	8.5
$Bray_2$ – ppm		50.8	18.2	13.2	9.0
Extr. nutrients ppm (1N NH_4 OAC at pH 4.8)					
P		2	1	1	1
K		223	56	138	31
Ca		529	73	60	41
Mg		131	40	40	46
Mn		4	3	1	2
Fe		9	15	7	6

Source : McIntosh and Suryatna, 1978.

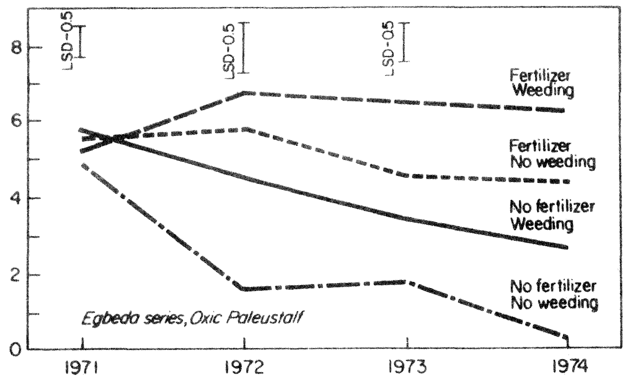


Fig. 1 **Effect of cultural factors on maize yield in southern Nigeria. (Moormann and Greenland, 1980).**

Management of "problem soils" for food crops

From the above it is clear that the highly weathered Ulti- and Oxisols that predominate in the areas currently under rain forest cannot be utilized for arable, annual food crops without major improvements. On the other hand, some permanent tree crops like rubber and oil palm (and even a demanding crop like cocoa) have been successfully established and cropped over prolonged periods of time on such soils.

Following measures have been suggested:

1 Liming

As a great part of the problem of tropical Oxi- and Ultisols (and Spodosols) is associated with low pH, liming has been repeatedly suggested as the most promising answer to the problem. But for many reasons liming in the tropics is still a controversial issue (Pearson, 1975). Liming practices that worked in temperate areas where 2:1 clay predominates, are not applicable to highly weathered soils with 1:1 clay and 2:1 Al – interlayered clay (Kamprath, 1980).

The predominant cation in acid tropical soils with a pH of less than 5 is aluminum (Coleman and Thomas, 1967). Very high lime rates are needed to exchange and precipitate aluminum, especially where aluminum-interlayered clays predominate.

Kamprath suggests that as a general rule the meq KCL-extractable acidity/100g x 2 will give the meq $CaCO_3$/100g in 1 ton of $CaCO_3$/ha. Based on this formula many soils in Kalimantan would require well over 30 ton of lime/ha.

Aluminum hydroxides resulting from increase in soil pH provide very reactive surfaces for phosphorus and possibly many other elements. In simple subsoil liming trials with sugar cane we found that liming was only beneficial when lime (5 ton/ha) was combined with phosphorus, magnesium and trace elements (boron in particular).

Apart from inducing deficiencies or imbalances with other elements, or being ineffective because of inadequate fineness, the high price of lime makes its use often uneconomical. In Indonesia the kg of lime is often only slightly cheaper than the kg of triple superphosphate.

Lime application is certainly beyond the reach of the average settler who is supposed to make his living from the "problem soil".

2 Organic matter application

As the yield decline observed in poor tropical upland soils is usually in line with the decline in organic matter, use of organic matter as a means to maintain and to improve soil fertility has often been suggested.

Organic matter has a number of known beneficial effects:

(1) It improves water-holding capacity of the soil and – especially in the form of mulch–reduces soil surface temperature.
(2) It provides most of the exchange capacity in highly weathered soils.
(3) It supplies nutrients, and keeps P and trace elements in better available form or reduces their fixation.
(4) It forms complexes with aluminum and manganese, thereby decreasing their concentration in the soil solution.
(5) It stimulates microbiological activity and contributes to improved physical properties through the formation of more stable soil aggregates.

But because of rapid decomposition, the effect of organic matter is short-lived, unless continued application is practiced. The low surface activity clay minerals do not form stable organo-mineral complexes.

3 Inorganic fertilizers

Response to applied chemical fertilizer is often disappointing and fertilizer application is therefore often not economical.

A number of different factors contribute to poor fertilizer response. The most frequent causes are:

(1) Aluminum toxicity.
(2) Unbalanced fertilizer use.
(3) Water or oxygen stress.
(4) Use of poor cultivars.
(5) Poor management, poor planting techniques.
(6) Weed competition.

As most of the potential new land areas are far from the markets and have poor infrastructure, price relations between fertilizer cost and produce price are such that fertilizer use at the low yield and response levels obtained is usually not economical.

Unless a low cost technology is developed, which at the same time permits continued cropping and produces reasonable yields, the "problem soils" should stay under forest or should be planted to tree crops. The current practice of dumping transmigrants into "problem soil" areas without a proved, low cost technology that permits efficient land use is certainly very destructive.

Suggested low cost management systems for "problem soils"

Any successful management system must aim to maintain as close as possible the conditions found under the natural forest – in order to make optimum use of the undisturbed topsoil.

Following approach is suggested:

1 Land clearing

(1) Minimum use of heavy equipment – for the extraction of commercial timber only.
(2) Ring bark and poison larger trees with 2-4-5T (for a more rapid decomposition of the wood).
(3) Underbrush.
(4) Fell poisoned trees.
(5) Burn.
(6) Re-stack and re-burn if necessary.

2 Land preparation

(1) After the burn or re-burn, 200 kg/ha of rock phosphate are broadcast.

(2) A cover crop of *Colopogonium muconoides, C. caeruleum, Phosphocarpus palustris, Pueraria javonica, P. triloba, P. mucuna,* etc. is sown respectively from cuttings. Replanting is done, where establishment failed or was poor.

(3) The land is left for 1-2 years under the cover crop. The cover crop serves the following main purposes:

a. It keeps the soil shaded and cool all the time.

b. It provides a thick layer of mulch.

c. It covers the unburned logs, thereby speeding up their decomposition and prevents them from becoming a breeding ground for black beetles.

d. It prevents infestation with weeds, (grasses).

e. It fixes atmospheric nitrogen.

3 Cropping and cropping patterns

Once a 100% dense leguminous cover has been established, a rotational cropping pattern can be introduced:

(1) 10m wide strips of the cover crop are sprayed out with cheap weedicides (like 2-4 D, Actril, Caramex or Grammoxone, Banvel, etc.).

(2) Upland rice, maize, cassava are planted under the mulch covering the soil after spraying out the cover crop. To prevent damping off (*Rhizoctonia* spp.) the mulch is removed from the planting row if planting is done during the wetter part of the year.

(3) Tillage is zero to minimal (shallow furrow in the planting row).

(4) Fertilizer application consists of 100 kg rock phosphate and 50 kg of KCL/ha/crop (applied after spraying out the cover crop). Where available, finely ground dolomitic limestone is applied after each harvest.

(5) A good leguminous cover will contain in its litter about 130 – 180 kg N, 8 – 12 kg P, 80 – 120 kg K, 15 – 20 kg Mg and 40 – 70 kg Ca/ha.

(6) Weeding consists mainly of preventing the cover crop from creeping back into the sprayed out areas and removing grasses (*Imperata cylindrica*) if they ever appear. Weeding is terminated 2 weeks (rice – 4 weeks (maize) before harvest to permit the cover crop to come back.

(7) Once the cover crop is re-established on the cropped area, new strips of cover crop are sprayed out for cropping (see Diagram 1 in annex).

With such system of "shifting cultivation" a farm family could manage a total area of 5 ha, consisting of 2.3 ha cash crops (rubber) and 2.5 ha food crops out of which in any year only 1.125 ha would actually be under food crops.

Discussion

To maintain soil fertility and good crop growth in a tropical climate, in the optimum case, the soil should be covered and moist all the year round.

Such conditions can be either provided by the rain forest or under the water cover in the rice paddy. Forest (tree crops) or paddy rice are the only two "climax" vegetation systems in the tropics (Von Uexkull, 1966) (Fig. 2).

Where (poor) tropical soils are to be cropped under upland conditions, a management system has to be used, that keeps the soil conditions as close as possible to those found under the natural forest.

Properly established and maintained, a number of creeping leguminous cover crops can take over the role of the forest vegetation (and even improve the soil) and at the same time provide easy access to the soil without the danger of weed infestation.

Cover crops play a central role in soil management for estate crops. Though cover crops have been tried in the past also for annual food crops, the approach used was too heavily influenced by

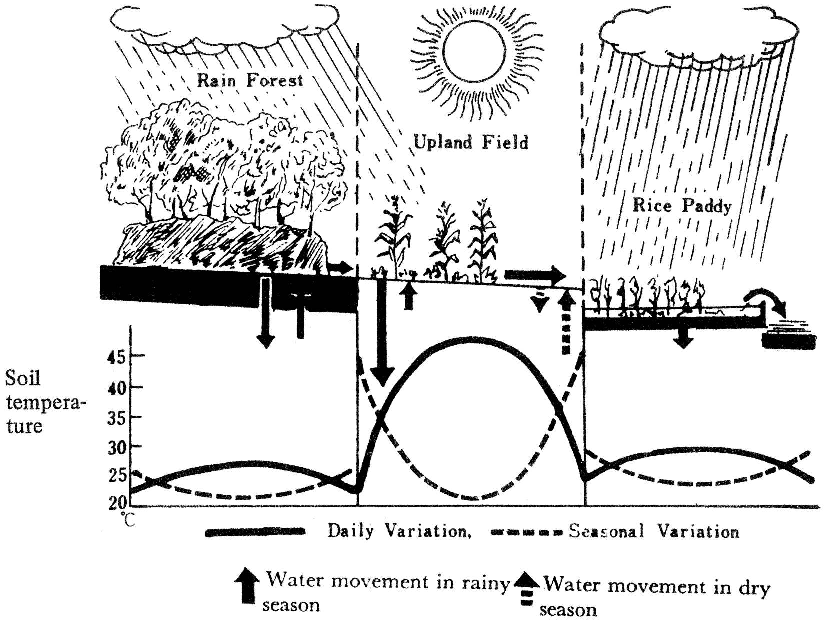
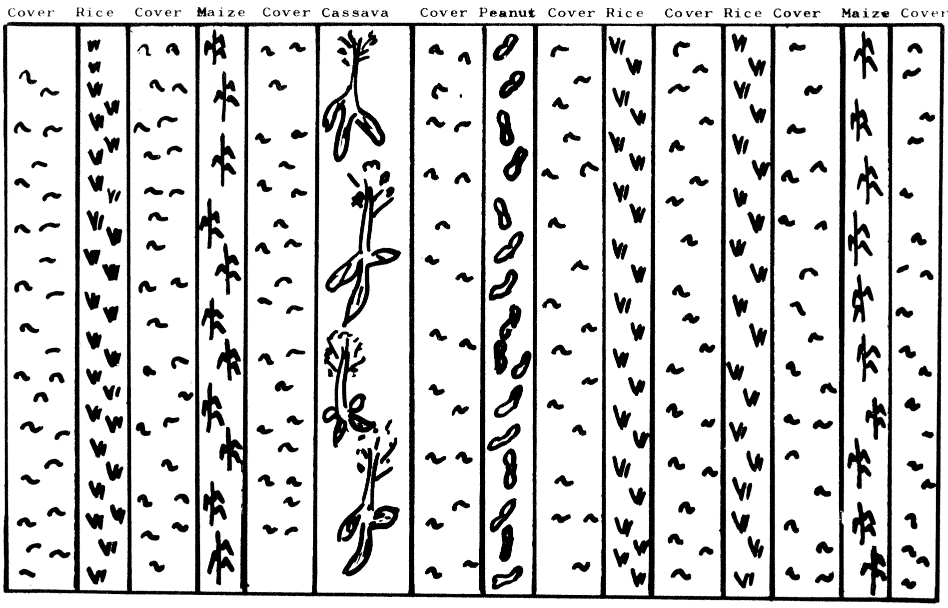


Fig. 2 Soil cover and soil fertility in the tropics.

Diagram 1 Suggested cropping system, based on rotating cover crops with food crops



the temperate climate "green manure" concept. In the low pH, low CEC tropical soils it is most important to keep the (undisturbed) topsoil cool, moist and shaded most of the time and therefore the soil must be covered all the time by a living or dead mulch or the canopy of a crop.

The basic management principles are:

(1) Minimum disturbance of the topsoil during land clearing and cultivation (zero tillage).
(2) Keep the soil covered all the time.
(3) Stimulate biological activity through continued, small dosages of P, K, Ca and Mg.
(4) Rotate food crops with leguminous covers (Diagram 1). Depending on the original fertility and fertility inputs the ratio between the area used at any time for food crops and the area under legume fallow can vary from 1:1 to 1:3. Only one food crop is taken, after which legumes are allowed to come back. This is done not only to maintain fertility but also to keep the plots free from grasses.

Though individual aspects of this approach have been suggested and tested by several researchers, no attempt has been made, to combine them into one comprehensive package.

Unfortunately we do not have yet comprehensive data to substantiate the suggested approach. But from the results of several observation plots we have full confidence that the approach is practical and that it can work.

References

1) BRICKMANN, W.C.F. and NASCIMENTO, DE J.C. (1973): The effect of slash and burn agriculture on plant nutrients in the tertiary regions of Central Amazonia. *Turrialba* **23**, 284-290.
2) COLEMAN, N.T. and THOMAS, G.W. (1967): The basic chemistry of soil acidity. *In*: R.W. Pearson and F. Adams, ed.: Soil acidity and liming . ASA, Madison Univ.
3) DENT, F.J. (1980): Major production systems and soil-related constraints in South East Asia. *In:* Soil related constraints to food production in the tropics. IRRI
4) DUDAL, R. (1980): Soil related constraints to agricultural development in the tropics. *In*: Priorities for a lleviating soil related constraints to food production in the tropics. IRRI 23–27.
5) INTERNATIONAL RICE RESEARCH INSTITUTE (1980): Soil related constraints to food production in the tropics. 468p.
6) KAMPRATH, E.J. (1972): Soil acidity and liming. *In*: US Nat. Res. Council: Soils of the humid tropics. Nat. Acad. of Sci., Wahington D.C., 136–149.
7) LANDELOT, H. (1961): Dynamics of tropical soils in relation to their fallowing techniques. Paper No. 11266/E FAO of the UN, Rome. 111p.
8) MALAYSIAN SOCIETY OF SOIL SCIENCE. (1981): Seminar on Management of Tropical Crops. Kuala Lumpur, March 30–31.
9) Mc INTOSH, J.L. and EFFENDI, Suryatana (1979): Soil fertility implications of cropping patterns and practices for cassava. *In*: Inter-cropping with cassava. Ed. E. Weber, B. Sostel and M. Campbell, IDRC, Ottawa. Ca. 142p.
10) MOORMANN, F.R. and GREENLAND, D.J. (1980): Major production systems related to soil properties in humid tropical Africa. *In*: Soil related constraints to food production in the tropics. IRRI, 1980.
11) NYE, P.H. (1961): Organic and nutrient cycles under a moist tropical forest. *Plant and Soil* **13**, 333-346.
12) ———— and GREENLAND, D.J. (1964): Changes in the soils after clearing a tropical forest. *Plants and Soil* **21**, 101-112.
13) PEARSON, R.W. (1975): Soil acidity and liming in the humid tropics. *Cornell Int. Agric. Bull.* **30**. Cornell Univ. N.Y.
14) SANCHEZ, P.A. (1976): Property and management of tropical soils. John Wiley & Sons. N.Y. 618p.
15) VON UEXKULL, H.R. (1966): Problems in development of modern tropical agriculture. Japanese Potassium Symposium, Sapporo. 1965, 26-40.

ANNEX A. Profile description of an Ultisol

Classification	: Soil Taxonomy : fine clayey, kaolinitic isohyperthermic Typic Paleudult
Location	: 37 milestone Kuantan – Termerloh Road, Malaysia.
Parent Material	: Shale interbedded with sandstone
Topography	: Undulating
Elevation	: 50m
Slope	: 12°
Vegetation/Land Use	: Poorly regenerating secondary forest
Drainage	: Well drained

Horizon	Depth	
AP	0 – 20 cm	: Dark greyish brown (10YR 4/2) fine sandy loam; very weak fine subangular blocky and coarse crumbs; friable; high biological activity; common worm casts; common fine roots, few coarse roots; rather sharp boundary.
B_1	20 – 35 cm	: Brownish yellow (10YR 6/6) fine sandy clay loam; weak medium and fine subangular blocky; friable; moderate biological activity, few termite nests and many biopores; few fine roots, diffuse boundary.
B_{21t}	35 – 52 cm	: Brownish yellow (10YR 6/6) fine sandy clay; weak medium and fine subangular blocky; very thin continuous clayskins on ped faces; friable; common biopores and few termite nests; few fine roots; diffuse boundary.

Depth (cm)	Horizon	Granulometry				Percentage		% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N	
0 – 20	AP	18.1	10.3	52.5	19.1	0.94	N.D.	0.84
20 – 35	B_1	30.7	9.7	44.2	15.4	0.42	N.D.	1.40
35 – 52	B_{21t}	35.3	9.0	41.2	14.4	0.32	N.D.	1.58

Horizon	pH			1N	Exch. cat. meq/100 g Soil				Extr. Acidity
	H_2O	KCl	ΔpH	KCl Al	Ca	Mg	Na	K	
AP	4.8	4.2	–0.6	1.89	0.22	0.15	0.04	0.12	5.50
B_1	4.6	4.0	–0.6	2.28	0.10	0.06	0.04	0.06	4.90
B_{21t}	4.9	4.1	–0.8	2.28	0.14	0.07	0.07	0.07	4.80

Horizon	CEC meq/100 gm Soil		Charge meq/100 gm Clay				Base sat %		Al sat% on PC
	NH_4OAc	Sum	PC	NH_4OAc	Sum	POC	NH_4OAc	Sum	
AP	3.06	6.03	13.4	16.9	33.3	19.9	18	9	78
B_1	3.12	5.16	8.2	10.1	16.8	8.6	8	5	90
B_{21t}	3.53	5.15	7.4	10.0	14.6	7.2	10	7	87

ANNEX B. Profile description of an Oxisol

Classification : Soil Taxonomy : clayey, oxidic, isohyperthermic Haplic Acrorthox.
Location : 20½ mile Air Hitam – Johor Baru Road Malaysia.
Parent : Granodiorite
Topography : Undulating to rolling
Elevation : 35m
Slope : 10°
Vegetation/Land Use : Shrub and other secondary vegetation
Drainage : Well drained

Horizon	Depth	
AP	0 – 25 cm	: Clay loam; dark brown (7.5YR 4/4) moderate, fine, subangular blocky and coarse crumbs; many fine roots; many biopores; rather sharp boundary.
B_1	25 – 57 cm	: Clay yellowish red (5YR 5/8); weak, medium subangular blocky; no clayskins; very friable; few fine roots; few biopores; diffuse boundary.
B_{21ox}	89 – 130 cm	: Clay; yellowish red (5YR 5/8); weak, medium to fine subangular blocky; no clayskins; no roots; diffuse boundary.

Depth (cm)	Horizon	Granulometry				Percentage		C/N	% Free Iron
		Clay	Silt	Fine Sand	Coarse Sand	O.C.	N		
0 – 25	AP	51	2	20	27	1.80	0.17	10	11.4
25 – 57	B_1	51	1	18	30	0.90	0.15	6	12.1
57 – 89	B_{21t}	51	3	16	30	0.48	0.09	5	12.2

Horizon	pH		ΔpH	1N KCl Al	Exch. cat. meq/100 g Soil				Extr.
	H_2O	KCl			Ca	Mg	Na	K	
Ap	4.5	3.9	−0.6	1.10	1.32	0.91	0.08	0.15	12.2
B_1	4.5	4.1	−0.4	0.74	0.10	0.11	0.14	0.14	9.8
B_{21ox}	4.7	4.3	−0.4	0.32	0.06	0.05	0.01	0.06	8.6

Horizon	CEC meq/100 g Soil			Charge meq/100 g Clay					Base sat %		Al sat %
	NH_4Cl	NH_4OAc	Sum	PC	NH_4Cl	NH_4OAc	Sum	PDC	NH_4OAc	Sum	
Ap	1.89	13.8	14.66	7.0	3.7	27.1	28.7	21.8	17.8	16.8	30.9
B_1	1.51	8.5	10.16	2.2	3.0	16.7	19.9	17.8	4.2	3.5	67.3
B_{21ox}	1.21	8.5	8.78	1.0	2.4	16.7	17.2	16.2	2.1	2.0	64.0

Discussion

Kyuma, K. (Japan): In dealing with what appears to be shifting cultivation it is necessary to distinguish 3 types. The first one is the traditional practice of shifting cultivation which is not too detrimental to the soil. The second type is shifting cultivation at the stage of vicious circle due to population pressure, which is very harmful to the soil. The third one is the worst. It consists of opening land by slash and burn and exploiting the soil until fertility becomes exhausted and the land is eventually abandoned and left barren. Is it your experience also?

Answer: I basically agree with you. However the indigenous people tend to limit their activities to better soils. Once they have to use poorer soils, even traditional methods do not prevent the disappearance of the forest and the intrusion of *Imperata cylindrica.* Of course the third type you mentioned is the most destructive. Unfortunately, this type which is not really "shifting cultivation" is spreading rapidly as a result of population pressure.

Tanaka, A. (Japan): What is the minimum size of a farm which allows to follow the system you suggested?

Answer: I believe it would be 4-5ha, with half of the area under tree crops such as oil palm, rubber, cocoa, coffee, pepper, etc. and the other half used for food crops, of which 1 ha maximum every year would be under crop.

Hew, C.K. (Malaysia): In Sabah, recent efforts have tended to avoid the use of heavy machinery such as bulldozer to clear land. Instead, in the jungle, the "semi-clearing" method is being adopted. This practice whereby some of the trees are left has enabled successful cultivation of cocoa, for instance.

Answer: I was fortunate to have seen some of the above work in Sabah and I have been impressed by the methods Malaysians use so as to avoid as much as possible disturbing the top-soil, hence compaction induced by heavy machinery.

Resende, M. (Brazil): In Brazil, in the humid tropics of the Amazon, a multiple cropping system with cocoa and rubber trees as shade trees has given good results.

Answer: In Malaysia and the Philippines coconut is considered as the best shade tree but in Malaysia rubber and even oil palm are used as shade trees to a limited extent, however.