Soil Problems in Relation to Tropical Crop Development and Soil Amendment Measures in China

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ABSTRACT

South China where various tropical plants can be found is endowed with plentiful rainfall and heat. Tropical crops, such as rubber, sisal, coffee, pepper, coconut, cashew, mango, sugarcane and tea have been grown on a large scale. But tropical crops are often seriously damaged by cold currents in winter and typhoons in summer. Their growth is constrained by nutrient deficiency due to low fertility and poor physical properties of soils, and by drought and insufficient water supply. Soil and water loss results in lower soil fertility and productivity. Yet higher output from tropical crops crops can still be obtained and soil fertility can be retained well by implementing measures including the growth of green manure and cover crops, mulching, application of fertilizers based on the diagnosis of the nutritional status, deep tillage, and construction of soil and water conservation facilities.

South China, i.e. Hainan Province and the southern part of Guangdong, Guangxi, Fujian and Yunnan provinces, enjoys a tropical climate with abundant rainfall and heat. A great variety of tropical plants thrives well in the area, especially in Hainan Province and Xishuangbanna in Yunnan Province which are important bases in China for tropical crop production such as rubber, sisal and sugarcane.

Soils and land use pattern in tropical crop area in China

In the hot and rainy tropical crop area in China, the annual cumulative temperature≧10°C is 8,000-9,000°C, and the annual average temperature is in the range of 19.5-21.4°C. The average temperature of the coldest month usually exceeds 15°C. Although the annual total rainfall amounts to 1,200-2,500 mm due the monsoon, there are marked dry and wet seasons. The dry season occurs from November to April during which the monthly rainfall is less than 50 mm, while the rainy season whose rainfall amounts 60-90% of the annual total occurs from May to October. Most of the rainfall in this season is typhoon-borne or thunderstorm-borne in nature. The invasion of cold currents from the North in winter causes the temperature to drop to less than 5°C which often induces cold damage to tropical crops. In summer, typhoons with storms also damage tropical crops, and wash away a large quantity of soil. The coexistence of a wet and hot season benefits plant growth, and brings about severe weathering which is related to soil formation and development. Tyhoons, cold, drought and poor soil properties are major constraints on tropical crop production in China.

1 Soil properties

It is hot and rainy in tropical China. The hot, wet summer and cool, dry winter here enable plants to grow all the year round resulting in high biomass production, but also entail intense weathering and decomposition. Soil formation therefore involves mainly a process of desilicification and allitization. The major soils under tropical crops in China are laterite,

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lateritic red earth and dry red soil, which have the following properties (Li *et al.*, 1978; ISSAS, 1978).

1) High leaching of silicon and base but large accumulation of sesquioxides

It was found that 50-70% of silicon in the tropical red soils in China had been transferred. This phenomenon also occurred in the case of calcium, magnesium and potassium with the highest percentage reaching nearly 100% (Table 1). On the other hand, sesquioxides accumulated in the soil, especially in that developed from alkaline rocks. For example, in laterite derived from basalt in Leizhou Peninsula, Guangdong Province, 63.8% of silicon had been transferred, while 15% of iron and 13% of aluminum had accumulated.

2) Lower acid reaction and base saturation

The pH value of most soils under tropical crops in China is in the range of 5.0-5.5, with pH 6.0-6.5 for the dry red soils. Exchangeable acids can be found in all soils. Exchangeable aluminum usually takes up a large part of the exchangeable products. Exchangeable cation percentage is so low that 100 mg of soil contains only 3-20 milligram equivalent. There is also a low exchangeable base saturation percentage amounting to only 20-40% (Tables 2,3)

3) Soil fertility decrease due to intense leaching and runoff

In the tropics abundant rainfall with high intensity concentrated in a rather short period leads to strong soil leaching. It was estimated that when the annual rainfall was 1,722mm^3 (corresponding to a dry year), the leachate from the surface soil up to a depth of 20cm per ha amounted to 368.9mm. The leachate contained 155.0kg of ammonium nitrogen, 119.2kg of nitrate nitrogen and 1,841.5kg of potassium (Table 4).

4) High biological activity in association with rapid biological decomposition

The wet and hot conditions in the tropics are favourable for plant growth resulting in a higher production of biomass and litter as well. The litter can amount to as much as 10.94 ton/ha/year of dry matter in tropical rain forests, and 8,517 ton/ha/year in mature rubber plantations (Cheng *et al.*, 1978). Such a large quantity of biological residues contributes to

Table 1 Chemical composition and transfer number of tropical red soil in China*

Location	Parent rock	Sample	Chemical composition (%)							Transfer number**				
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SiO_2	CaO	MgO	K_2O	Na_2O
West Guangdong	Basalt	Soil (1mm)	35.75	51.53	15.59	Trace	0.46	0.1	0.08	63.8	100.0	97.2	93.5	98.8
		Saprolite	42.55	23.15	15.75	0.62	2.47	0.55	0.78	41.0	95.2	79.2	51.2	83.1
		Parent rock	49.28	15.83	2.82	8.84	8.13	0.77	3.59	—	—	—	—	—
Hainan Island	Granite	Soil (1mm)	54.83	24.87	5.00	Trace	0.35	0.79	0.18	50.9	100.0	71.3	84.8	95.2
		Saprolite	65.19	17.79	2.56	0.24	0.54	2.26	0.71	26.0	85.0	44.3	45.3	76.4
		Parent rock	71.83	16.13	1.01	1.30	0.79	3.37	2.45	—	—	—	—	—

* Source: Chemical properties of soil in China by Li Qinkui *et al.* *In*: Soil Science Journal, vol 5, 1957.

** Transfer number is calculated according to the method of πepe bMaH.A.N. (1964)

$$t=\frac{t^1-t^2}{t_1}X100\% \qquad t=t'X\frac{\text{parent rock } Al_2O_3}{\text{soil } Al_2O_3}X100\%$$

Where t is transfer number (%); t_1 is oxide percentage in parent rock (%); t′ is oxide percentage in soil (%)

Table 2 Ratio between exchangeable hydrogen and aluminum

Location (Parent material)	Soil	PH	Organic matter (%)	Exchangeable hydrogen meq/100g soil	Exchangeable aluminum meq/100g soil	H/Al
Lingao Hainan (Basalt)	Topsoil	4.37	3.92	0.36	2.80	0.13
	Subsoil	4.31	2.34	0.23	1.74	0.13
	Deep soil Undersoil	4.10	1.32	0.22	1.21	0.18
Baoting Hainan (Granite)	Topsoil	5.65	2.98	0.14	0.26	0.54
	Subsoil	5.45	1.81	0.33	2.03	0.16
	Deep soil Undersoil	4.91	0.79	0.13	2.27	0.06

Table 3 Exchangeable base content

Looation	Parent material	PH	Organic matter (%)	Exchangeable base (meq/100g soil) K	Na	Ca	Mg
Lingao, Hainan	Basalt	4.37	3.92	0.17	0.043	0.50	0.024
Baoting, Hainan	Granite	5.65	2.98	0.60	0.030	2.50	0.120
Nadn, Hainan	Gneiss	4.90	1.65	0.13	0.020	0.11	0.006
Beihai Chiangxi	Neritic deposits	4.88	2.10	0.051	0.022	0.11	0.046

Table 4 Leaching quantity of Laterite in Danxian, Hainan*

Depth of soil (cm)	Leaching quantity (mm)	NH_4-N (kg/ha)	NO_3-N (kg/ha)	P (kg/ha)	K (kg/ha)
20	368.9	155.0	119.24	0.86	1841.5
40	26.1	11.97	27.27	0.94	450
100	1.4	2.5	1.17	0.03	3.0

* 1985; Rainfall: 1,722,3mm.

the accumulation of a large amount of organic matter and ash elements in the soil (Table 5). Under forest vegetation, the organic matter content reaches a value as high as 4-5% in the top soil. Once the vegetation is destroyed, microorganisms become active, and organic matter is rapidly mineralized resulting in the rapid decrease of the content. According to Lin Xinxiong, laterite in Hainan Island after 9-11 years of cultivation experienced a 13-63% reduction of the organic matter content in the surface soil, with an average of 35%. The relative content of amino-nitrogen in the organic matter also decreased, while the relative content of ammonium nitrogen increased.

2 Current status of tropical crop production in China

Tropical land area in China is about 48,000km^2, i.e. 0.5% of the country's total land area. In order to meet the needs of local consumption and the country's economic development, the

Table 5 Dead litter and nutrient content under tropical rain forests and rubber plantations*

Type	Annual quantity of litter (kg/ha)	N		P^2O^3		K_2O		CaO	MgO
		%	kg/ha	%	kg/ha	%	kg/ha	kg/ha	kg/ha
5-6 years old rubber stand	8517	1.49	146.25	0.078	15.9	0.97	22.87	186.75	66.75
Tropical rain forest	10904.2	1.36	148.5	0.20	21.22	0.28	30.8	—	—

*Source: Data from Yunnan Tropical Forest Biologioal and Geological Community Station, Academia Sinica.

government encourages the cultivation of tropical industrial crops in the tropical and tropical-marginal areas. Under the joint efforts of tropical crop scientists and production sectors, the cultivation of commercial tropical crops became successful and a large amount of products could be obtained.

Tropical land in China is utilized mainly for the cultivation of rubber trees, which now cover an area of 574,000ha (ranking fourth among the world rubber-producing countries) with an annual dry rubber production of 240,000 tons. The per-unit-area-yield of rubber trees was as high as 1,500kg/ha, and even 3,000kg/ha through the construction of windbreak networks, terracing, planting of wind-and cold-resistant clones and good management (Huang *et al.*, 1982). With the successful breeding of cold-resistant varieties and improvement of cold resistance cultural practices, the cultivation of rubber trees has extended to areas at 24°N, far beyond the world traditional rubber-growing area (He *et al.*, 1978).

Sisal is another tropical crop grown on a large scale in China. With a growing area of 13,500 ha, it gives 23,000 tons of hard fiber annually, equivalent to 2,800kg/ha.

Coffee cultivation has markedly increased in recent years, covering 11,500 ha at present. Robusta coffee is grown only in the coastal platform around Hainan Island while Arabica is cultivated in the other areas. Some 5,181kg of dry coffee bean can be obtained per ha in the high-yielding plantations in the high altitude area in Yunnan Province.

There are 22,500ha of land under tea bush in China. In the low altitude area of Hainan Island, tea has been intercropped successfully with rubber trees in commercial plantations. The intercropping is beneficial in affording typhoon protection for tea plants and higher economic benefits.

As a condiment favoured by many people, pepper is a tropical crop of high output value. Early in the 1950s, pepper cultivation expanded in Hainan Island, but all the plantings were nearly entirely destroyed by pepper foot rot (*Phytophthora palmivora*). Now the disease has been brought under control mainly through the improvement of water management in combination with chemical treatment. The practice was developed by the South China Academy of Tropical Crops. A high pepper yield of 7,500kg/ha has been obtained through the planting of two shoots in a big hole, vine pruning, dense planting, cultivation of multiple layers of fruiting canes, and split fertilization. The pepper area now covers 13,000ha in Hainan, Guangdong, Yunnan and Guangxi Provinces in China, which makes China the third largest pepper-growing country in the world.

Coconut cultivation is restricted in the eastern and southern coasts of Hainan Island to an area of 18,500ha. Few commercial plantations have been established so far. Coconut milk is an important beverage in China.

Cashew covers an area of 9,200ha in the southwestern part of Hainan Island where the climate is hot and dry and the soil fertility is low.

Cassava, a starch and fodder crop, is grown both in a scattered way and over wide areas in China. Sugarcane which used to be grown in irrigated fields only is also cultivated in dry fields. It is a major economic crop in Hainan, West Guangdong, Southeast Guangxi and South Yunnan provinces.

Mango, pineapple and banana which are the three most popular tropical fruits in China cover altogether 15,000ha. Mango has been extended quickly in recent years. The new plantings will be fruiting soon.

There are also many tropical medicinal plants grown in China such as betelnut palm, *Alpinia oxyphylla, Amomum longiligulare* and *Morinda officinalis*. China sometimes has a surplus of these products.

There is still much land available for tropical crops in China and China will top its tropical land resources for a larger tropical crop industry by discriminate growing, diversification of farming and multi-storey cultivation.

Soil constraints on the development of the tropical crop industry in China

Plants thrive themselves in the wet and hot tropical areas in China. Vast stretches of undulating and hilly lands with deep soil horizons are potentially suitable for tropical crop expansion. However there are several soil constraints. For instance, intense mineralization results in the rapid decomposition of organic matter. Soil fertility decreases and soils become harder due to the leaching of soil nutrients, water and soil loss caused by heavy and intense rainfall. Soil becomes dry due to the high temperature and evaporation. All these factors restrict the yield and expansion of tropical crops. These constraints are discussed in more detail below.

1 Problem of organic matter and nitrogen supply

Under adequate plant cover, especially under dense forests, the availability of abundant biological substances and dead litter supplies laterite soils with higher organic matter and nutrient amounts. In the surface of ferric laterite soil under forests in Hainan Island, the organic matter content is as high as 4.5-6%, and the nitrogen content 0.18-0.22%. But rapid mineralization accelerates the complete decomposition of the dead litter in rubber plantations by only 4-5months. On grassland, the small amount of dead leaves associated with severe soil and water erosion reduces the fertility as well as the organic matter and nitrogen content of vast wastelands. For example, on the hilly land in West Guangdong Province, where short grasses are scattered, the organic matter content of the topsoil of lateritic red earth is only 1.42%, and nitrogen content 0.6%. Such a low soil fertility hinders the growth of tropical crops. The girth increment of rubber trees in this case is only 1cm in a year. However, fertilizer application and soil amelioration can improve the growth of the trees (Table 6).

Insufficient supply of N element is the usual cause of poor growth of tropical crops. The insufficiency can be ascribed to the low organic matter content in the soil, and the rapid mineralization, leaching and evaporation. On the other hand, the fast growth of the plants requires a large amount of nitrogen in a relatively short period that results in a deficiency.

2 Problem of mineral nutrient supply

Mineral nutrient content in the soil is dependent on the parent rocks. Thus some soils contain an insufficient level of phosphorus, potash, or magnesium.

Total phosphorus content in the soil developed from acidic rocks such as granite and

Table 6 Effect of fertilizer application on growth of rubber tree in Tuanjie State Farm, Guangdong

Treatment	Girth increment (cm) Year							
	1st	2nd	3rd	4th	5th	6th	7th	8th
No application	5.0	6.3	9.0	12.1	11.5	16.8	22.4	27.4
Annual compost 5kg/tree	6.0	12.4**	16.6**	23.6**	23.0**	29.0**	35.4**	40.8**

** Significant difference.

Table 7 Inorganic phosphorus content in soil of Hainan Island

Location	Depth (cm)	Inorganic phosphorus (mg/100g soil)			
		Total	$AlPO_4$-P	$FePO_4$-P	$Ca_3(PO_4)_2$-P
Baoting	0-15	15.4	2.4	12.2	0.8
Nada	0-10	11.6	2.4	7.4	1.8

neritic deposits is only 0.01-0.03%. Although the total phosphorus content in laterite developed from basalt is high, two thirds of the phosphorus is in the form of occluded ferrallitic phosphate enclosed by ferric oxide, which cannot be easily absorbed by the crops. Thus phosphorus fertilizer application to tropical crops is very effective (Zhang, 1986) (Table 7).

Potassium deficiency occurs in the soil under tropical crops in China except for South Hainan Island and Xishuangbanna in Yunnan Province. Rubber trees, coffee and pineapple often show potassium deficiency symptoms.

The low content of magnesium in the soil results in magnesium deficiency symptoms in rubber trees, orange and mango. The incidence of yellow disease is as high as 78% in severe cases, or even higher when a sufficient supply of potassium is available in the soil (Lu *et al.*, 1988).

3 Problem of water supply in the soil

Water supply to plants depends on the water content available in the soil. The available moisture range is ofter referred to as the ratio of wilting moisture to field moisture capacity. The wilting moisture ratio is rather high as it increases with the increase of the clay particle content in the soil, the content of which is 42-67% in soil under tropical crops in China. Generally speaking, the clay particle content in laterite developed from basalt is 57% while the wilting moisture ratio of immature rubber trees is 23%. Therefore, although the field moisture capacity is usually as high as 30% or more, the available moisture range is only about 10%. In the tropical areas, high temperature is related to higher evaporation and transpiration especially during the dry season from November to April of the following year when little precipitation occurs. The monthly rainfall from December to March of the following year is often less than 50mm whereas the monthly average temperature is still as high as 22°C. Thus drought hinders the growth of tropical crops, even leading to their death in particular in the savanna area in West Hainan Island where only cashew is able to grow.

4 Excessive content of sand or clay particles

The soil texture in the tropical crop region in China can be classified into three types;

Table 8 Soil particle composition in Hainan Island

Location	Parent material	Depth	Mechanical composition					Texture
			Fine gravel (3-5mm)	Coarse sand (1-3mm)	Sand (0.01-1mm)	Silt (0.001-0.01mm)	Clay (0.001mm)	
Danxian	Gneiss	0-10	0	0	60.5	11.5	28.0	Medium clay to loam
Wanning	Granite	0-15	3.45	31.8	47.06	6.14	15.0	Light clay to loam
Chengmai	Basalt	0-30	0	0	12.55	24.35	61.3	Heavy clay
Lingao	Neritic deposits	0-15	0	8.7	79.0	2.7	9.6	Sandy loam

clay loam and loam developed from gneiss, granite, shale, etc ; clay and heavy clay derived from basalt and limestone, the clay particle content of which can be as high as 40-60%, or even 70-80% ; and sandy soil developed from neritic deposits. The sand grain content in this type of soil is 79%, while the clay particle content is lower than 10% (Table 8).

The imbalance of the sand and clay content in the soil results in poor physical properties. Clay soil is impermeable when waterlogged, and becomes hard when dry. Sandy soil has a poor structure and low water-holding capacity. Severe soil erosion occurs when the ground vegetation is destroyed.

Soil management and improvement measures for land under tropical crops in China

Lower soil fertility, poor mineral nutrient supply, drought in dry season, and soil loss in the rainy season are limiting factors to the development of tropical crop production in China. The adoption of soil management and improvement measures is the only means to increase tropical crop production.

1 Growth of green manure crops and cover plants, and application of organic manure

The increase of the soil organic matter is essential to the preservation of the soil fertility. The cultivation of leguminous green manure crops and cover plants in tropical crops plantations for one year and a half prevents the organic matter content in the soil from declining while the nitrogen content increases. It was estimated that *Calopoganium caeruleum* and *Pueraria phaseoloides* can produce 30-50t/ha of fresh shoots and leaves annually, equivalent to 14.85ton dry weight containing 363kg nitrogen, 27kg phosphorus and 321kg potassium (Table 9).

The growth of leguminous cover crops can also improve the soil texture by increasing the soil porosity and the amount of water stable aggregates resulting in a water permeability 4.9-9.2 times that of the bare land.

Tropical crops in China mainly receive organic manures with some inorganic fertilizers becasuse the combined application is more effective.

2 Mulching

Mulching is an effective method to prevent the soil from drying up, improve the soil physical properties and increase soil fertility as well as cool the earth temperature in rubber,

Table 9 Effect of growing green manure crops on soils in rubber plantations

Green manure crop	Organic matter (%)	Total nitrogen (%)	Available potassium (ppm)
Natural grass	2.24	0.122	48
Calopogonium mucunoides	2.52	0.141	68
Centrosema pubescens	2.53	0.133	104
Mimosa invisa var. *inermis*	2.28	0.133	104

Source: Data from Tropical Crops Research Institute of Yunnan Province, tested in 1974 on 1964 plantings.

Table 10 Effect of mulching on soil moisture content

Treatment	Soil moisture content (%) at different depths (cm)				
	10	20	30	40	50
Mulching (6 months)	15.1	17.0	15.6	18.9	19.6
No-mulching (6 months)	10.1	13.4	15.6	17.7	19.3
Mulching (10 months)	12.7	13.0	12.8	13.1	15.2
No-mulching (10 months)	8.2	10.0	13.5	15.6	18.3

coffee and pepper plantations.

Based on the report of Huang Zongdao *et al.* in West Guangdong, the daily range of earth temperature was only 6.75°C by mulching while 26.8°C without mulching. Mulching was also able to decrease the soil evaporation. The difference in the soil moisture content between mulching or absence of mulching was 4.5-5.0% (Table 10).

In the decay and decomposition process, the mulching materials add organic matter, nitrogen and other nutrients to the soil. It was estimated that the organic matter content in the soil under mulching for two years increased from 1.95% to 3.15% while the available NPK contents in the soil increased by 1-10 times.

In case of shortage of mulching materials, a polyethylene film can be used instead of covering the ground, which can also play the role of conserving the moisture, maintaining the temperature and protecting plant roots.

3 Manure application based on diagnosis of leaf nutrition

Fertilizer application is associated with adequate growth and high yield of tropical crops. But as mentioned earlier, there are variations in the soil types, parent materials and mineral nutrient contents in China's tropical crop plantations. Usually, N and P fertilizer application is effective. Experiments carried out in Danxian, Hainan showed that the application of N fertilizer enabled to accelerate the growth of young rubber trees by 6.8%, and P fertilizer by 4.1-5.8%. Application of N fertilizer increased the rubber yield by 5.1%, and NP fertilizer application increased the rubber yield by 7.4% (Lu *et al.*, 1982).

The effects of potassium and magnesium fertilizers varied markedly with the soil types. The requirement of potassium is high for tropical crops such as rubber trees, coffee, sisal, coconut, pineapple and sugarcane. However the potassium price is high and the source is limited. When the available potassium content in the soil exceeds 80ppm, potassium fertilizer application is often associated with negative effects. The effects of magnesium fertilizer are

related to the magnesium supply in the soil and are proportional to the potassium supply. When there is an adequate supply of potassium, the effects of magnesium fertilizer are also good. In China's crop tracts, soils in certain locations exhibit a low magnesium supply. However laterite soils developed from basalt are not deficient in magnesium due to the extremely low supply of potassium. On the contrary, in the laterite soils derived from granite in South Hainan Island the content of magnesium is five times higher than that of the laterite developed from basalt. Rubber trees offten suffer from magnesium deficiency bacause of the abundant supply of potassium.

It is therefore necessary to apply fertilizers discriminately based on the diagnosis of leaf nutrition in tropical crops for economic and efficient purposes. Some practical procedures have been worked out for rubber, pepper, coffee and sisal.

4 Deep tillage to accelerate soil ripening

The root systems of tropical crops of economic importance are deeper than those of field crops. In the case of compact, hardened and impermeable soils, deep tillage coupled with the supply of green manure, organic manure and P fertilizer could help loosen the soil and accelerate its ripening to promote an adequate development of the root systems and in turn fast growth and high yield of the crops. In tea plantations, sisal and sugarcane fields and citrus orchards, the practice of trenching for filling with green manure, application of organic manure, P fertilizers and limestone in combination with close planting between widely spaced interrows can lead to high and early yield. Through deep tillage in rubber plantations, the rooting systems of the crop formed rapidly a larger number of roots, resulting in 1-3 times more nutritive roots than in the control area. As a result, the rubber trees showed a dark -green canopy, rapid girth increment and an increase of yield of 8-35% in the second year after tillage. The water permeability of the soil subjected to deep tillage was also 45-155% higher than that of the soil with superficial tillage (Table 11).

5 Water and soil conservation

As tropical China is affected with heavy and abundant rainfall, and tropical crops here are all grown in slope fields, terracing to prevent the loss of water and soil is an important measure for the exploitation of tropical soils. Rubber plantations in China consist of contour ledges 1.8-2.5m wide with an inward slope of 15°. The quantity of soil washed away in the

Table 11 Effect of deep tillage on soil water permeability

Treatment	Water intake rate cm/min	Water permeability rate cm/min	Relative water permeability (%)
No-deep tillage	0.218	0.190	100
Deep tillage (40cm)	0.305	0.276	145.3
Deep tillage (60cm)	0.548	0.485	255.3

Table 12 Effect of different types of terracing on prevention of water and soil loss

Terracing type	Soil washed (m^3/ha)	Thickness of soil horizon washed (cm)
No-terracing (control)	196.15	1.983
Contour ledge	11.55	0.116
Horizontal terrace	3.75	0.037
Furrow terrace	23.25	0.232

ledges was reduced by 15times (Table 12). Terracing also increased the moisture content in the soil by retaining the overland runoff. Moisture content in the surface soil at a depth of 0-20cm in terraces was 40% higher than that in natural sloping land.

In conclusion, the adoption of the management and improvement measures mentioned above will enable China to maintain and preserve the soil fertility, to secure the increase of the production of tropical crops in tapping the red soil resources for the promotion of the tropical crop industry.

References

1) Cheng Shiweng, Gong Decheng and Long Biyun (1978): Variations in the fertility of soils under rain forest and rubber. Research on tropical plants. pp.10-18.
2) He Kang and Huang Zongdao (1987): Rubber culture in the northern part of tropical area.
3) Huang Zongdao and Li Shicong (1982): Cultural practices for 150-200kg of dry rubber/mu/year in West Hainan. Chinese Journal of Tropical Crops, vol.3, no.1.
4) Institute of Soil Science, Academia Sinica (1978): Soils of China.
5) Li Chingkwei (1978): Red soils of China.
6) Lu Xingzheng (1982): Fertilizer application based on nutrient diagnosis of rubber trees, Chinese Journal of Tropical Crops, vol.3. no.1.
7) Lu Xingzheng, etc. (1988): Patterns of yellow disease due to Mg deficiency in rubber plantations in China. Tropical Crops Technology, 1988, vol.2.
8) South China College of Tropical Crops (1961): Rubber cultivation in China.
9) Yunnan Provincial Tropical Crops Research Institute (1977): Some aspects of soil management in rubber plantations in relation to rubber soils in Xishuangbanna. Yunnan Tropical Crops Technology, 1977, vol.1.
10) Zhang Shaoruo (1986): Transformations and effects of phosphorus fertilizer in tropical soils. Current progress in soil research in P.R.C.

Discussion

Verapattananirund, P. (Thailand): If the farmers grow cover crops between the rows of rubber trees they cannot get an income from the trees up to 6-7 years. How do they make a living?

Answer: When cover crops are grown between the rows of rubber trees, income cannot be derived in immature plantations. In the case of State farms, the Government supports the workers financially. In small holdings, the rubber growers always intercrop upland rice, sugarcane and groundnut between the rows of rubber trees. When rubber growers can get some income, they are willing to plant cover crops to improve the soil.

Toledo, J.M. (CIAT): Since grazing of cattle under the rubber plantations is common in South China and Hainan Island, what are the positive and adverse effects (for example compaction) of this practice on rubber yield and sustainability of the plantation?

Answer: If grazing of cattle under rubber plantations is not excessive, the grass grows well and there are positive effects on the rubber trees and soils. If the grass cannot grow normally, there are negative effects on rubber trees and soil fertility. In Hainan Island, one ox is grazed over one hectare of rubber plantation.