Soil Constraints on Sustainable Plant Production in Sri Lanka

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ABSTRACT

Sri Lanka is an island located at the southern tip of India. The land area covers 65,685 km^2. Fourteen major soil types have been identified within the country. Main soil constraints that have adversely affected agricultural production in the island are poor aeration due to waterlogging, sea water intrusion, low base status, acid sulphate conditions and acidity, salinity, high leaching losses, soil degradation due to erosion, low range of available soil moisture and several other constraints associated with poor soil physical properties. These constraints are mainly due to the topographical, climatological, geological and mineralogical conditions and to poor land and crop management practices. Researchers have already conducted studies to identify most of these constraints in order to overcome them. Measures including breeding of tolerant varieties, development of better land, water, crop management and soil rehabilitation practices have already been implemented while further studies are being currently conducted. Although many activities have been initiated to alleviate soil constraints, the pressure for land associated with the population expansion has further aggravated the degradation of the land.

Introduction

1 Location

Sri Lanka is situated only a short distance off the southern tip of the Deccan Peninsula of India, stretching over about 447 km North-South from 50 55' to 90 50' N and about 224 km East West from 790 42' to 810 52' E. Total surface area of the island is 65,635 km^2 with a coastline of 1,700 km^2 (Fig. 1).

2 Physiography

Within this surface area, the southern-central portion is occupied by a high hill mass (the central Highlands) rising to the elevation of 2,527 m (the highest peak being Piduruthalagala at 2,527 m), which though deeply dissected is said to comprise the former highest peneplain surface. Usually two more peneplains (the middle and lower) surround the central highlands extending towards the sea coast.

The lowest peneplain including the coastal plain which is commonly known as 'Low country' is narrower in the West, East and South, but it broadens out to a vast track in the North. From the inner edge of the lowest peneplain the middle peneplain rises up steeply to about 300 m and reaches an elevation of 1,000 m or higher. This area is called the 'Mid-country' of Sri Lanka.

Rising again steeply from the middle peneplain, the highest peneplain has an average height of 1,500 to 2,000 m and is characterized by a complex of plateaus, mountain chains, and basins. This highest peneplain is called the 'Up-country' of Sri Lanka.

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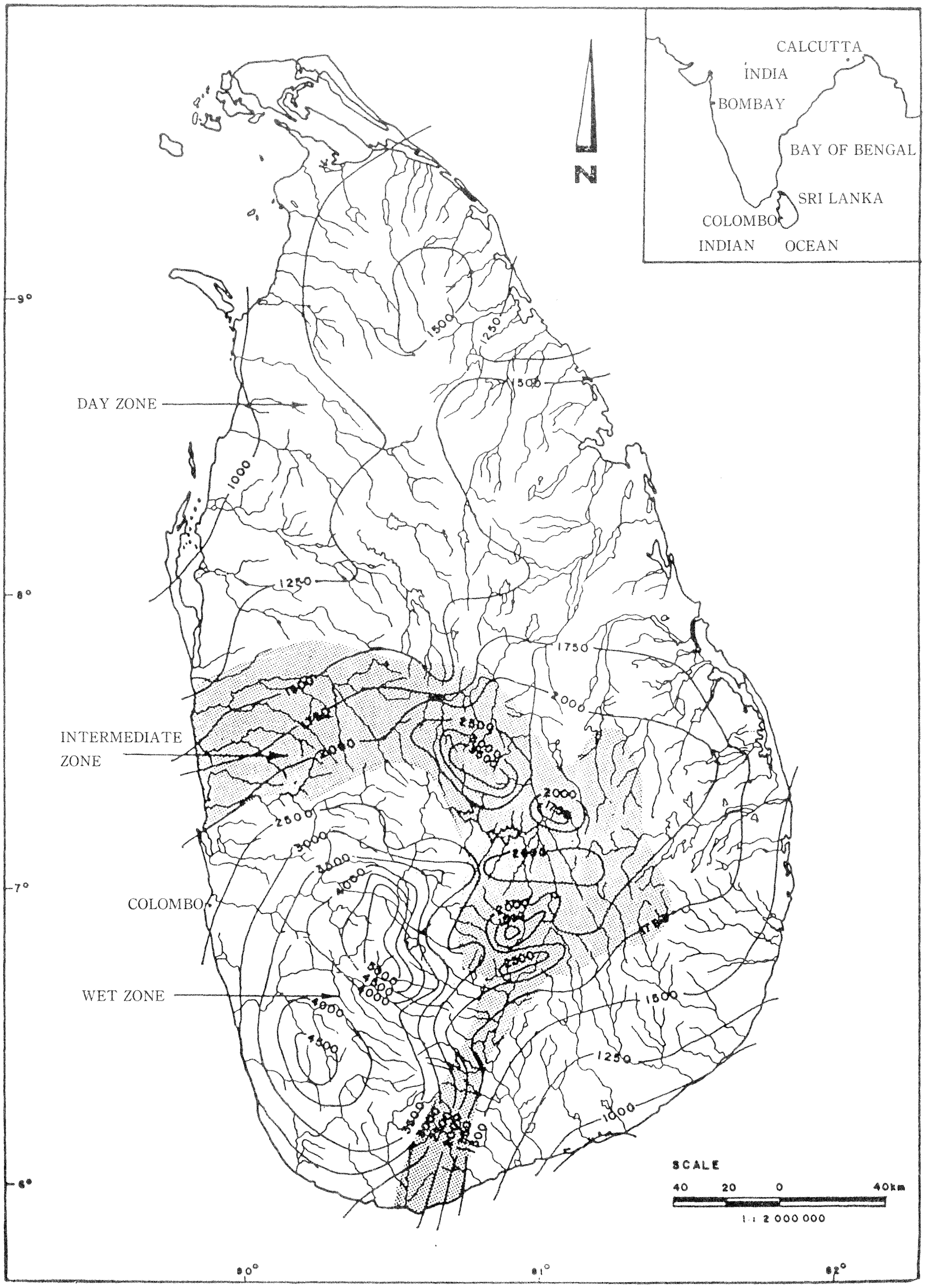

Fig. 1 Climatic zones and annual isohyets (mm).

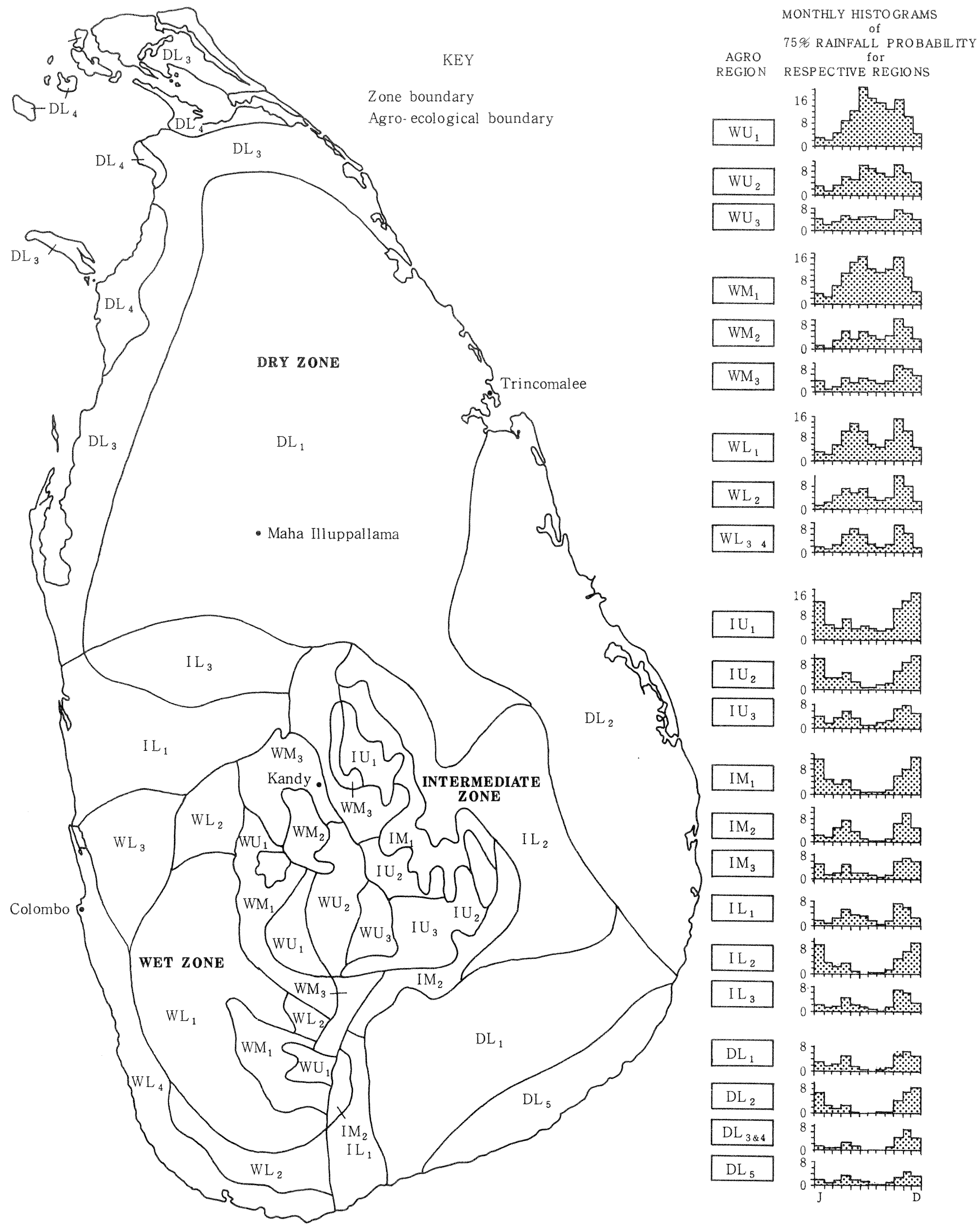

Fig. 2 Agro-ecological regions of Sri Lanka.

3 Climate

According to the Koppen's classification of climate, the climate of Sri Lanka is classified as tropical monsoon with a wet and dry climate but with only a brief dry season.

Rainfall generally heavy is unevenly distributed and is the only form of precipitation. Fundamentally, it is of convectional type with the monsoons dominating during their respective season. Within a total area of 6.56 million hectares, three broad climatic zones, wet zone (1.54 million hectares, intermediate zone (0.85 million hectares) and dry zone (4.05 million hectares) have been recognized. These major climatic zones were further sub-divided into a total of 24 agro-ecological regions on the basis of soil properties, monthly rainfall distribution and elevation (Fig, 2).

4 Rainfall

The annual rainfall distribution pattern is distinctly bimodal for most parts of the country. The mean annual rainfall ranges from 5,000 mm in the wettest parts to about 875 mm in the semi-humid to dry areas. This seasonal rainfall pattern is associated with a regional phenomenon as well as a local phenomenon. The monsoon rainfall, North-east in mid-November to mid-January and South-west in May to mid-September periods occurs as a regional phenomenon. The inter-monsoonal convection rains effective during March and April and again in October to mid-November occur as a local phenomenon.

During the convectional season rainfall occurs all over the island whereas during May to September, i. e. the Southwest monsoon season the Southwest lowland and western highland receive the highest rainfall. However the rest of the island i. e. the dry zone receives little or no rains during this period, due to the leeward effect of the central highlands of the country. The period of October to November during which autumnal inter-monsoonal rains occur and the following period of Northeast monsoon rain are the main periods of rainfall for the dry zone of Sri Lanka.

5 Geology

The island of Sri Lanka is situated in one of the most ancient and stable parts of the earth's crust, the southern Indian shield. This basement which bears a striking resemblance to that of tha Deccan and Canadian shield is very complex.

The highly crystalline metamorphic rocks belonging to the Paleozoic and the Pre-Cambrian era occupy more than 80% of the island, the rest of which consists of Mesozoic (Jurassic), Tertiary (Miocene) and Quaternary sedimentary formations.

The highland series, the oldest formation widespread in the area crossing the island diagonally from Southwest, is composed of (a) the Khondalite group and (b) Charnockites. The Khondalite group is made up of a variety of rock types. (1) Granet-sillimanite schists and gneisses. (2) Quartzites and quartz schists (3) Quartz-feldspar Granulite and garnetiferous gneisses. (4) Crystalline limestones and clay granulite (5) graphitiferous schists. Of these, garnet-sillimanite rocks which consist of metamorphosed clay or shale, are the most striking rocks of the group.

6 Present land uses

There are distinct land use patterns which are specific to different regions at least partly due to the influence of the agro-ecological conditions in the country.

Table 1 gives data on land use in Sri Lanka according to the Department of Census and Statistics, Land Utilization Committee and data tabulated by the Land Use Division.

The Agriculture sector accounts for the majority of land use in Sri Lanka. Plantation agriculture, irrigated annual crops, market gardens, home gardens, permanent rainfed cropping and rice cultivation as major sub-sectors in agriculture account for around 2.5 million hectares or 40% of the land area.

Table 1 Area of land utilization (000ha)

Land use category	Area
Non-agricultural lands	20
Homestead gardens	970
Coconut	326
Tea	222
Rubber	230
Paddy	758
Cocoa	5
Cardamon	5
Cinnamon	3
Other minor export crops	60
Palmyra	27
Sugarcane	7
Rainfed annual crops	2
Market gardens	
Shifting cultivation	1000
Tobacco	2
Improved pastures	3
Damana grasslands	81
Patna	65
Villu grasslands	25
Other grasslands	62
Fernland	14
Savanna	77
Scrub	289
High yield forest	12
Medium yield forest	207
Low yield forest	1425
Non productive forest	1236
Forest plantation	79
Dense forest	1346
Open forest	1725
Swamp and marsh	35
Unused land	22

Source: Land utilization committee (1968),
Census and statistics (1981), land use division (1984).

7 Agriculture

The dominant land use patterns in agriculture with important features that distinguish the regions are as follows:

1) Tea, rubber, coconut and home gardens in upland areas and rice in valleys, in the rolling to undulating low country wet intermediate zones (elevation less than 300m).
2) Tea, rubber, coconut and minor export crops in upland areas and rice in valleys and terraced slopes of the mid-country wet and semi-wet intermediate zone (elevation between 300 and 1,000m).
3) Tea, fruits and high value crops on upland slopes of the up-country wet and intermediate zones (elevation higher than 1,000m).

4) Rice, fruits and vegetables in the mid-country intermediate zone (elevation between 300-1,000m).
5) Irrigated rice and field crops in the low country dry zones.
6) Partly irrigated rice in valleys and rainfed upland crops in the low country dry zones.
7) Rainfed rice in dry zone (in the coastal belt).
8) Irrigated market gardens, high valley crops on the Regosol belt.
9) Irrigated high value crops in low country dry zone (Jaffna).

8 Soils

Fourteen great soil groups have been identified. These soil groups and their surface area are given in Table 2 and Fig. 3.

Table 2 Area of the major soil Groups in Sri Lanka

Soil group	Area (000ha)
Reddish Brown Earths	1610
Low Humic Gley Soils	950
Non Calcic Brown Soils	163
Red Yellow Latosols	280
Calcic Red Yellow Latosols	40
Immature Brown Loams	205
Solodized Solonetz	210
Grumusols	15
Red Yellow Podzolic Soils	1490
Reddish Brown Latosolic Soils	60
Alluvial Soils	450
Regosls	190
Bog and Half-Bog Soils	60
Lithosols	200
Old Alluvium	30

Source : land use division, irrigation department.

The predominant upland soils in the rolling to undulating landscape of the low country dry and semi-dry intermediate zones are Reddish Brown Earths. The bottom lands or valleys of this landscape are occupied by low Humic Gley Soils. Both soil groups cover about 2 million hectares. The dominant soil group in the wet and semi-wet intermediate zones is Red Yellow Podzolic, while the island valleys in this landscape are occupied by low humic gleys and alluvial soils. All these soil groups account for about 1.5 million hectares. The remaining area is made up of several other soil groups, some of which are agriculturally very important.

9 Soil constraints in Sri Lanka

The soil constraints that have adversely affected the agricultural production in Sri Lanka are due to various factors. These constraints could be broadly categorized as poor land and crop management, topography of the land, climatic factors, geological factors or a combination of the above factors. Locations of these soil constraints can further be grouped according to the agro-ecological zones of the island. Some of these soil constraints that prevail in the island can not be completely overcome due to their severity. For example the soil constraints in the low-lying areas which are due to rainfall and topography cannot be completely removed. But the soil constraints that result from unfavourable land and crop

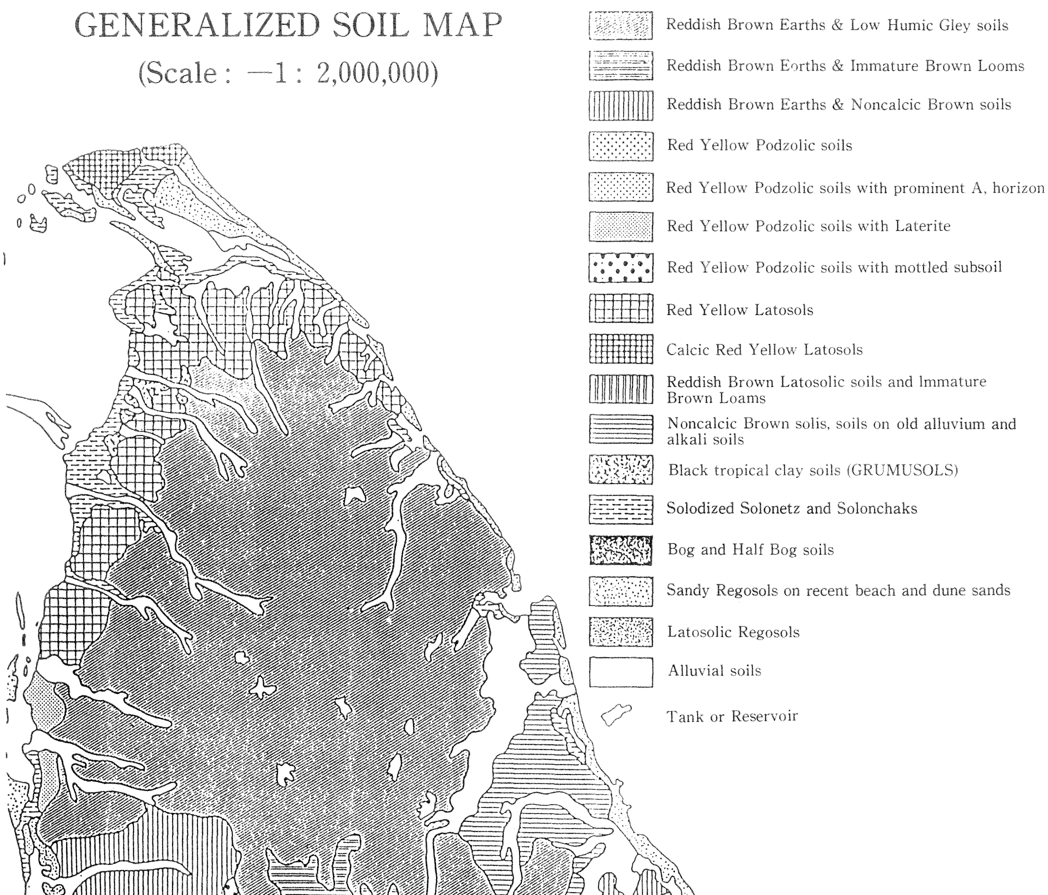

Fig. 3 Generalized soil map.
(Scale : 1 : 2,000,000)

management activities could be minimized by adopting correct measures.

1 Soil constraints in dry zone of Sri Lanka

1) Reddish Brown Soils-Alfisols

The Alfisol region of Sri Lanka is confined to the dry zone of the island and is located within the lowest peneplain of the island that is floored by crystalline metamorphic basement rocks of the Pre-cambrian era (Panabokke, 1978). Presently about 0.4 million hectares of lands are under rice and about 0.2 million hectares of lands are utilized for homestead gardens and other uses. Due to the increase in the population and high cost of food import the development of the Alfisol areas started in the late forties.

These soils are low in phosphorus and the main constraints are associated mainly with the physical properties of Alfisols (Panabokke, 1975).

The texture of the soil becomes heavier with depth, from sandy clay loam at the surface to clay loam to sandy clay with gravel in the sub-surface. This gravelly subsoil horizon is typical in the Alfisols. The percentage of gravel in the sub-surface horizon is about 10-15% while the gravelly horizon which underlies the sub-surface horizon contains about 50-70% of gravel. Although the amount of gravel in the gravelly horizon creates a large number of macro-pores, the large amounts of clay soil and fine sand that occupy these pores make the horizon compact and massive in structure. This is due to the poor root penetration and low hydraulic conductivity in this horizon. Thus the gravelly horizon of the Alfisols reduces the effective root zone by limiting most of the root distribution to the horizons overlying it. According to Joshua (1988) poor root penetration is due to the high bulk density and the low value of total porosity. The pore space in this soil consists mainly of micro-pores. The gravelly horizon of Alfisols tends to hold a higher amount of water even at a tension greater than 1,000cm. This fact also indicates that the gravelly horizon consists of very fine pores.

Nayakakorale (1989) showed that the maximum depth and root penetration in soybean was restricted to 90—105 cm is Alfisls. It has been reported in other soils that the maximum rooting depth of soybean was greater than this value. He observed that the root activity had been greatly reduced by a layer of 38% volumetric gravel content with higher bulk density ($1.69g/cm^3$). The restriction of the root activity in the sub-surface soil layers in the Alfisols is due to the presence of gravel layers.

At soil saturation, Alfisols have a volumetric moisture content of about 45%. The aeration capacity which gives an indication of the volume of freely draining pores was only 7% in the gravelly horizon while 16% in the surface horizon, which could also adversely affect the root growth due to the poor aeration in the gravelly horizon. Further anaerobic conditions could also occur in the sub-surface horizons if the moisture contents increased even slightly above the field capacity (Joshua, 1988). Hence the water table could develop rapidly due to heavy rainfall or due to excess irrigation. The author also observed that the hydraulic conductivity in the gravelly horizon tended to retard the internal drainage of the surface and sub-surface horizons. Abeyrathna (1956) noticed that the depression in yield of annual crops occurred more frequently in very wet years than in dry years.

The structural stability of Alfisols is much lower than that of the Reddish Brown Latosols and Reddish Brown Podzols (Joshua, 1988 ; Panabokke, 1978).

These Alfisols easily slake under rainfall, making tillage operations difficult during the rainy season. Tillage can be performed within a small range of moisture content (Joshua, 1988). Aberathna (1956) also identified this constraint and recommended to reduce the tillage operations to the minimum level during the land preparation activities.

Panabokke (1976) showed that nearly 85% of the available moisture is lost at low tensions. As result the soil dries out very early. Therefore during the dry period the soil appears like rock. Any attempt to use power implements during this period can be disastrous and is costly (Abeyrathna, 1956).

These studies show that the main constraints of Alfisols are the presence of a gravelly horizon, poor structure, low range of available moisture content. Hence any agricultural practices in Alfisols have to be developed to suit the soil physical properties of this soil group.

Very few studies have been carried out to overcome the problem of the presence of a gravelly layer in the sub-surface of Alfisols. The causes which limit root growth in the gravelly horizon can be eliminated by mechanically disturbing the horizon. Deep ploughing and ripping can be practiced. This is not practically feasible due to high cost.

Therefore cultivation practices have to be adapted to shallow rooting and the compact horizon below the root zone (Joshua, 1988). Planting of semi-permanent deep-rooted crops which could penetrate this horizon could solve this problem (Nayakakorale, 1990).

Joshua (1988) showed that information on effective rainfall, knowledge of rooting depth for each crop, rainfall and moisture balance would be important to overcome the soil constraints in Alfisols.

Joshua (1988) reported that conventional ridge and furrow and furrowed basin methods of irrigation could only be effectively used in this soil group. Farm irrigation efficiencies of 75 to 85% can be easily achieved with the furrowed basin method.

The build-up of the water table which is often observed especially during the main rainy season due to poor soil conditions can only be reduced by adopting an efficient surface drainage system. Lowering of water table by subsurface drainage may not be econmically feasible as drain spacing should be small. This problem could be alleviated by proper water management practices (Joshua, 1988).

Water application rate should also be considered due to the poor structural stability of Alfisols. Due to the high velocity of running water considerable scouring and erosion of the irrigation canals may occur. Joshua (1988) recommended an application rate of 5 1/sec for furrowed basin irrigation method.

2) Soil constraints in Non-Calcic Brown Soils

Non-Calcic Brown Soils occur mainly in the eastern part of Sri Lanka and are found scattered in the zone of Alfisols. This soil approximately covers an area of 0.613 million hectares. The testure of the soil is loamy sand in A horizon while in the B horizons it is sandy clay loam. The infiltration rates and the hydraulic conductiuity of this soil are very high and the water retention characteristics are low (Mapa, Bodhinayaka, 1988). The CEC values of these soils are less than 10mm/100g soil and often below 5mm/100g soil (Jayakody, 1989).

Potassium status of this soil has been reported to be medium to low (Panabokke, 1967). Jayakody (1989) reported that in Non-Calcic Brown Soils 14 to 18% of potassium leached from a rice crop when fertilizer was added. It was found that irrigation water contributed to 43 and 57% of the recommended amount of fertilizer in major and minor (Maha and Yala) rainy seasons. The presence of potassium in the water of reservoirs in the dry zone has been reported by Amarasiri (1973) and Thenabadu and Ekanayaka (1985).

Jayakody (1989) recommended a combined management practice of soil, water and fertilizer to reduce the potassium losses in these soils. He also stressed that potassium should be available in irrigation water when recommendations for the application of fertilizers are made. Reduction of percolation losses by frequent irrigation of a small amount of water, split application of fertilizer were also suggested by Jayakody (1989). Use of granular types of fertilizer can also alleviate the high leaching losses in these soils.

3) Leaching problems in Regosols and Latosols of dry zone

This type of leaching problem also occurs in the Regosols and Latosols of Sri Lanka. Texture of these two soil groups is coarse. The Regosols are related to very deep, whitish, excessively drained sand formations occurring along the coast, as beaches, beach ridges and dunes. Kuruppuarachchi (1990) observed high N losses in Regosols. He reported that the N content of the groundwater had increased in this area. The use of granular type fertilizer can reduce the leaching losses that occur in these soils.

Latosols are located in the northwestern part of Sri Lanka between Mannar and Puttalam. Calcic Red Latosols soils are found in the Jaffna Peninsula. High N contents in groundwater in the Jaffna area have been reported.

4) Soil constraints in Grumusols

These soils occur in the Mannar area of the northern part of Sri Lanka. They are imperfectly to poorly drained soils. Color is dark is dark gray brown to black. The clay content is high. Grumusols show favourable chemical properties that are offset by unsuitable physical properties (Panabokke, 1961). Due to the high clay content, the soil becomes very sticky when wet and very hard when dry, making cultivation of crops extremely difficult. As these soils cracp in the surface when dry, seepage and percolation losses are further enhanced.

2 Soil constraints in wet zone of Sri Lanka

1) Low bases and high acidity in Red Yellow Podzolic Soils

The highland soils of the wet zone are low in exchangeable bases, strongly acid in reaction, with low phosphorus and potassium contents but fair amounts of nitrogen and organic matter due to the low temperature and high rainfall.

Of the total area of Sri Lanka about 30% consists of acid soils which occur in the wet and intermediate lowlands and central highlands.

The major cause of the acidity in these soils is the extensive leaching that occurs due to heavy rainfall. The acid soil area receives between 2,000-5,000mm of rainfall annually. These areas receive rains from both monsoons and inter-monsoons. Major soil type in this area is represented by Ultisols. The Ultisols in the region (up to 1,000m elevation) have been developed for plantation crops such as tea, rubber, and coconut. The inland valley system has been developed for rice.

The area above 1,000m is mainly under tea with an area of approximately 0.1 million hectares consisting of acid soils under food crops including rice, potato and vegetables.

The use of organic and chemical fertilier and lime (ground dolomite) is a regular practice in potato-and vegetable-producing areas. This area is very famous for exotic vegetables and potato cultivation.

Due to the acid condition of these soils, the yields of high value crops tend to decrease. The pH ranges from 4-5 in some areas where this soil is present (Thenabadu and Kalpage, 1974). Several studies have been carried out to evaluate the effectiveness and rate of lime application. Ponnamperuma (1958) reported that higher yields could be obtained when 11t/ha of ground lime stone was applied to this acid soil (pH range of 3.8 to 4).

Application of lime in tea lands in these areas is also a common practice in Sri Lanka.

2) Soil erosion problems in wet zone

Due to factors such as topography, rainfall and the poor land and crop management practices, erosion problems have developed in steeplands of the mid-and up-country of Sri Lanka. Among the major land use types present in these areas tobacco, vegetables, tea and vegetable gardens have been identified as the most hazardous land use systems.

(1) **Soil erosion in tea lands**

Tea is mainly grown in the mid-country wet zone, up-country intermediate zone and up-country wet zone areas of Sri Lanka. Most of the tea lands in these zones are planted with tea seedlings. The majority of these lands which are located on steep slopes are subjected to serious soil erosion processes, due to the presence of bare patches and poor land and crop management practices. The percentage of poorly managed seedling tea in the Nuwara Eliya district amounts to 55% while about 75% in the Kandy district. Manipura (1972) has reported that the annual soil loss rate is 40t/ha in poorly managed seedling tea lands.

This process of soil erosion has been continuing for the last decade and Krishnarajah (1985) showed that more than 30cm of soil has been so far removed from these lands. Due to the poor nutrient conditions the yield of tea in these lands is very low.

The erosion from the tea lands has been identified as one of the major causes of soil degradation in the mid-and up-country areas of Sri Lanka.

Vegetatively-propagated tea (V.P tea) provides a perfect canopy cover to the soil due to its uniform growth and due to the contour planting system practiced. A study conducted at Giraiama, in the mid-country wet zone, showed that the soil loss amounted to 0.3mt/ha/y (Krishnarajah, 1983).

Although the soil could be very well protected by this system the VP tea is established at a very low rate. Zijistra (1989) showed that in the Nuwara Eliya district only 100-200 ha are being converted into VP tea, annually. At this rate it will take more than 100 years to convert all the poorly managed tea lands into VP tea in this district. The main causes are the cost for the replanting operations and the long non-income generation phase that occurs during the conversion process. It has been estimated that this operation would cost about 400, 000R/ha. It has been recommended that a detailed research program be initiated to develop a system where landowners can obtain some income during the conversion phase.

The maintenance of a weed cover in the poorly managed tea lands could also reduce the erosion rate significantly. Studies conducted by the Tea Research Institute showed that a weed cover could be maintained in tea lands without a significant yield redumtion (Ekanayaka, 1990).

Immediate remedial measures have to be taken on this matter to reduce the serious land degradation that occurs in the mid-and up-country of Sri Lanka. If such a program is not initiated land degradation in the tea-growing areas will continue. Eventually these lands will become completely degraded and it will be impossible to grow any crops.

Since these tea-growing areas are within the catchment of major reservoirs that were constructed under the Mahaweli river project, the eroded soil from tea lands may become trapped in these reservoirs. It was revealed that more than 40% of the capacity of the Polgolla dam (in the Mahaveli river) had been filled with sediments.

Tea land owners should be provided with an attractive subsidy scheme to reduce this soil erosion problem. This type of subsidy or incentive scheme will be beneficial for the government in the long run, since it may contribute to a significant increase of the national tea production.

(2) **Soil erosion problems in vegetable-and tobacco-growing steeplands**

The tobacco and vegetable land use type present in the mid-country intermediate zone of the country has also created serious erosion problems. Steeplands of these areas are used to grow crops such as tobacco and vegetables during the main rainy season. These crops are grown without effective soil conservation measures. Krishnaraja (1984) found that the soil loss rates for tobacco reached 70t/ha/yr for vegetables. It was observed that more than 25cm of top soil had been removed in the tobacco lands of this area.

Farmers must use high doses of fertilizers for these lands due to poor fertility status associated with soil erosion. The Ceylon Tobacco Company who extended its assistance for the cultivation of tobacco in 9,000 ha of lands in these areas has reduced its activities up to 3,000 ha. According to an officer of this company they found that it is no longer profitable to grow tobacco in these degraded lands.

One of the main causes for bringing these steeplands into cultivation is the population expansion that has occurred in this area. It has been reported that more steeplands are now permanently being cultivated by farmers for this reason. Hence some alternative lands have also to be found for the people of this area to overcome the problem. Zijistri (1989) showed that in the Nuwara Eliya district 6.3 people have to live from 1 ha of such lands.

The Department of Agriculture started a subsidy scheme for soil conservation in this asea which has not become successful due to the low subsidy rate, lack of perseverance in the conservation measures and farmers' interest. Several studies have been carried out by the Department of Agriculture to overcome these problems. Recent studies have been initiated to examine the impact of agronomic measures on soil conservation and soil rehabilitation of these lands. The rehabilitation of agricultural lands using plant species such as *Gliricidia,* Vetever grass is being tested under this program. Further possible rehabilitation measures that could be adopted to upgrade the damaged soil are also being considered.

3)Fertility status in paddy tracts in mid-country

Recent studies conducted by the Department of Agriculture have shown that there are considerable differences in the same rice tract depending on the topographic location in the mid- country paddy-growing areas. Paddy lands located in the valley bottoms of the mid -country are classified according to their position in the paddy tract. "Godakumbura" lands are located in vally heads subjected to water stress during dry periods. "Madakumbura" land is found especially where 2 or more tracts intersect. The water table in these lands is on or closer to the surface. These paddy fields are inundated during most of the year. "Madakumbura" land is found in the center of the tract where adequate moisture is available throughout year and drainage is adequate (Somasiri *et al.,* 1978). It has been reported that the phosphorus levels on the "Madakumbura" land are low (Nagaraijha, 1984). Joshep (1986) reported that the response to nitrogen was high in Godakumbura.

4) Waterlogging conditions in rice lands in low country wet zone

Approximately 60,000 ha of land in the coastal belt of the Southwest quarter of Sri Lanka lies in the low-lying areas. These lands consist of paddy fields, unutilized swamps, marshes, grasslands, etc. They are interspersed with residual laterite land with low relief and both land types are confined to the coastal plain of Southwest Sri Lanka. The elevation ranges from 0 to 3m above mean sea level in lands bordering major rivers. Since these lands occurl largely in flood plains, the deposition of alluvium is a major soil-forming process in these areas. In the areas adjacent to residual highland, deposition of colluvial material also takes place. Since these lands are low-lying relative to the surrounding landscape drainage is poor, anaerobic conditions occur and reducing process continues as evidenced by the mottled and gleyed horizon in the soil profile.

Since these areas experience heavy rains from the two monsoons and also from inter-monsoons intense leaching takes place on these soils which are strongly acidic and low in bases. Furthermore these wet conditions have promoted the occurrence of reduction processes and accumulation of organic matter in soils. The process of accumulation is rapid in depressional sites like back-swamps, lands adjoining lagoons and lakes.

Dimantha (1977) classified the soils in this area into three broad groups, the bog soils, Alluvial soils and half-bog soils. According to the US Dept. of Agriculture the bog soils are designated as "Histosols".

The mineral composition of most of these soils consists mainly of fine-textured i. e. clay and clay loam. Bulk densities of these soils are very low. During floods these low-density materials often rise with the water and are washed away if paddy plants are present. If the flood water is not flowing, the raised surface layers settle back when the water subsides. If the surface layer is detached from the lower layer for a long time paddy plants suffer due to lack of nutrition because the roots dingle in the water and have no contact with the soil underneath.

Soil pH of Histosols ranges from about 4.5 to 5.5. When most of these soils became dry the pH decreased by 1.5 to 3 units presumably due to the oxidation of sulphides. The content of soluble salts is low in these soils due to extensive leaching, flushing, dilution, etc. The base saturation is very low and ranges from 2 to 25%. The content of exchangeable bases such as calcium, magnesium and potassium is generally low due to intense leaching. The organic matter content of the bog soil is 80% while that of the Alluvial and half-bog soils is lower. The carbon/nitrogen ratio of the bog soils is about 15 to 25%. Although the nitrogen content is high, much of it is not available due to the high carbon/nitrogen ratios. Due to the anaerobic conditions the mineralization rate of organic matter is also low. Therefore the release of N is low. The process of fixation of phosphorus is also low due to the high content of organic matter. The available silica is also reported to be low in these soils. Other workers have reported a high content of manganese, aluminum and sulphide, all of which be toxic to paddy.

The submerged conditions result in the decrease of the redox potential. In addition to the increase of the concentration of ferrous iron, hydrogen sulphide, etc. incomplete decomposition of organic matter leads to the formation of methane, ammonia, amine, mercaptan, alcohols, organic acids, etc. Some of these substances are toxic to rice (Thenabadu, 1966).

Several researchers have reported about bronzing. This physiological disorder, which adversely affects the growth of paddy plant is common in this area (Baba, 1958 ; Ponnamperuma, 1955). Inada (1966) showed that bronzing occurs under low Eh conditions, lower pH, high concentration of ferrous iron with low pH ranges, high concentration of sulphides especially hydrogen sulphide.

Due to these unfavourable soil constraints, the lands of these low-lying areas have been either not cultivated or only marginally cultivated for a long period of time. However during the last 25 years, due mostly to changes in social factors like increase of population, decreasing food supply and rising unemployment, interest was generated in the cultivation of these areas.

Ponnamperuma (1960) found that the problem of bronzing in strongly acid soils could be reduced by the application of lime at the rate of 13t/ha. Inada (1966) reported that lime was very effective in preventing this disease in bog soils. Further he reported that the application of fully decomposed compost or organic materials could increase the yield of rice especially in sandy areas of the bog soils.

Rice being the traditional crop grown in these soils seems to be the obvious crop to be recommended for these poorly drained soils. But it is even difficult for rice to establish itself in these problem soils.

Varieties of rice will have to be bred to withstand short duration floods, highly reducing conditions, in addition to showing other desirable agronomic characteristics.

Rice breeders of Sri Lanka have managed to develop several hybrid rice varieties to overcome this problem. Regional Agricultural Research Station, Bombuwela which is located in the low-lying problem soil area has succeeded in introducing some tolerant varieties to these soil types.

In these low-lying areas grasses and sedges can tolerate the conditions even better than rice. The utilization of some of the marginal lands for the cultivation of fodder grasses and sedges for manufacture of mats, baskets, etc. should be studied (Dimantha, 1977). The author further suggested that plants of economic importance such as *Bacopa monniera,* used for indigenous medicine, *Sonnaratia caseolaris,* a tree bearing edible fruits with roots used to obtain cork, *Nipa fruticans,* a palm utilized in Malaysia for the manufacture of sugar and honey, *Anona glabra,* a shrub in which roots are used to obtain cork should also be grown in this area.

Dimantha (1977) recommended the following management practices for these soils.

a) Improvement of drainage system is desirable to reduce flood hazard, remove excess water and improve the redox potential.
b) Time of sowing and harvesting has to be carefully selected. The general line of action

is to sow (or transplant) well ahead of the period when floods are expected, so that plants would be tall enough to stand above the flood level and mature during the dry season.

c) Liming is necessary when the soil pH is low. The Department of Agriculture recommended to incorporate rice straw ash to supply potassium and silica.

d) Adequate nitrogen, phosphorus and potassium applications are necessary. Studies carried out by the Department of Agriculture have confirmed the need for the application of nitrogen fertilizer from the very early stages of rice growth.

Dimantha (1977) stated that the management practices for the three soil sub-groups are different. For the bog soils the following additional practices were proposed.

a) The water table should be maintained around mean sea level with a view to preventing strongly acidic conditions which would promote the decomposition of the organic matter so as to further lower the pH, etc. The foregoing consideration will have to be weighted against the accumulation of toxic substances due to partial decomposition of organic matter under anaerobic conditions. A drainage submergence cycle should be worked out to suit the cultivation program.

b) As the bearing capacity of the soil is low, no-tillage methods for land preparation using total and systemic weedicides should be worked out to enable rapid land preparation necessary to keep up with the cultivation schedule.

c) The bunds of the paddy fields (liyaddas) should be built into a sufficient height so as to withstand minor floods.

d) The use of granular form fertilizers, insecticides and weedicides would be more suitable since the chemicals could be broadcasted from bunds.

e) As the risk of failure in the cultivation of bog soils is high, a package of intermediate level management practices at a low cost but giving adequate returns should be developed.

5) Management of half-bog soils

These soils are more productive than the bog soils and are found at low elevations. If correct management practices are adopted, high crop yields are possible.

As these soils are also subjected to flooding, the time of sowing is important when rice is grown in these soils. Since the interval between harvest of one crop and sowing of the next will consequently be short, the application of weedicides may be necessary in these areas too. Transplanting should be practiced in these soils because the farmer could gain considerable time and also improve the chances of survival of the crop in the event of flood, immediatley after crop establishment. The consistency of soil is ideal for transplanting. Crops could be managed satisfactorily in these soils by also adopting the management measures mentioned for the bog soils.

6) Management of alluvial soils

Since these soils are located at higher elevations that the other two types of soils the management is slightly different. As these alluvial soils tend to dry out frequently, early paddy varieties may be utilized so that their cultivation could be limited within the rainy period.

Dimantha (1977) recognized the importance of developing an integrated management program for a tract that contains all three soils due to the differences in the hydrological conditions associated with different land levels. Rice cultivation cannot be practiced at the same time throughout the paddy tract. With regard to the timing of sowing, the sowing of the tract could be started at the lower end about 11/2 months ahead of the higher areas, e. g. around February the land preparation could be started in the lower areas and in March in the upper parts of the tract. However harvesting has to be completed during the dry period. Therefore varieties of suitable maturity have to be selected so that although sown over a period of 11/2 months the harvesting will take place at one time.

7) Nilwala flood protection drainage scheme

Due to the drainage of the low-lying areas of the Nilwala river, flood plains have created serious problems associated with the development of acidity. This problem was reported in flood protection and drainage schemes. Several studies were initiated to overcome this problem. Dimantha (1977) warned that the build-up of the acidity level due to the lowering of the water table in bog soils has to be considered when drainage is carried out. High acidic level occurs due to the oxidation of the sulphides present in ill-drained soils.

Weerasinghe *et al.* (1989) conducted a study to examine the influence of water management practices to overcome the acidity poroblem. They found that a higher yield could be obtained if fields were kept under continuous submergence, namely a 20% increment of yield over the alternation irrigation regime of 5 day cycles. There was a 60% yield reduction in fields that were subjected to drying and wetting cycles. They further found that transplanting does not give positive results when the soil is subjected to the drying and wetting pattern of the water regime. In the fields which were subjected to periodical drying the pH of the soil dropped and created a favourable situation for aluminum toxicity.

Pathirana *et al.* (1989) tested several varieties to examine their performance under the low pH conditions of these soils. They found that the transplanted seeds survived while the broadcasted seeds were destroyed. It was revealed that the varieties BW 272-3, BW 279-2 and BW 272-8 gave 3,14, 2.96 and 2.68t/ha grain yield, restpectively. Furthermore it was found that the newly introduced cultivars BW 85 and BW 100 also gave higher yields.

8) Sea water intrusion

When the level of the rivers and streams is very low the lands that are in the lowest elevations of these low-lying areas in the Southwest coastal areas are prone to tidal intrusion of saline water. This occurs mainly in the flood plains of smaller rivers where the catchmest area is smaller.

Damage to crops in February and March or August and September, especially during the very early stages results from salt water intrusion. By proper timing of cultural operations and selection of proper varieties this problem could be alleviated (Panabokke, 1977).

According to Silva (1977) salt water intrusion occurs when the tides move up the rivers. This inland movement of saline water can be prevented by the construction of salt water exclusion bunds and regulation.

Dimantha (1977) reported that in inland areas below 0.3m msl electrical conductivity values of 2 to 5 millimohs per cm are generally reached with peak values of around 6 to 7 millimohs per cm during the dry periods. In Iranavillu the Eh values were as high as 10 to 20 millimohs per cm.

Breeding of salt-tolerant paddy varieties could also be a solution especially for areas where no physical measures have been provided to exclude salt water (Dimantha, 1977).

The soils which are present in areas below 0.3m msl are markedly affected by waterlogging, flooding and salinity. Reclamation maintenance and research in these areas are very costly where sowing is practiced during the dry period and the plants are apparently affected by salinity (Feb. Mar. Aug. Sept.). If the lands are sown late to avoid the salinity, the crop may be damaged by floods. Breeding of varieties tolerant to saline soils is essential. Another approach would be to supply a sufficient amount of water with low salinity from the upper reaches by means of pumps and keep the head of the water adjusted to the crop stage to prevent tidal intrusion and dilute any salt present. Dimantha (1977) also suggested that an intermediate level of management practices acceptable to the farmers should be developed.

3 Nutrient deficiencies in Sri Lanka soils

Tolhurst (1954) reported the presence of deficiencies in manganese and boron in tea soils. It was also reported that zinc was deficient in tea nurseries and iron in rapidly-growing VP tea plants (Tolhurst, 1959 ; 1961). Molybdenum was also reported to be deficient in tea plants recovering from pruning (Tolhurst, 1963).

Symptoms similar to those caused by boron toxicity have been reported in rubber estates (Jeevarathana, 1967).

Lathiff and Amarasiri (1982) reported the presence of sulphur deficiency in mid-country rice soils. They showed that some paddy soils in Sri Lanka have responded to sulphur fertilizer. With the current NPK mixtures used for paddy fields sulphur deficiency is seldom observed in mid-country rice soils. Based on the higher yield arising from intensive cultivation practices and better land and crop management practices, it is likely that greater amounts of sulphur are removed from land than before. Furthermore it was revealed that sulphur availability under flooded conditions is low. Under the present situation rice plants could be subjected to sulphur deficiencies in future. Nagarajha (1983) reported that zinc has been found to be deficient in lowland rice in Sri Lanka.

4 Future problems and prospects for improving soil productivity for sustainable plant production

Among the above-stated soil constraints leading to serious problems for agriculture, only the soil constraints associated with poor land and crop management practice can be significantly corrected. However this is also a difficult task since, due to the present population growth, the demand for land has increased and people have to use steeplands to make their living by growing crops in these unsuitable lands. Degraded lands due to poor land and crop management practices will have to be developed if suitable lands are not found.

Corrective measures for problem soils should only be introduced after careful study of the problem. About 10,000 ha of agricultural lands became degraded due to drainage operations carried out in the low-lying areas.

Several rice breeding stations in Sri Lanka, are attempting to breed some promising rice varieties suitable for the problem soils.

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Discussion

Wakatsuki, T. (Japan): Could you explain in greater detail why soil erosion is so pronounced in the tea plantations of Sri Lanka? Indeed in view of the long tradition of tea cultivation in Sri Lanka, one would have expected that the farmers would know how to prevent soil erosion from occurring in such lands.

Answer: The new system of planting along contours was only introduced by the Tea

Research Institute about 20 years ago. Vegetatively propagated tea was not used previously and seedling tea was planted. Erosion of tea lands is due to the lack of confluence of the tea bush cover as bare patches are prone to erosion associated with high rainfall, in particular in the mid-country area. As a result, the yield tends to decrease. Landowners are able to obtain an income even from poorly managed tea lands by applying large doses of fertilizers. The tea lands in the up-country still produce a higher yield due to favourable climatic conditions. However, since fertilizer application is decreasing due to high cost, a further reduction of yield from poorly managed tea lands is anticipated.