SUSTAINABLE AGRICULTURE

Issues, Perspectives and Prospects in Semi Arid Tropics

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INDIAN SOCIETY OF AGRONOMY

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Proceedings of the

First International Symposium on Natural Resources Management

for a Sustainable Agriculture

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THE SOIL COMPONENT IN SUSTAINABLE AGRICULTURE

H. Eswaran and S.M. Virmani

1. INTRODUCTION

The change of emphasis from increased productivity to sustainability of agriculture has taken place over the last few years. Most definitions of sustainable agriculture recognize some or all of the following as being an integral part of the system:

1. Buffered against risks
2. Stabilized over time
3. Synchronized with climate
4. Harmonized with the environment
5. Sensitive to soil degradation
6. Responsive to changes

The concept of sustainable agriculture does not, however, preclude increased production but in addition calls for a maintenance of the resource base. From an agronomic research point of view, the concept though simple, requires a marked change in research administration, the design and monitoring of field trials and the parameters to be measured. From a development point of view, socioeconomic considerations take on a more important role with farmer awareness and appreciation of the concept of sustainability becoming more crucial.

The resource of concern here is the soil and indirectly, all the components of the environment. In production surplus countries, water quality is an important issue particularly the pollution of the water resources through the use of some fertilizers, pesticides and herbicides. Even in this case, the soil through its buffering capacity, plays an important role in controlling the amount of pollutants reaching the water system. As the quantities of organic and inorganic compounds added to the soil in developing countries is significantly lower, water quality is not yet an issue in many of these countries and will not be considered here.

The purpose of this paper is to examine the role of soils in sustainable agriculture and to evaluate the current constraints or limitations of knowledge of soil resources in developing countries. The paper focuses on the soil and its role in sustainable agriculture, recognizing that production and sustainability is a multi-faceted problem.

2. SOIL DIVERSITY IN THE TROPICS

Although the term tropics is a meaningful agro-ecological zone for most practical purposes, there is a broad range of climatological conditions and a broader range of soil conditions prevailing in the tropics. Agro-climatological assessments, particularly of the semi-arid tropics (SAT) has been elaborated in great detail by Virmani and co-workers (Virmani et al, 1986) and by climatologists such as the contribution of Troll (1965). Information on soil climate is lacking and this is an equally important parameter in assessing crop performance.

2.1. Soil climate : Soil scientists define the tropics as the zone generally between the Tropics of Cancer and Capricorn, with a mean annual soil temperature at 50 cm depth of more than 8 ^{o}C and a difference between mean summer and winter soil temperatures of less than 5 ^{o}C. The low amplitude in soil temperature signifies an iso-temperature regime and a temperature of 8 °C or more implies that soil temperature is not a constraint for plant growth in the tropics. Table-1 presents the different soil temperature regimes (STR) in the iso-regions recognized in Soil Taxonomy (Soil Survey Staff, 1975).

Soil moisture is more difficult to measure and though there are procedures for monitoring soil moisture during the year, a mathematical model developed by F. Newhall (1972) and refined by Van Wambeke (1981, 1982, 1985, 1987) is employed to evaluate it. Several soil moisture regime (SMR) classes are recognized and relevant ones for the tropics are aridic, ustic, udic and perudic. A combination of SMR and STR indicates the considerable range of agro-environment that exists in the tropics. Figure 1, illustrates the SMR status for Hyderabad, Bellary, Bangalore and Trivandrum, all located in southern India to show the variability of SMR. All the sites have an isohyperthermic STR and an ustic SMR (except Bellary which has an aridic SMR) but as shown in Table-2, the period during which the soil moisture control section is dry, partly dry or moist is different.

SMR and STR are major controls of the kinds of farming systems that can be practised. The four stations in Table-2 can be used to illustrate this (Figure 2). Bellary has no period when the MCS is moist. The period during which part of the MCS is dry or moist is short and usually very unpredictable. From soil moisture point of view, there is a probability of more than 70% for crop failure and so sustained agriculture requires irrigation. Hyderabad and Bangalore have a sufficient long period during which SMR is moist. Even though the moisture lost by potential evapotranspiration and that percolated into the soil is in general higher than rainfall, the storms during the rainy season can result in water excess and thereby runoff. Technology, as developed by the International

Crops Research Institute for the Semi-Arid Tropics (ICRISAT), is designed to remove this excess water, for soils with this moisture distribution pattern. Trivandrum presents another situation. The amount of rain received during the rainy season far exceeds the storage capacity of any soil and the demands of potential evapotranspiration; an important component of farming system in this area, is the removal of excess water during the rainy season, temporary storage and its utilization during the dry season. Removal also implies potentials for erosion and so grass water-ways or similar conservation technology is required.

The characteristic feature of soil moisture in the semi-arid tropics is its intransigent irregularity as shown in Fig. 3. Taking Hyderabad station as an example (Fig. 4), the soil moisture control section may range from almost dry, depicting an aridic SMR to near complete moist - a wet ustic. In Hyderabad, however, the SMR is ustic in nine out of ten years. In the sixty seven years during the period 1894 to 1960, the SMR was aridic only in eight years but an evaluation of this extreme drought probability must be considered in designing management systems.

The significance of SMR and STRs is illustrated in Figs. 5, 6 and 7, where the distribution of the major crops of India is plotted on a SMR-STR map of India. Figure 5, shows the distribution of millet which is concentrated in the north and north west of the country, in the transition area between aridic and ustic (At). Being a drought resistant crop, it can survive in these areas with short duration growing season. Similar agro-environment prevails in the central part of southern India around Dharwad, Bellary, Kurnool and a smaller area in Tamil Nadu around Kovilpatti. In these areas, it is not a major crop but the information suggests that these are potential areas for expansion. The groundnut distribution (Fig. 6) shows a different distribution. From soil climate point of view, the ideal regions are those with a Typic Tropustic (St) or Udic Tropustic (Sw). A high concentration is observed in central part of southern India; this may be due to traditions but the SMR studies indicate that this is not the best area. One could similarly evaluate for sorghum (Fig. 6). However, final recommendations for the discriminatory use of soils would require an assessment of soil capabilities coupled with other factors such as irrigation availability and socioeconomic considerations.

2.2. Soil variability : The concept of soil diversity is a function of the scale of observation. The classes in Soil Taxonomy (Soil Survey Staff, 1975) provide for expression of this diversity. There is no good estimate for the number of classes occurring in the tropics, particularly for the lower categoric levels. An estimate by Eswaran et al (1989) is given below in Table-3.

Table-4 (Virmani and Eswaran, 1989) lists some of the more important great groups of soils in the SAT. Some major constraints are indicated for each great group. It should be noted that most soils in the SAT have some kind or combination of constraints. The soil qualities important for sustainable agriculture are many but can be reduced to 10:

1. Available water-holding capacity
2. Nutrient retention capacity - cation exchange capacity
3. Nutrient availability - pH and base saturation
4. Nutrient fixation
5. Chemical constraints - acidity, sodicity
6. Physical constraints - low hydraulic conductivity, permeability, high bulk density. crusting
7. Effective soil volume - depth to root restricting layer, stoniness
8. Surface tilth
9. Erodibility
10. Water-logging

In Table-5, the soil qualities listed previously which are major constraints are provided for each of the dominant great groups in the SAT. Similar tables may be constructed and with greater degree of reliability for the lower categories, such as subgroups, families or even soil series. Eswaran (1977) has developed similar tables of constraints for the subgroup category for a few orders of soils.

It is necessary to establish standards for threshold values, with respect to specific uses, for each of the soil qualities. The Soil Conservation Service of USDA has for example, established the soil loss tolerance "T value" as a kind of soil quality standard. This standard is used to determine if a practise or sets of practises are essential to meet resource management needs.

Until and unless such soil quality standards are established, it will be difficult to monitor soil degradation and consequently the effects of management. From the point of view of sustainable agriculture, soil quality standards :

- provide a basis to evaluate changes in soil conditions due to management;
- provide the tools for monitoring changes;
- provide the basis for legislation for soil stewardship;
- provide a means of signalling potential problems in order to trigger research or development activities;
- provide the criteria for evaluating sustainable agriculture

There is an urgent need for the international scientific community in collaboration with potential users to develop guidelines for these standards. As the socioeconomic conditions vary, each country would probably need its own set of standards.

3. SOIL DEGRADATION

The cause of soil degradation, in many instances, is improper soil use and management. Absence of appropriate management techniques is often related to poverty, field and farm size, under development, and other socioeconomic constraints. Degradation is driven by demographic and landuse trends and aggravated by various obstacles to agricultural progress and sustainable landuse. These include legal, macroeconomic, policy, and institutional impediments to resource conservative landuse.

Soil degradation (FAO, 1983), manifests itself in several ways, such as :

- Reduced crop yields by :

  1. leaching and washing out of plant nutrients and fertilizer
  2. deterioration of soil structure and texture and exposure of subsoil;
  3. reduction of soil rooting depth
  4. poor aeration of soil
  5. chemical imbalance

Erosion (El Swaify et al., 1984), is the most important degradative process manifesting itself both at site and off-site :

- Reduction in agriculture land and declining land value
- Sedimentation of reservoirs, rivers and drainage systems
- Increased frequency and severity of flooding
- Loss of water resources
- Reduction in fish stocks and breeding grounds
- Effect on power generation
- Effect on health and the quality of life

Rates of degradation is a function of the soil and its physiographic location. The relationship between degradation and sustainability for agriculture is illustrated in Fig. 8, where three distinctly different kinds of soils - Oxisols, Alfisols and Vertisols - is used. In the Oxisol, the inherent productivity ror comparable uses is low and with onset of degradation, the productivity declines rapidly. In the Alfisols, there is an initial buffering period during which time, the soil can accept abuse but after this threshold period, there is a rapid and continuous decline. The Vertisols, particularly those with a thick solum, represent a third situation where with time, the soil exhibits several threshold situations. At each threshold, the soil attempts to equilibrate or even recuperate. If the effective volume of the soil is reduced, which happens in medium and shallow Vertisols, the productivity drops rapidly.

Pierson et al (1983) have developed an index to assess productivity and relate this to soil loss. With their simulation techniques they show that, for some Mollisols in Minnesota, erosion affects productivity on slopes greater than about 12%. On these slopes, productivity is reduced by more than 10% in about 25 years when there is a constant soil loss. Soils with a lithic contact at shallow depth lose their productivity as soon as the top soil is lost and so soil depth is an important parameter in assessing soil productivity.

Management technology can be designed to counteract the consequences of degradation. However, the amounts of inputs required is a function of the degree of degradation and the kind of soil. Conversely, management technology can be practised to reduce risks, and the relation of inputs required for sustainable agriculture to risks is illustrated in Fig. 9. The decision on level of inputs or in other words the kinds of farming system to be adopted is a socioeconomic question (Virmani and Eswaran, 1989) linked intrinsically to risk aversion.

From a purely soils point of view, in general, the farmer on the better soil is less prone to risks than the one working with the marginal soils. The soils basically buffer the farming system.

4. SOIL RESOURCE INVENTORIES

Operationally sustainable agriculture is applied at the farm level and for most purposes the minimum decision area (MDA) can be taken as one hectare. To obtain an appreciation of the soils on this MDA, a soil map at a scale of 1:10,000, where 1 cm^2 on the map is equal to 0.41 ha (1 acre), is needed. There is practically no developing country in the world which has a program of systematic soil surveys at this scale and this is the major constraint to developing the prerequisites for sustainable agriculture in these countries. Such maps are needed to design appropriate farming systems, target soil conservation measures, recommend fertilizer policy and monitor nutrient and other needs ot the farmer, and make efficient utilization of the extension services.

For a country to adopt a policy of sustainable agriculture and operatonalize this policy, soil resource inventories at several scales are needed. At the national level, there must be an inventory of the Major Land Resource Areas (MLRA). MLRA maps are used at national levels :

1. as a basis for making decisions about agricultural issues;
2. as a framework for organizing and conducting resource conservation programmes;
3. for geographic organization of research and conservation needs and the data from these activities;
4. for coordinating technical guides between states and districts of a nation and between countries;

5. for organizing, displaying, and using data in physical resource inventories, and

6. to aggregate natural resource data.

MLRAs are most important for agricultural planning and have value for interstate, regional, and national planning and are most important tools for targeting sustainable farming systems technology. Fig. 10, shows a MLRA map of Uganda developed by Yost and Eswaran (1989). An assessment of the sustainability of agriculture for each of the MLRA units can be determined to guide national planning.

Soil resource inventories at intermediate scales between the MLRA map and farm level maps may be made if time, personnel, facilities and funds permit. In most LDCs this is not the case and so emphasis must be on the farm level maps.

Farm level maps, such as the one in Fig. 11 (Yost and Eswaran, 1989) are expensive to make and require highly trained personnel. There must be a national institution to coordinate the effort and develop and provide the standards for evaluation. In most LDCs, soil surveys are done on contract and by expatriates. Standards, methodology, criteria all vary and few of these maps have long term use. In addition to making maps, the extension service and decision makers must be trained to use the maps. The national institution must provide basic soil services to backstop potential users. These are some of the ingredients to the goal of sustainable agriculture.

Soil resource inventories at any scale, aggregate soils based on distinctive features into classes which may be related to potentials or constraints. The inventories are generally made for specific purposes, the most important one being the assessment of the nations soil resources. The inventories generally provide sufficient information for most interpretations or applications and this aspect of utilization of soil survey information is referred to as 'soil survey interpretations' This requires ancillary data and research to match soil conditions to crop performance or other uses of soils.

Many soil survey organizations consider their task accomplished when the map and report is published. This delusion has contributed to lack of utilization of soil survey information in many countries. Translating the technical information in soil survey reports for the use of potential users is also a task of soil survey organizations and one which can be done only in collaboration with other disciplines.

With the advent of the information age which we have entered, the kind and detail of soil information required is gradually changing. Group therapies of the medical profession serve some purposes but do not heal tooth-aches. Similarly, general soil maps have useful functions as discussed before but are of little use to the farmer. The challenge of the future is to provide site specific information and the technology is now available to enable this. These include the following :

* Geographic Information Systems (GIS) - GIS capability permits servicing the individual farmer; the current constraint is that data are not available to drive GIS.

* Global Positioning Systems (GPS) - GPS will become an integral tool of soil surveys and will be linked to GIS. GPS enables precise georeferencing of field observations and is already being tested for precise fertilizer and pesticide application on a field by field basis.

* Digital elevation model (DEM) - An additional tool of GIS, DEM will become an integral tool in designing farming systems and targeting conservation practices.

* **Simulation models and expert systems** - The progress in these fields is astounding. One major constraint which is a basic driver for any of these models, is soils information. In many developing countries, not only the quantity of information but also the quality of data are major constraints. The situation today is too many models chasing too few data.

Many soil survey organizations will continue to proceed with their classical approach to soil surveys. It is upto the users of soil survey information to demand for marked changes and improve the delivery and quality of the information.

5. EVALUATION OF SUSTAINABILITY

There is few methodology to evaluate sustainability of farming systems or agricultural practices. Some approaches are considered here, first to evaluate farming systems and later to develop a methodology for testing sustainability. One of the constraints is frequently the lack of long term experiments designed to monitor sustainability. Virmani and Eswaran (1990) have employed some long term experiments from ICRISAT (ICRISAT, 1974, 1986) to not only illustrate the concepts being developed but also hoping that such research will be initiated in other agro-environments. Any future research activity designed to monitor sustainability must be based on process oriented conceptual models and the data generated and measured must be those required by the model.

Lal and his colleagues (Mbagwu, Lal and Scott, 1984) conducted a series of experiment to test the consequences of erosion. Figs. 12, 13, 14 depict the results of this decapitation research. Fig. 12 and 13, show that each soil responds differently to topsoil erosion. The real impact of erosion losses is illustrated by Fig. 13, which shows the role of P addition on the soils each of which had been "eroded" to a certain depth.

Such basic research is infrequent despite the fact that they provide the basis for managing the soils. However, based on such work and the detailed monitoring by ICRISAT (Virmani and Eswaran, 1990) several generalizations can be made with respect to the behaviour of soils. Fig. 19, depicts the relative soil quality ratings for a number of soil orders found in the semi-arid tropics (SAT). It must be remembered that within each order there are a number of soils and consequently such generalizations are fraught with errors. Fig. 17, looks at a suborder of Alfisols, Ustalfs, and Fig. 18 at a suborder of the Vertisols, Usterts, to illustrate the differences within a suborder. Finally, Fig. 19, looks at three depth families in a great group of the Usterts, Chromusterts, and shows the variability in crop response one can expect. Superimposed on the soil conditions is both the atmospheric and soil climates which further modify the responses and behaviours. Farming systems technology must take into account these variables to be efficient and effective from the point of view of sustainability.

6. CRITERIA FOR SUSTAINABILITY

Virmani and Eswaran (1989) developed criteria for the test of sustainability of farming systems based on principles determining agrotechnology transfer (Silva and Uehara, 1985):

- **Technological feasibility (T).** Monitoring over a period of time and understanding the behaviour of the system is essential to ensure the technological feasibility of a system. The real test of the system is its response during adverse weather or adverse soil conditions. Although enhancing productivity is the goal, the behaviour of the system during `bad years´ ensures acceptance.

On farm trials (with minimal intervention of the scientist, whose role is limited to initial guidance and discrete monitoring), provide the basis for evaluating sustainability of the system. A clear strategy to monitor indicators of change must be established prior to initiation of on-farm trials and later when the system is recommended for general use.

- Economic viability (E). Marketing facilities, distance to markets etc., are the variables, apart from the value of the product, which determine economic feasibility. These can be ascertained with a fair level of accuracy. However, major shifts in market economies may require changes in the farming systems. Elasticity of the system then becomes a limiting factor.

- Political desirability (P). The farming system must be in tune with the political aspirations and strategies of the country. Crop diversification is a common goal of many countries, and this must be respected and attempts made to incorporate it into the system.

- Administrative manageability (A). Improved technologies frequently require greater inputs including labour, as shown by ICRISAT (1986). New farming systems must be introduced gradually and with good training and field demonstrations. Each farmer has a ceiling of performance and exceeding this may prove detrimental. The farming system package must be modular and new modules can be introduced as the farmer graduates.

- Social acceptability (S). This is very important in societies with entrenched traditions particularly religious traditions. If labour requirement coincides with important festive occasions, the system is in jeopardy. It is not meaningful to harvest after the harvest festival.

- Environmental soundness (N). This test of sustainability has not received as much attention as it deserves. It is largely a function of soil qualities and methodologies to assess impact on environment are not sufficiently well conceived. There is an urgent need to establish indicators of change which must necessarily be at several levels. Monitoring of the resource base using soil qualities listed previously provides the indicators of change. Equally important is to develop simple parameters for use by extension workers and at a lower level, by farmers.

An assessment of sustainability of agricultural practices can be made using the following relationship :

$$ASI = (T \times E \times P \times A \times S \times N) / 1000$$

where, T, E, P, A, S and N are ranked from 0 to 10 and,

ASI = Agriculture sustainability index
T = Technological feasibility
E = Economic viability
P = Political desirability
A = Administrative manageability

S = Social acceptability
N = Environmental soundness

Table-6, evaluates the ASI for traditional cropping systems as practised in the Hyderabad area and compares it with the improved cropping systems on Vertisols recommended by ICRISAT.

Guidelines for rating the elements of ASI must be developed but as can be seen from Table-6, a quantitative assessment can be made for evaluation purposes. From the point of view of sustainability, the economic viability of the system which is linked to the risk of the farmer, is a most crucial element. Figure 19, shows a diagrammatic depiction of ASI as a function of management level. Land classified as 'unsustainable' in this scheme is generally steep lands or fragile ecosystems which should not brought into agriculture. Land considered as 'marginally sustainable' must be brought under a conservation reserve program. Such land should be under forestry but if under agriculture, it should be taken out of agriculture for recuperation and only brought into agriculture for national emergencies. The 'conditionally sustainable' land would require special conservation pracatices and attention with respect to other inputs. The 'prime land' is the nations bread basket and government support in the form of fertilizers, pesticides etc. must be provided to maximize production.

Soils belonging to the four land classes also relate to risk factor which is the major control of sustainability. The prime land may be considered as kind of a buffered system which is able to take some abuse from the operator and which requires some effort to degrade. The unsustainable land on the other hand is already a fragile ecosystem and if misused, quickly can become 'non-land'

8. A STRATEGY TO DEVELOPMENT

If there were easy solutions, we would not have the current situation of a rampant degradation of the natural resource base. Institutional strengthening is perhaps the foremost issue and should be considered as the priority activity in any donor funded program. This is a long term activity but should be persued simultaneously to any short term operational activities. The strengthening is not only of the technicians but also the institutions themselves; each country should develop centers of excellence which can collaborate and receive inputs from the international community.

On the short term, one could recommend a whole range of donor supported activities which includes :

1. developing MLRA maps (1:1 million)
2. making and interpreting large scale (Farm level) maps
3. strengthening soil laboratories through interlaboratory cross-checks, development of analytical methodologies and junior staff training
4. training on soil survey, soil classification and management of soils. Provide an opportunity for scientists of the region to get together and exchange experience and information
5. use and application of geographical information systems (GIS) to store and retrieve resource information
6. land evaluation and a land use database
7. utilizing the soil resource information for sustainable agriculture

Table-7, lists some of the issues, their causes, and required technology in developing countries. The first step is to know the natural resource base. No agricultural development can take place without this information. Following this or simultaneously, the major resource problem affecting most countries - soil erosion - can be addressed. This requires acceptance by decision makers of a stewardship and a commitment to soil conservation which involves the establishment of an institutional framework and allocation of necessary funds.

When there is sufficient information on the soil resources of the nation as when a MLRA map is produced, decision makers can develop the philosophy of discriminatory use of soils. This implies the matching of crops to soils and if wisely practised, it would result in a self sufficiency in most agricultural products with a concomitant savings in foreign exchange. This would finally pave the way for putting sustainable agriculture into practise.

Sustainable agriculture cannot be imposed onto any country; a country has to graduate to attain this goal and the role of international donors is to help the countries through the tortuous path to sustainable agriculture.

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Table-1 : Soil temperature regimes (STR) in the tropics

Soil Temperature Regime	Mean annual soil temperature at 50 cm depth
Isomesic	8 - 15 °C
Isothermic	15 - 22 °C
Isohyperthermic	22 - 29 °C
Isomegathermic	> 29 °C

Table-2 : Period during which soil moisture control section is dry, partly dry or moist for four selected stations in S. .ndia

Name	Soil moisture control section (No. days)		
	Dry	Partly Dry	Moist
Bellary	287	73	0
Hyderabad	175	31	154
Bangalore	76	140	144
Trivandrum	54	61	245

Table-3 : Estimates of number of soils in each category of Soil Taxonomy, in the tropics

Taxonomic Level	Estimate of number of soils
Order	11
Suborder	45
Great Group	200
Subgroup	1,250
Family	1,000,000*
Series	5,000,000*
Phases of Series	10,000,000*

*Estimates

Table-4 : Major soil great groups in SAT

Order	Great Group	Major Constraints
Alfisols		
	Plinthustalfs	Soil volume, rooting, (Ms)
	Natrustalfs	Sodium problems
	Paleustalfs	Erosion, Ms
	Kandiustalfs	Erosion, nutrient supply, Ms
	Kanhaplustalfs	Erosion, nutrient supply, Ms
	Rhodustalfs	Erosion, P fixation, Ms
	Haplustalfs	Erosion, Ms
Entisols		
	Ustifluvents	Ms
	Ustorthents	Ms
	Ustipsamments	Extreme Ms
Inceptisols		
	Ustochrepts	Ms, slope
	Ustropepts	Ms, slope
Mollisols		
	Natrustolls	Sodium
	Paleustolls	Ms
	Calciustolls	P fixation, Ms
	Argiustolls	Ms
	Haplustolls	Ms
Oxisols		
	Acrustox	Ms, P fix., low nutrients
	Eutrustox	Ms, P fix.
	Haplustox	Ms, P fix., low nutrients
Ultisols		
	Plinthustults	Ms, low perm., acidity
	Paleustults	Ms, acidity
	Kandiustults	Ms, acidity, low charge
	Kanhaplustults	Ms, acidity, low charge
	Rhodustults	Ms, acidity, P fixation
	Haplustults	Ms, acidity
Vertisols		
	Chromusterts	Tillage, Ms
	Pellusterts	Tillage, Ms
Andisols		
	Haplustands	Ms, P fixation

Ms = moisture stress

Table-5 : Major soil great groups in SAT

Order	Great Group	Soil Qualities									
		1	2	3	4	5	6	7	8	9	10
Alfisols											
	Plinthustalfs	X	X		X			X		X	
	Natrustalfs	X		X		X	X	X			X
	Paleustalfs				X					X	
	Kandiustalfs	X								X	
	Kanhaplustalfs	X	X							X	
	Rhodustalfs	X	X	X						X	
	Haplustalfs									X	
Entisols											
	Ustifluvents										X
	Ustorthents							X			
	Ustipsamments	X	X	X			X				
Inceptisols											
	Ustochrepts	X						X		X	
	Ustropepts							X		X	
Mollisols											
	Natrustolls					X	X				X
	Paleustolls										
	Calciustolls				X						
	Argiustolls										
	Haplustolls										
Oxisols											
	Acrustox	X	X	X	X	X				X	
	Eutrustox	X	X		X	X				X	
	Haplustox	X	X	X	X	X				X	
Ultisols											
	Plinthustults	X	X	X	X	X				X	
	Paleustults	X	X	X	X	X				X	
	Kandiustults	X	X	X	X	X				X	
	Kanhaplustults	X	X	X	X	X				X	
	Rhodustults	X	X	X	X	X				X	
	Haplustults	X		X	X	X				X	
Vertisols											
	Chromusterts						X		X	X	X
	Pellusterts						X		X	X	X
Andisols											
	Haplustands	X			X	X				X	

Table-6 : Calculation of ASI using fictyional data

Factor	Traditional	ICRISAT
T	4	6
E	3	7
P	8	7
A	8	5
S	8	6
N	2	8
Product	12,288	70,560
ASI	12	71

Table-7 : Natural resources and sustainable agriculture

Objectives	Major Problems	Primary Causes	Technology Needed	Constraints
1. Knowledge of Natural Resource base	1. Lack of base-line info 2. Lack understanding of relationships 3. Inability to interpret data 4. Need for coordinated data base 5. Need standardization	1. Lack of data 2. Unreliable data quality 3. Lack of monitoring facilities 4. Lack of data base management systems 5. Lack of trained	1. Relational data base & management systems 2. Systems approach to problem identification and solving 3. Cost-effective methods for monitoring 4. Operational Labs	1. Institutional framework 2. Trained personnel 3. Adeauate funding for research and development 4. Field studies and data generation 5. Quality of data
2. Resource soil loss	1. Deforestation 2. Off-site damage 3. Lowered water quality 4. Reduced species Diver 5. Reduce crop yields 6. Greenhouse effect	1. Shifting cultivation 2. Commerce, timber 3. Steepland cultivation 4. Forest fires 5. Lack of grazing Land 6. Lack of fuelwood	1. Sedentary farm syst. 2. Agroforestry 3. Alley cropping 4. Low input soil conser. 5. Alternative energy source	1. Socio-economic 2. Farm size/pattern 3. Production risks 4. Market/income stability 5. Institutional support
3. Discriminatory Land-use	1. Wet lands 2. Steep-lands 3. Desertification 4. Soil Loss 5. Non-agricultural uses	1. Population stress 2. Overgrazing 3. Land speculation 4. Lack of planning 5. Lack of instit. framework	1. Impr. Cultivars 2. Impr. Soil management 3. Farming systems 4. Land stewardship 5. Conserv. technology	1. Farmers awareness 2. Socio-economic 3. Lack of extension 4. Lack of applied research 5. Instit. Framework
4. Sustainable agriculture	1. Decline soil fert. 2. Surface soil loss 3. Weeds and pests 4. Decline water quality 5. Changes in soil biota 6. Fluctuations in productivity 7. Degradation of ecosystem	1. Lack of site-specific technology 2. Continuous mono-cropping 3. Crop residue removal 4. No nutrient replenish 5. Lack soil/water conservation	1. Soil specific farming systems 2. Soil biotechnology 3. Water harvesting and other technology 4. Fertilizer management and technology 5. Detailed soil surveys	1. Socio-economic 2. Absence soil data base 3. Lack of extension serv. 4. Lack of site-specific farming systems packages 5. Lack of other base-Line data 6. Institutional framework

Figure 1.--Moisture Status: (a) Bellary, (b) Hyderabad, (c) Bangalore, (d) Trivandrum

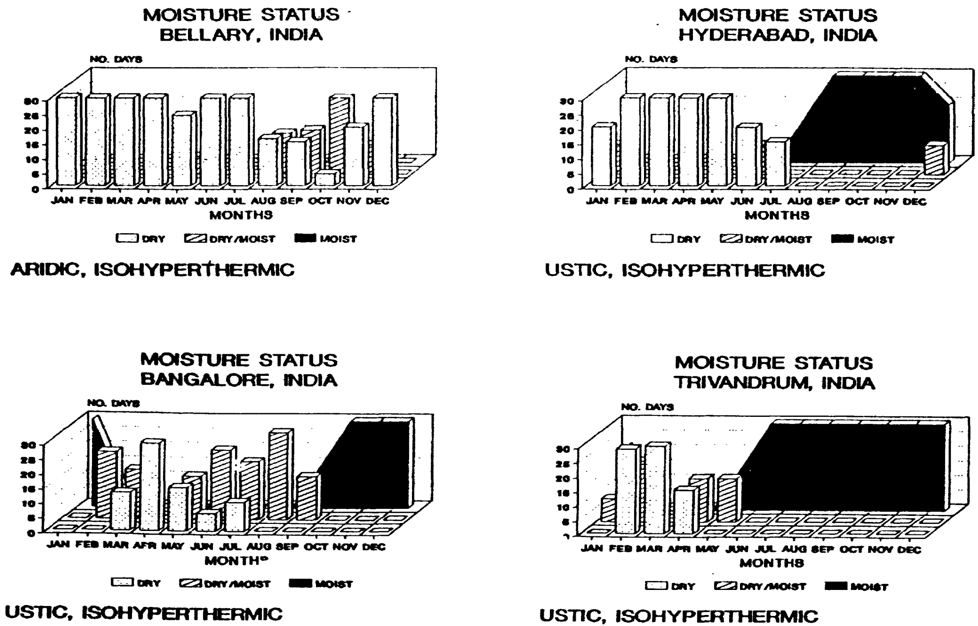

Figure 2.--Water Balance Pattern: (a) Hyderabad, (b) Trivandrum, (c) Bangalore, (d) Bellary