MANAGEMENT OF VERTISOLS FOR IMPROVED CROP PRODUCTION IN THE SEMI-ARID TOPICS: A PLAN FOR A TECHNOLOGY TRANSFER NETWORK IN AFRICA

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Abstract

In the Vertisols of semi-arid India (Usterts), ICRISAT has shown that by the application of efficient land, water and crop management techniques, crop yields of the order of over 3 tons per ha can be harvested successfully where traditional methods only yield 500-700 kg per ha. Some of the components of this technology can be progressively applied to the African Vertisols and vertic soils. Verification trials and additional experiments may be required to adapt the available improved technologies in Vertisols to the semi-arid tropical regions of Africa.

This paper also outlines the background leading to the proposal for the establishment of a Vertisol management network for increased crop production. A suggested list of activities for collaborative research and the institutions that are comparatively strong in various activity areas has been compiled. Finally some items towards an agenda for developing a workshop network proposal are identified.

The Semi-Arid Tropics

Semi-arid climates[1] cover much of the tropical areas of the African continent stretching in a broad band from west to east in the sub-Saharan region, and including much of eastern and south-central Africa. In Asia they cover much of India and parts of Burma

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[1] Following Troll's classification, the semi-arid tropics have been defined as areas where monthly rainfall exceeds potential evapotranspiration for 2-7 months. In these areas the mean monthly temperature is above 18°C.

and Thailand. The northern territories of Australia, several countries in southern Africa, including Mexico, Venezuela, Brazil, Paraguay, and Bolivia lie within this region.

The tropical regions are characterized by high evapotranspirational demand. Temperatures are fairly high for most of the year, usually exceeding a mean of 18°C in all months. The semi-arid areas have a short rainy season. Most of the rainfall is received within 2 to 5 months – from June to October in the northern hemisphere and from October to April in the southern hemisphere.

Of the different climatic elements which are important for crop production in the semi-arid tropics (SAT), rainfall is the most variable. The total annual rainfall varies considerably, ranging from 400 to 2000 mm. The coefficient of variation of annual rainfall is 20-30%. In most years the rainy season in the SAT is long enough for annual crops to grow. Indeed, there is often excess water in the rainy season, a part of which can be stored in the soil, but most of it runs off and causes soil erosion. In the SAT, the management of land, crops, and livestock is intimately associated with the water resource availability.

Distribution and Properties of Vertisols

Vertisols occur in many climates. There are approximately 310 million ha of these soils in Asia (mostly in India), in America (mostly in the United States of America, Venezuela, and Argentina), in Australia, and in the continent of Africa.

Vertisols occur extensively in several countries in Africa under arid, semi-arid, and humid climates, and have an agroecological potential for food production well above their present level of use. According to Swindale (1982), there are approximately 104 million ha of Vertisols and vertic soils in Burkina Faso, Niger, Nigeria, Chad, Sudan, Ethiopia, Somalia, Kenya, Burundi, Malawi, Zambia, Zimbabwe, and Botswana (Figure 1). Some small areas occur in other countries of Africa, and altogether about 30% of the world's Vertisols are located in Africa.

Vertisols are a highly productive group of soils. They contain at least 30% clay, and the dominant clay mineral is usually one of the smectite group. These soils are generally 60 cm deep or more. Vertisols are therefore able to retain considerable amounts of available water in the soil profile. Due to the nature of the dominant clay mineral, they exhibit shrinking and swelling properties, and are highly erodable. Their physical properties make them difficult to handle. For example, they are heavy soils and are difficult to cultivate; further, some exhibit a 'gilgai' formation, and therefore the preparation of the seedbed on these soiis presents many difficulties. Due to their low terminal water intake rates, they easily get waterlogged during the rainy season.

In Africa, three suborders of Vertisols (as defined in *Soil Taxonomy*) are found:

- **Torrerts**: Vertisols of deserts or very low rainfall areas of the arid tropics, generally having less than 2 humid months annually.
- **Usterts**: Vertisols in summer-rainfall areas of the SAT, generally having 2-7 humid months annually.

– **Uderts**: Vertisols in the humid tropics, generally having more than 7 humid months annually.

Figure 1 shows the distribution of Vertisols and vertic soils in the African continent. Sudan, Ethiopia, Chad, Nigeria, Somalia, Zimbabwe are some of the countries which have a large proportion of their land in the Vertisol and vertic soils group. Table 1 lists some of the countries reported to have Vertisols and vertic subgroups by climatic regions. This is based on the information furnished by the participants of the IBSRAM workshop (IBSRAM, 1985) and the FAO report (FAO, 1965). The data are generalized and need review and updating.

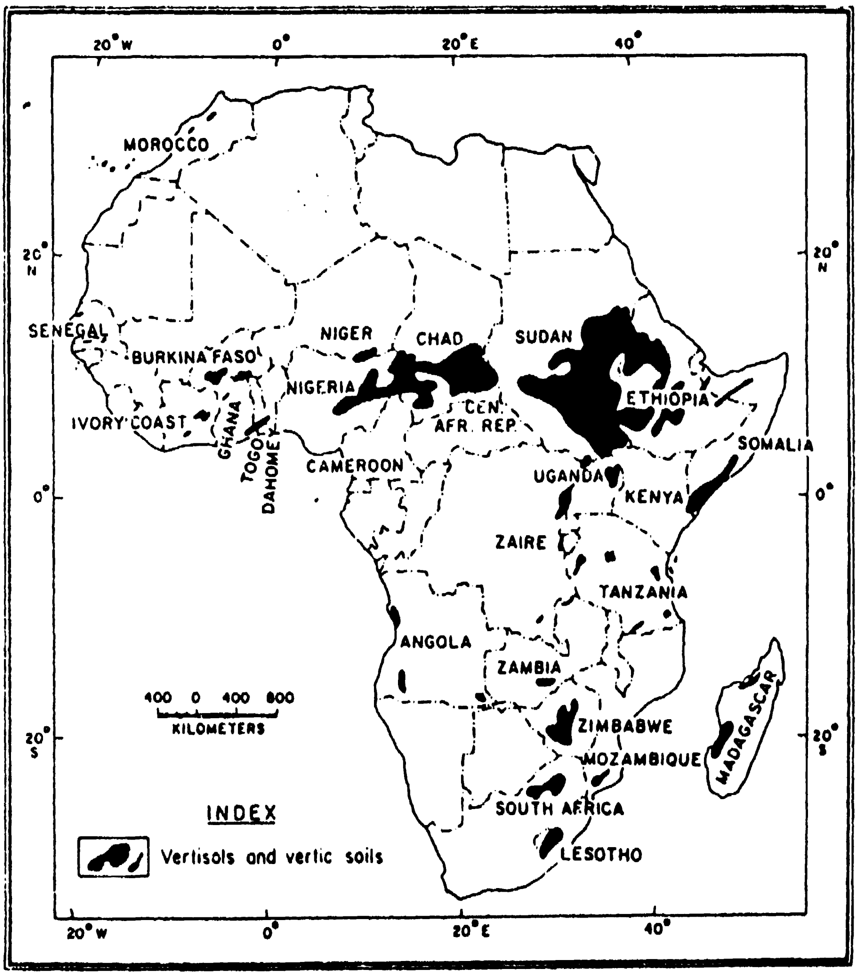

Figure 1. Areas of major distribution of Vertisols and vertic soils in tropical and subtropical Africa (FAO, 1965).

Table 1. A tentative list of countries in Africa with Vertisols and vertic soil groups by climatic zones*

Humid and subhumid	Semi-arid	Arid
Cameroon	Botswana	Chad
Ethiopia	Burkina Faso	Somalia
Sudan	Burundi	Sudan
Zaire	Chad	
Mozambique	Ethiopia	
Angola	Kenya	
Uganda	Malawi	
Dahomey	Niger	
Togo	Nigeria	
Shana	Sudan	
Ivory Coast	South Africa	
	Zambia	
	Zimbabwe	
	Senegal	
	Tanzania	
	Uganda	
	Ghana	

*Source: FAO (1965) and IBSRAM (1985).

Current Management of Vertisols in Semi-Arid Africa

Since Vertisols and vertic soils occur in diverse agroecological environments in Africa, they are used for a variety of purposes. The Torrerts, Vertisols of the arid areas, are generally under natural grassland and associated vegetation and are used for extensive agriculture, mainly cattle raising. Where irrigated, these soils are highly productive, and are used to grow a variety of tropical crops. The management of irrigated Vertisols poses many problems: they become waterlogged, and soil salinity can also develop if water management is inefficient. In Sudan, Torric Vertisols are used mainly for growing cotton. In the semi-arid areas of Africa which have a ustic moisture regime, Vertisols and vertic soils are sometimes used for raising crops like sorghum, millet and maize in the uplands, and rice, teff, etc. in the lowlands. In some areas of southern Africa, wheat is also grown in these soils. However, in most instances the intensity of cultivation is very low. Their common current land use is pasture-livestock production systems. The lowland Vertisols of the humid tropics have a udic moisture regime. Generally these are not cultivated, but in some cases they are used for growing rice and teff.

To summarize, the current land use of Vertisols and vertic soils in Africa is limited to livestock farming, grazing, and related animal farming activities. These soils are not extensively used for raising food crops, and they primarily sustain subsistence-level animal production systems. Where crop production activity is prevalent, the per ha yield of crops is quite low. On an average, in rainfed agriculture grain yields of 250-500 kg/ha of most crops are commonly reported. The components of improved agriculture do not seem to have touched the Vertisol areas of Africa.

We have calculated the length of the crop-growing season for a few locations of Vertisols in Africa to illustrate their agroecological potential, and have also included data from the ICRISAT Center in Hyderabad (India) for comparison. The data (Table 2) show that except for the Torric Vertisols, the Usterts exhibit a crop-growing season with a length of 130-240 days. The thermal environment of the locations studied is also suitable for growing tropical and subtropical crops. We believe that through the application of appropriate land and water management and crop production technologies, the Vertisols and vertic soils of Africa can be efficiently harnessed for increased crop production. Based on the experience gained at ICRISAT, the agricultural production on these soils can be significantly increased. Under soil and climatic conditions which are somewhat similar to those found in Africa, ICRISAT has shown that through the scientific management of Vertisols and vertic soils in a semi-arid environment, a sustained and high crop production can be achieved in dryland farming conditions.

IBSRAM's Proposal for Launching a Vertisol Soil Management Network

In February 1985, IBSRAM – the International Board for Soil Research and Management, in cooperation with several other institutions, organized a workshop on the Management of Vertisols for Improved Agricultural Production at the ICRISAT Center in India. At this meeting it reviewed the important principles of improved Vertisol management technology and its application for increasing production under diverse farming systems. The workshop discussed research priorities for the improved management of Vertisols for sustained agricultural production. In the dryland semi-arid areas, it noted that soil-related problems associated with improved Vertisol management are: surface drainage during the rainy season, lack of water in the dry season, and inadequate plant nutrients. In the irrigated use of Vertisols important research priority areas were also identified. Some of these are: drainage, salinization, irrigation scheduling, crops and cropping systems, soil and water management, weed control, soil testing for available nutrients, and standardization of methods for evaluating nutrient deficiencies.

The IBSRAM workshop (IBSRAM, 1985) also discussed the verification, testing, and validation of improved technologies developed by different institutions. It was considered essential to select components suitable for local needs, and it was suggested that a Vertisol soil management network should be organized without delay. A set of principles for a successful Vertisols network were listed.

- o Establish a common objective and then set priorities.
- o Allocate resources by the national research programmes for the network.
- o Identify the comparative advantages and leadership capabilities of the various research organizations with improved technologies.

Table 2. Rainfall, temperature, and length of the growing season at some selected locations in Vertisol areas of Africa, and Hyderabad, India.

Moisture climatic environment	Location/ country		1	2	3	4	5	6	7	8	9	10	11	12	Annual
Torrerts	Khartoum/ Sudan	Rainfall (mm)	0	0	0	1	5	7	48	72	27	4	0	0	164
		Temperature (°C)	22	24	27	31	33	33	31	29	31	31	27	24	29
		Growing period	Undefined – July-September												
Usterts	Maiduguri/ Nigeria	Rainfall (mm)	0	0.3	1	4	34	78	180	227	112	23	0.3	0	659
		Temperature (°C)	22	24	29	31	32	30	27	26	27	28	25	22	27
		Growing period													135
Ustarts	Moundou/ Chad	Rainfall (mm)	0	< 0.3	2	40	118	171	244	303	250	96	4	0	1228
		Temperature (°C)	25	27	30	31	29	27	26	25	25	27	27	25	27
		Growing period													210
Uderts	Addis Ababa/ Ethiopia	Rainfall (mm)	24	25	68	93	50	105	228	263	174	41	3	15	1089
		Temperature (°C)	16	18	19	19	20	18	15	15	15	15	15	15	17
		Growing period													240
Usterts	Hyderabad/ India	Rainfall (mm)	2	11	13	24	30	107	105	147	163	71	25	6	704
		Temperature (°C)	21	24	27	30	34	29	26	26	26	25	23	21	26
		Growing period													210

- o Supply coordination and logistics.
- o Look at the levels of interaction required.
- o Link national cells (units) with other agencies.
- o Establish principles for the selection of areas of activity.

Management of Vertisols in the SAT: ICRISAT's Work in India*

In the Indian subcontinent, about 70 million ha of Vertisols and vertic soils occur, mostly in the ustic moisture regime in peninsular India. In this region the farmers are small landholders who operate 2-4 ha farms and own a pair of oxen for draught. These small farmers of limited means are generally not able to cultivate their farms in time for the planting of rainy-season crops. Their land is often exposed to short-term waterlogging. Most farmers can raise only one crop a year on these soils, even in relatively assured rainfall areas.

ICRISAT has now assembled a technology for improved management of Vertisols suitable for the SAT. It facilitates growing two crops, one in the rainy season and another in the postrainy season. Adoption of this improved Vertisols management technology has resulted in considerable increases in crop production. Where a farmer harvested about half a ton of sorghum or chickpea by using his traditional system, a total yield of some three tons of grain per ha has been consistently harvested through a two-crop combination under the improved Vertisols management system at ICRISAT during the past nine years of experimentation (Table 3). Further, in the vertic soils several intercrop combinations, e.g. sorghum-pigeonpea or millet-pigeonpea, have produced yields of 2-3 tons/ha under medium-fertility treatment (60-12-0), as shown in Table 4. The introduction of the new system has also resulted in (i) a considerable reduction in soil erosion; (ii) a much higher *in-situ* moisture conservation, and therefore in higher rainfall-use efficiency (Table 5); and (iii) much more dependable harvests year after year (Table 3).

The improved Vertisols management technology

The technology for improved management of Vertisols is a framework. It consists of several interrelated components, each of which consists of several options. The components of the improved technology are:

Land and water management

Improved land and water management practices are applied for alleviating the constraints, such as waterlogging, which arise due to the physical properties of Vertisols.

* A detailed explanation of the technology may be found in Kanwar *et al.* (1982) and Virmani *et al.* (in press). Ryan *et al.* (1982) have given details on the economic aspects of the improved Vertisols management technology and indicated some constraints to its adoption in the Indian semi-arid tropics.

Table 3. Grain yields under improved and traditional technologies on deep Vertisols* at ICRISAT Center in 9 successive years.

Year	Cropping period rainfall (mm)	Grain yield (kg ha^{-1}): Improved system: double cropping – Sorghum/ maize and	Grain yield (kg ha^{-1}): Improved system: double cropping – Sequential chickpea/ intercropped pigeonpea	Grain yield (kg ha^{-1}): Traditional system: single crop – Sorghum	Grain yield (kg ha^{-1}): Traditional system: single crop – or chickpea
1976/77	708	3204	717	436	543
1977/78	616	3076	1223	377	865
1978/79	1089	2145	1256	555	532
1979/80	715	2295	1195	500	450
1980/81	751	3587	920	596	563
1981/82	1073	3194	1047	635	1046
1982/83	667	3269	1095	630	1235
1983/84	1045	3051	1766	838	477
1984/85	546	3355	1014	687	1232
Mean	801	3020	1137	587	771
SD	209	482	289	138	327
CV (%)	26	16	25	24	42

Average rainfall for Hyderabad (29 km away from ICRISAT Center) based on 1901-84 data is 784 mm with a CV of 27%.

*Available water-holding capacity of 180 cm deep soil profile is 240 mm.

Table 4. Grain yields of some cropping systems grown on vertic soils* under low (0-0-0) and medium (60-12-0) fertility at ICRISAT Center in operational-scale experiments.**

Year	Cropping period rainfall (mm)	Soil fertility	Sole pigeonpea	Grain yield (kg ha^{-1}): Sorghum/ pigeonpea	Grain yield (kg ha^{-1}): Millet/ pigeonpea	Grain yield (kg ha^{-1}): Groundnut/ pigeonpea	Grain yield (kg ha^{-1}): Sole sorghum
1981/82	1073	Low	700	937	1201	1387	516
		Medium	868	2175	3581	1423	3234
1982/83	667	Low	1041	2219	2190	2214	1170
		Medium	1217	4291	3178	2917	2869

* Available water-holding capacity of 50 cm soil profile is 80 mm.

** Source: ICRISAT (1983, 1984).

Table 5. Annual water balance and soil loss (t/ha) for traditional and improved technologies in Vertisol watersheds, ICRISAT Center, 1976/77 to 1983/84.

Farming systems technology	Water-balance component				
	Annual rainfall (mm)	Water used by crops (mm)	Water lost as surface runoff (mm)	Water lost as bare-soil evaporation and deep percolation (mm)	Soil loss (t/ha)
Improved system: double-cropped on broadbed and furrows	904	602(67)*	130(14)	172(19)	1.5
Traditional system: single crop in postrainy season, and cultivation on flat	904	271(30)	227(25)	406(45)	6.4

*Figures in parentheses are amounts of water used or lost expressed as percentage of total rainfall.

Vertisols have very poor internal drainage when they are wet. Under the improved system of management, microwatersheds of 3-15 ha size were taken as units for land and water management and agronomic practices. Surface drainage is improved through the provision of surface drains and land smoothing. The *in-situ* water conservation improvements are brought about by laying out the bed-furrow (ridge-furrow) cultivation systems along the contour. Since the surface runoff water is discharged in a controlled manner, the loss of soil is considerably reduced and water-use efficiency is increased considerably (Table 4). At the ICRISAT Center, the main features of this system are that a slope of 0.4 to 0.6% graded broadbeds and furrows (50 cm apart) are made which lead into grassed waterways and finally lead to a dug tank or a drain (Figure 2). By following this stem the soil moisture storage is increased and the drainage of excess water is faciated.

Primary tillage to prepare a rough seedbed is best carried out soon after the harvest of the postrainy-seaon or rainy-season crops. Land should be harrowed whenever 20-25 mm of rain is received over a period of one-two days. When blade-harrowing is done, the clods easily shatter and a satisfactory seedbed is attained.

Dry sowing ahead of onset of rainy season

Since the preparation of the seedbed and the sowing of crops present serious problems in Vertisols, we find that the planting of crops in dry soils ahead of the commencement of rains ensures their establishment early, and avoids the difficulty of planting in

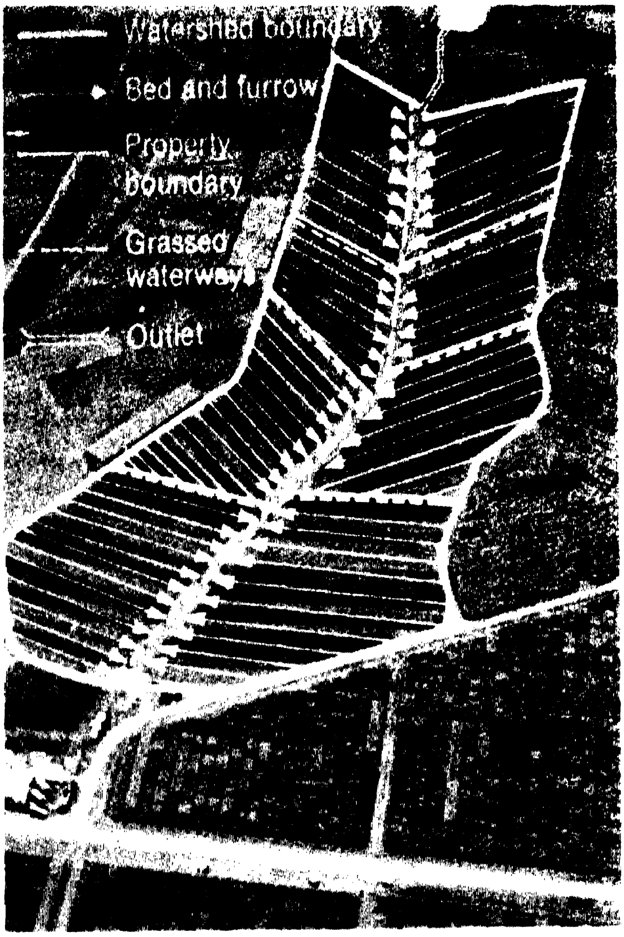

Figure 2. Some important layout features of a small agricultural watershed on a Vertisol at the ICRISAT Center.

a set, sticky soil. We have noted that dry seeding is successful where the early season rainfall is fairly dependable and seeds are placed at a depth of 7-10 cm. At the ICRISAT Center, good stands were established by dry seeding of crops such as mung, sunflower, maize, sorghum, and pigeonpea (Figure 3).

Improved cropping systems

The introduction and adoption of improved cropping systems provide a continuum of crop growth from the commencement of the rainy season until most of the available moisture is utilized by the crop. At ICRISAT we have found that this can be achieved by:

* intercropping of long-duration crops (e.g. pigeonpea) with short-duration crops (e.g. maize or sorghum or soybean).
* sequential cropping of crops (e.g. sorghum or maize followed by chickpea or safflower).

Figure 3. A two-week-old stand of dry-sown maize intercropped with pigéonpea combination tested on a Vertisol watershed at the ICRISAT Center.

Fertility management

In the tropics the management of soil fertility is very important for realizing the full potential of improved cropping systems. At the ICRISAT Center we have found that the management of soil and fertilizer nitrogen is necessary in Vertisols. We have also observed that the application of phosphates and zinc is also required. Our studies have shown that the inclusion of legumes in the crop rotations or in intercrop systems has substantially reduced the fertilizer nitrogen needs (by about 40 kg N ha) of the subsequent cereal crops.

Efficient farm machinery

For a successful implementation of the improved Vertisols management system, we have observed that it is necessary to carry out all the operations thoroughly and in good time. Since animal draught is the main source of energy available to small farm operators of semi-arid areas in Asia and Africa, much of ICRISAT's work is related to animal-drawn equipment. We have found that the use of a wheeled tool carrier (e.g. Tropicultor or Nikart) is a most efficient technique for managing Vertisols in India.

Appropriate crop management

In order to realize the full potential of improved land and water management and cropping systems, it is essential that an appropriate set of crop management practices be adopted. Weed control, integrated pest management, the placement of fertilizers at an appropriate depth and their application at critical stages of crop growth are some of the crop management factors which could lead to the realization of high and sustained yields on Vertisols.

Since most SAT soils are deficient in nutrients like N, P, and Zn, we get good responses to applied fertilizers. The application of fertilizers in the right doses and at the right time, and the adoption of appropriate methods in their application, is the way to obtain good results from fertilizer application in Vertisols (Kanwar and Rego, 1983).

One important aspect of the improved Vertisol technology is the synergistic effect of various components when applied together, as compared with their individual effect. This point has been brought out convincingly after ten years of watershed-based experimental results from ICRISAT (Table 3). Kanwar and Rego (1983) and Kanwar *et al.* (1984) noted during the steps taken to improve Vertisols technology conducted at ICRISAT that though the contribution of fertilizers was highest, the response to fertilizers was most highly marked when they were applied in combination with improved l and water management treatments and the adoption of improved agronomic practices. This observation has great relevance in the African continent. Here fertilizers are costly and in most instances have to be imported. All efforts therefore must be made to realize maximum fertilizer-use efficiency by applying the principles of improved Vertisol technology.

Suggested Agenda for a Vertisol Management Network in Africa

Purpose

We believe that in the African context the main purpose of a Vertisols management network is to tackle successfully issues related to increased agricultural productivity, sustainability, and the introduction of appropriate technologies in the Vertisol and vertic soil areas. We further believe that such research should receive priority because of the vast underutilized potential of Vertisols for crop production. As a first step, we suggest that improved technologies that are already available should be screened and tested both in Usterts and Uderts. Issues concerning the improvement of productivity of irrigai Vertisols should receive priority where soil-related problems are major constraints to creased crop yield.

Main problems to be solved

In terms of the adoption and testing of new technologies, the major problems to be tackled are likely to be in the following three areas: soil management, cropping systems, and land and water management. A partial listing of some researcheable issues is given in Table 6.

Table 6. Major areas of adoptive research in the Vertisols and vertic soils of Africa.

Area		Problems and issues
1. Soil management	o	Tillage-cultivation, seedbed preparation, timing of operations
	o	Agricultural machinery – kind, draught, availability
	o	Nutrient management – N, P, micronutrients
2. Cropping systems	o	Intensification of cropping where crops are already grown
	o	Introduction of new crops
	o	Socioeconomic considerations
3. Land and water management	o	Drainage
	o	Irrigation water management
	o	Scheduling of irrigation
	o	Soil/water quality

Other location-specific problems, e.g. management of acid Vertisols, effective soil conservation tillage/cultivation methods for Vertisols located in areas with >4% slope, may be investigated.

Training needs

Training will be an important part of the agenda of a successful Vertisols network. Training will be required for creating an awareness of the need for the introduction of improved technologies for increasing crop production, and will need to be undertaken by collaborators for the implementation of the network programme, by those responsible for the testing and adoption of new technologies, and those contributing to the development of a data base and its management.

Expected outputs

Over a period of 5 years of operation, the project is expected to achieve some of the following objectives through the application of improved Vertisols management technology:

* locally adaptable technology packages for increasing crop production of Vertisol and vertic soil areas;
* improved cropping systems options for adoption by farmers of different areas;
* a few diversified agricultural systems for alternate management of Vertisols;
* a cadre of trained staff; and
* a substantial strengthening of institutional linkages.

Collaborating institutions

A suggested list of institutions where there are opportunities for training and collaborative research, and where research results are available for evaluation with a view to adoption in the Vertisols and vertic areas of Africa, is given in Table 7. We propose that IBSRAM provide the necessary backup support for coordination of the network activities, and for organizing financial support.

Table 7. A suggested list of institutions for developing collaborative activities of the network.

	Soil suborder		
	Torrerts	Usterts	Uderts
o Soil characterization	National Res. – SMSS – IRAT/Gerdat		
o Agroclimatic evaluation	ICRISAT Agrhymet	ICRISAT Agrhymet	ICRISAT
o Cropping systems	National Res.	ICRISAT	IRRI for rice-based systems, ICRISAT for postrice cropping
o Land and water management	National Res.	ICRISAT	IRRI/ICRISAT/IITA
o Crop management	To be identified	ICRISAT	IRRI/ICRISAT + other institutions
o Soil management	US Soil Salinity Lab. SMSS	ICRISAT	IRRI
o Tillage equipment and related research			
Animal-drawn equipment	ICRISAT/IRAT/NIAE/National Res.		
Powered machines	NIAE Tillage Lab. Netherlands	NIAE Tillage Lab. Netherlands ICRISAT	IRRI Tillage Lab. Netherlands NIAE
o Fertility/nutrient	National Res. IFDC IRAT	ICRISAT IFDC IRAT National Res.	IRRI IITA IFDC IRAT National Res.

Issues Needing Immediate Attention for Formulating Network Plans

1. A complete inventory of soils (at the suborder level) and of climate (rainfall, evaporation, temperature, radiation) is necessary to characterize the agroecological potential of the Vertisols and vertic soils in the region concerned. These base data would be required both for the design of improved technologies and for their transfer.
2. Assembly of information on improved land-use and cropping systems suitable for Vertisols and vertic soils of the semi-arid humid-subhumid tropics of Africa.
3. Assessment of research needs, identification of locations where research could be carried out, and promotion of cooperation for interchange of information.
4. Exchange of germ plasm of improved cultivars amongst institutions for testing new cropping systems.
5. Identification of locations for training staff.
   Establishment of a Vertisols soil management unit (SMU).
   Location of an SMU network coordinator.

Conclusion

The Vertisols of Africa, which are situated mostly in ustic (Usterts) moisture regimes, have fairly long growing seasons, and consequently can be used to harvest successfully one or two crops per year. On such soils improved dryland agricultural practices for increased crop production could be adopted. For bringing about improvements in agriculture in Vertisols in the ustic moisture regimes, the major soil problems to be overcome are related to tillage, land preparation, water management, and the identification of suitable cropping systems. In the case of Uderts, issues related to drainage, preparation of land for planting of postrainy-season crops, and soil fertility management are the priority areas for research. In the Vertisols of the highland regions, some of the important agenda of adoptive research would be to fit crops into the available growing season, and to determine the management, water control, fertilizer application, and land preparation which they require. Some of the priority areas of research for a Vertisols and vertic soils management network for Africa would be the characterization of soil, and the study of climatic and biotic constraints to increased crop production.

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